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

B Page, KD Peters, RR McIntosh, D Hamer, AMM Baylis, MD Sumner, R McGarvey and SD Goldsworthy

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.

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)	No. trips required to visit 95% of all cells used: 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

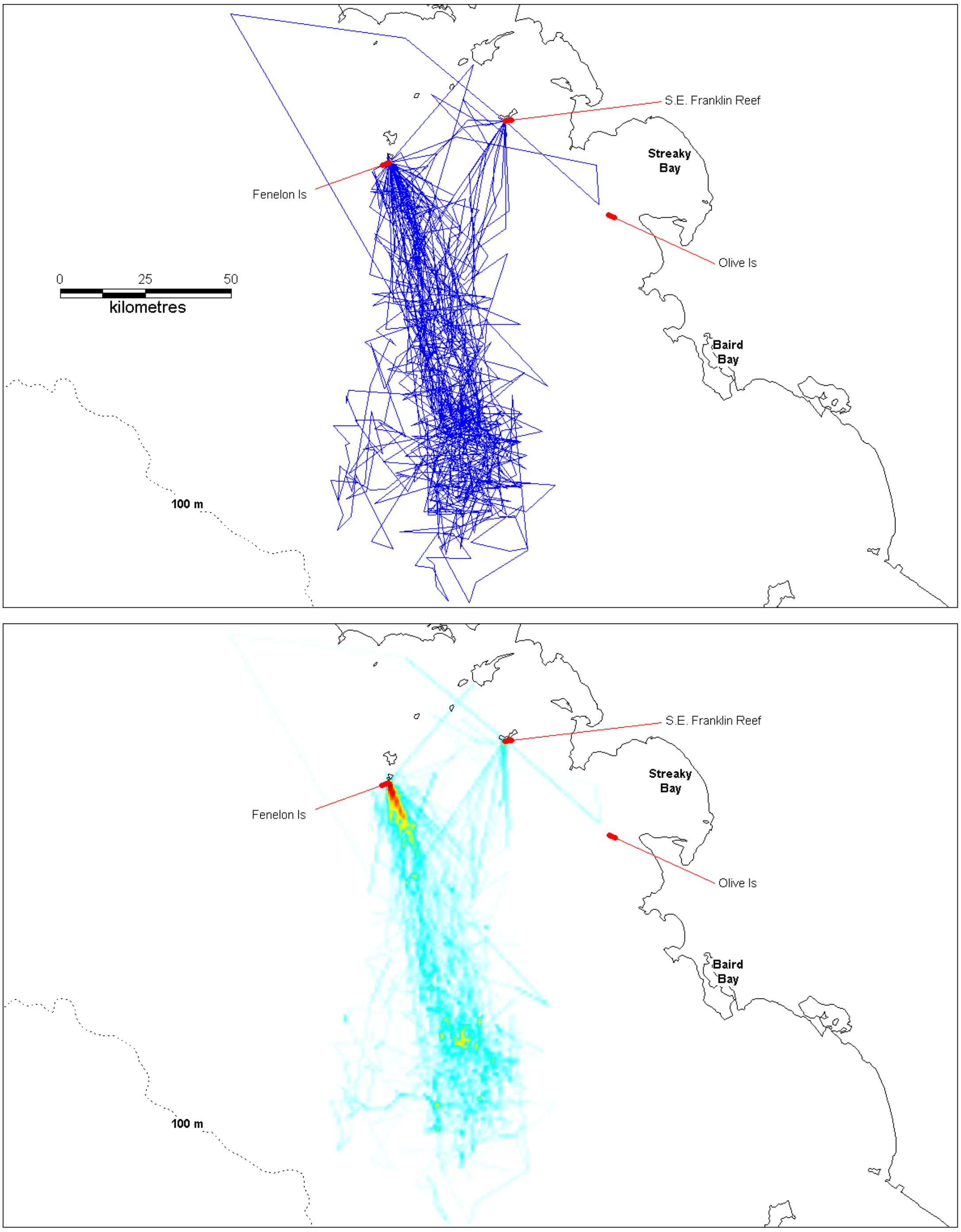


Fig. 9.1. An example of the tracks based on 132 foraging trips (top panel) and the time spent in 1 x 1 km grid cells (bottom panel) by an adult female ASL (seal 651) from SE Franklin Is. On the time spent in area map, red represents regions where the seal spent more time followed by orange, yellow, green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

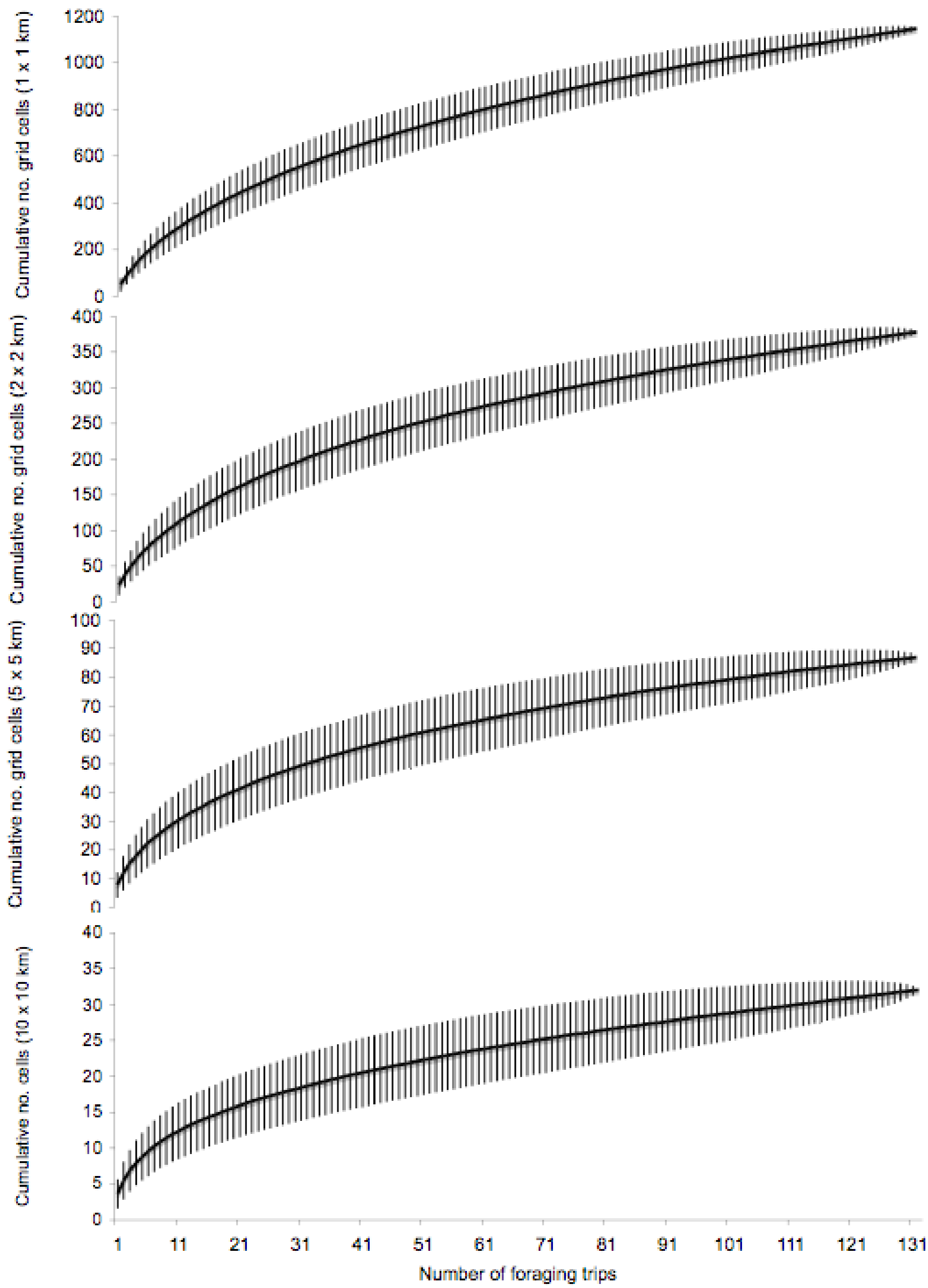


Fig. 9.2. An example of the mean and standard deviation of the number of foraging trips conducted relative to the cumulative number of grid cells visited by adult female ASL (seal 651) from SE Franklin Is. For each spatial scale, the respective number of foraging trips required to reach both the asymptotic 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

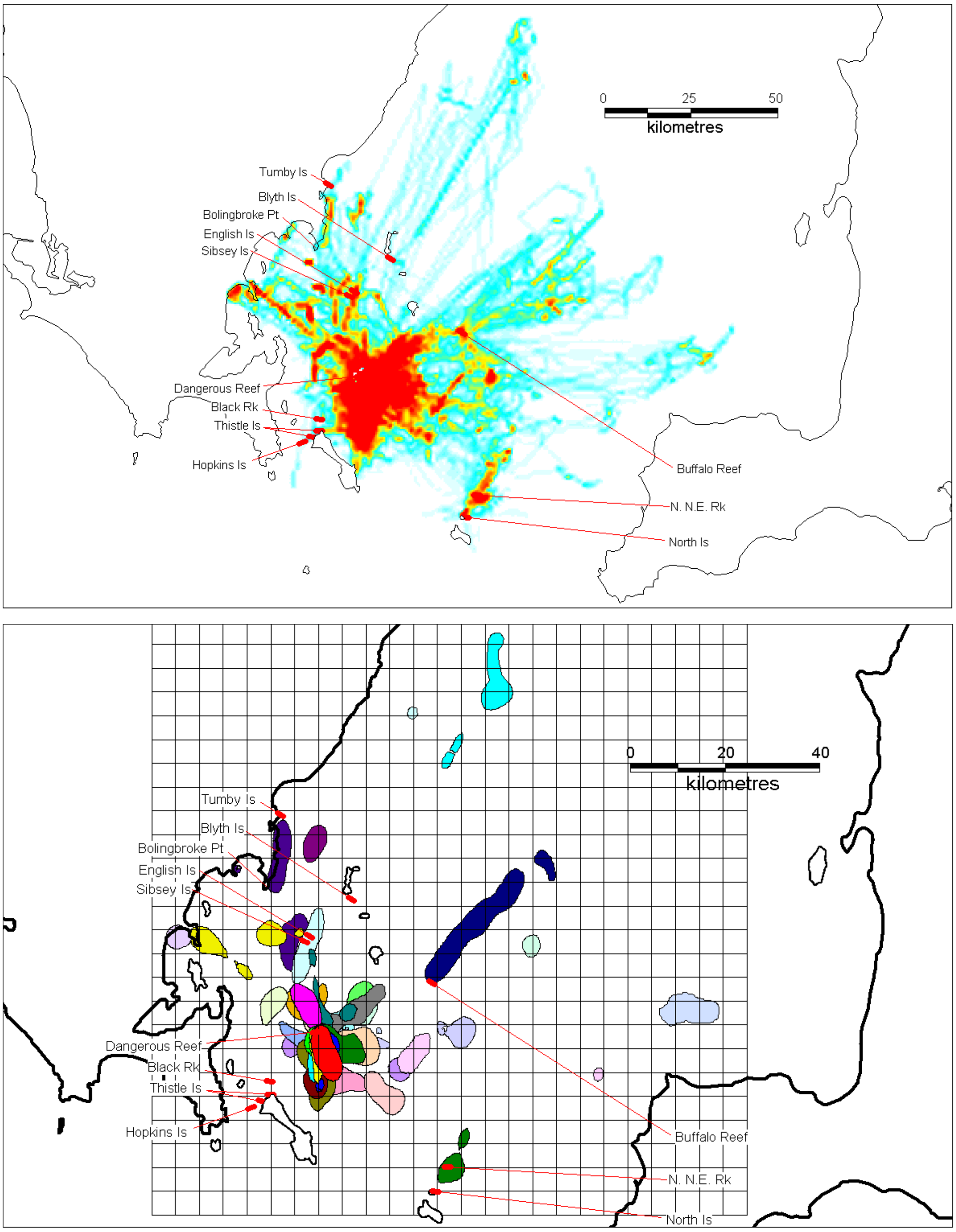


Fig. 9.3. The foraging areas used by 34 adult females from Dangerous Reef, expressed as time spent in area (top plot) and 50 % kernel probability plots (bottom plot). Islands used by at least 1 adult female are shown. Top plot: time spent in 1 km^2 cells by adult females, where red represents regions 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.

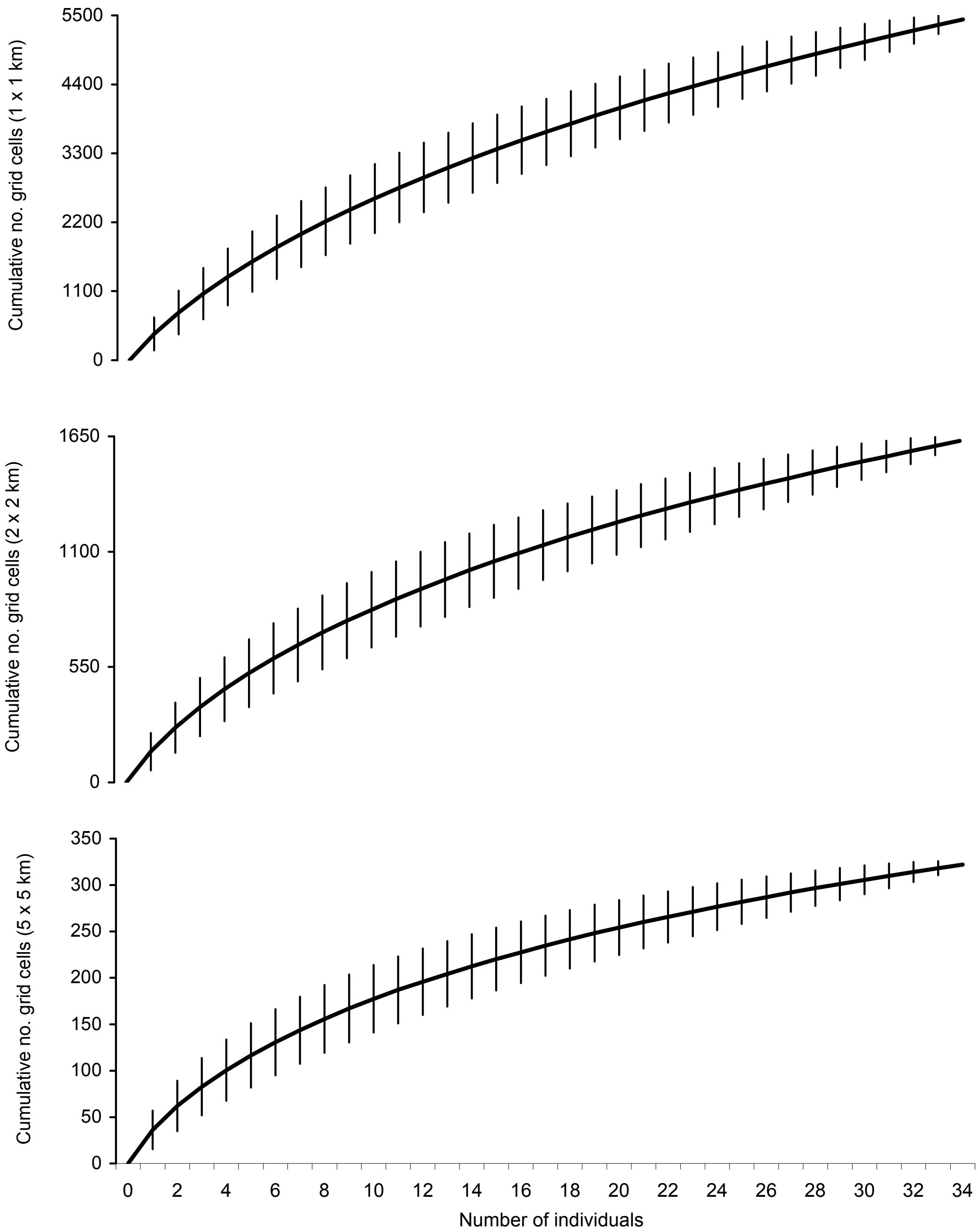


Fig. 9.4. Based on the actual number of cells visited, these graphs show the mean and standard deviation of the number of individuals satellite tracked relative to the cumulative number of grid cells visited by each adult female ASL from Dangerous Reef. For each spatial scale, the respective number of 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.

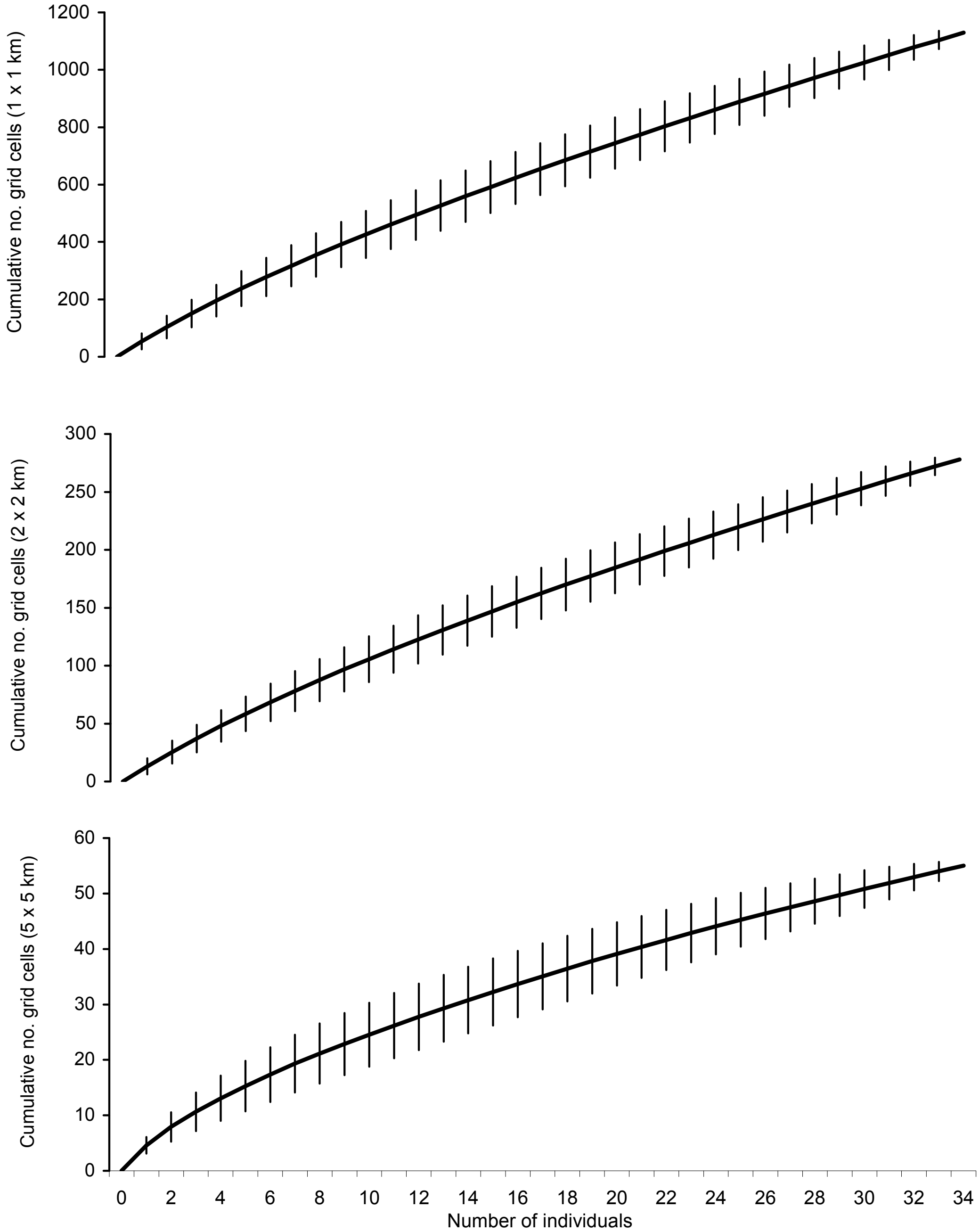


Fig. 9.5. Based on the 50 % kernel density function, these graphs show the mean and standard deviation of the number of individuals satellite tracked relative to the cumulative number of grid cells visited by each adult female ASL from Dangerous Reef. For each spatial scale, the respective number of 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.

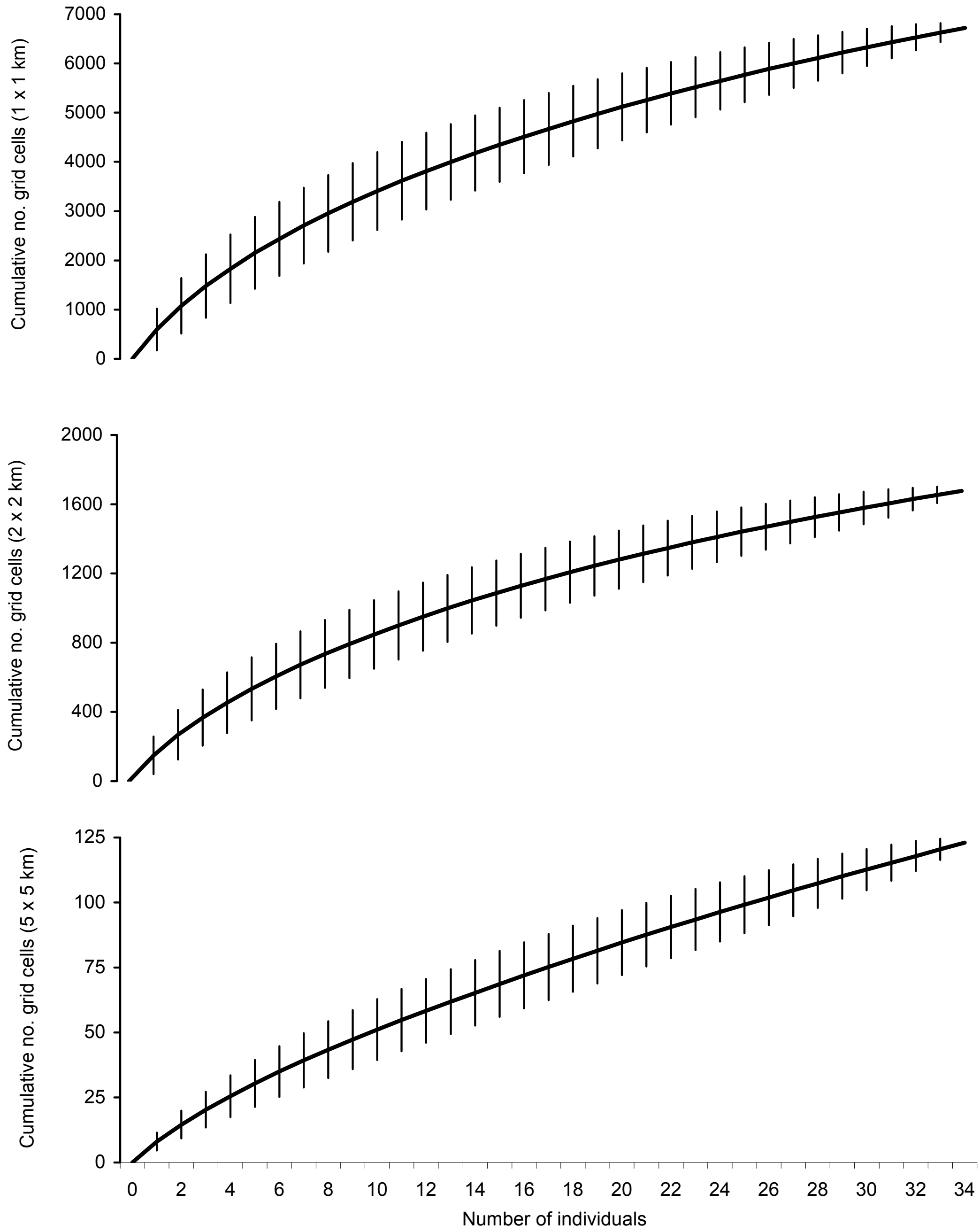


Fig. 9.6. Based on the 95 % kernel density function, these graphs show the mean and standard deviation of the number of individuals satellite tracked relative to the cumulative number of grid cells visited by each adult female ASL from Dangerous Reef. For each spatial scale, the respective number of 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.

14 ACKNOWLEDGMENTS

This research was funded by the Primary Industries and Resources South Australia – Aquaculture and the Fisheries Research and Development Corporation (2004/201). We thank Ian Nightingale (PIRSA Aquaculture) for proposing and supporting the development and funding of this project and to Carina Cartwright (formerly PIRSA Aquaculture) for assisting in project development and support during the initial two years.

We thank the Australian Southern Bluefin Tuna Industry Association (formerly the Tuna Boat Owners Association) and David Ellis and the Marine Mammal – Marine Protected Area Aquaculture Working Group for their support and assistance with the project. We thank Mr Chris Brookes of the Stehr Group (Port Lincoln) for recording and reporting seal-aquaculture interactions. We thank Brett Dalzell, Robbie Sleep, Andy Causebrook, Tamahina Cox and Cathy Zwick (SA DEH, Ceduna) for logistical support, accommodation and extensive assistance with field work in the Nuyts Archipelago, and Ross Belcher, Simon Clark, Sarah Way and Paula Peters (SA DEH, Port Lincoln) for support and help with field work at islands in southern Spencer Gulf. We also thank Sarah Way and Simon Clark for providing accommodation and extensive logistical support in Port Lincoln, before and after field trips.

We thank the crew of the *RV Ngerin*, Master Neil Chigwidden, Engineer David Kerr, Mate Chris Small, and Cook/Deckhand Ralph Putz, Shane Cole (Port Lincoln) and Protec Marine (Port Lincoln - Phil Crogan and Tony Jones) for boat charter assistance with field work at Dangerous Reef. We also thank John Collinson and Nick Turich (SARDI Breakwater Bay) for assistance with ASL surveys in Spencer Gulf. Robbie Sleep (DEH at Ceduna) Matt Guidera (Sceale Bay) and Perry Will (Ceduna) provided transport to Olive Is and the islands of the Nuyts Archipelago. For boat charter assistance with field work to: West Waldegrave Is we thank Johnnie Newton (Elliston), Jones Is we thank Alan Payne, Nicolas Baudin Is we thank Leigh Amey of DEH at Venus Bay.

We thank Jason Nichols (La Trobe University and SARDI – Aquatic Sciences), Simon Clark, Paul Rogers, Alex Ivey, Annelise Wiebkin (SARDI – Aquatic Sciences), Dr Mary-Anne Lea (University of Tasmania), Kit Kovacs and Christian Lydersen (Norwegian Polar Institute), Ray Carpenter (Port Lincoln) and Nathan Dowie (Kangaroo Is) for assistance with satellite tracking field work. We thank Mike Sumner (University of Tasmania) for advice and assistance with filtering of satellite telemetry data. We also thank Bec McIntosh for contributing her unpublished data on the ages of ASL.

We thank our colleagues who assisted with counts of ASL on islands: Bec McIntosh of La Trobe University, Melbourne; Alastair Baylis, Jane McKenzie, Derek Hamer and Kristian Peters (SARDI Aquatic Sciences); Simon Clark, Beau Pulford, Sarah Way and Peter Wilkins (Department for Environment and Heritage at Port Lincoln); Cathy Zwick (Department for Environment and Heritage at Ceduna); Mel Berris (Kangaroo Is); Terry Dennis (Encounter Bay); and Paul Seager (NSW National Parks and Wildlife Service at Broken Hill). In addition, we thank Terry Dennis and Bec McIntosh for advice on ASL and Nick Nicholls (CSIRO Sustainable Ecosystems, Canberra) for statistical advice.

The work was conducted under animal ethics permits from the La Trobe University Animal Ethics Committee, the PIRSA Animal Ethics Committee, the SA Department for Environment and Heritage Animal Ethics Committee and the CSIRO Sustainable Ecosystems Animal Ethics Committee. Permission to conduct the project and to work in the seal colonies within Conservation Parks was granted by the SA Department for Environment and Heritage (with thanks to Peter Canty and Kate Lloyd).

15 STAFF

A/Prof Simon Goldsworthy (SARDI Aquatic Sciences)

Dr Brad Page (SARDI Aquatic Sciences)

Dr Peter Shaughnessy (SA Museum)

Mr Derek Hamer (SARDI Aquatic Sciences, The University of Adelaide)

Mr Kristian Peters (SARDI Aquatic Sciences, The University of Adelaide)

Dr Rebecca McIntosh (La Trobe University)

Mr Alastair Baylis (SARDI Aquatic Sciences, The University of Adelaide)

Dr Jane McKenzie (SARDI Aquatic Sciences)

16 REFERENCES

Alava, J.J. and Salazar, S. (2006) Status and Conservation of Otariids in Ecuador and the Galápagos Islands. pp 495–519. In ‘Sea Lions of the World’. (Eds A.W. Trites, S.K. Atkinson, D.P. DeMaster, L.W. Fritz, T.S. Gelatt, L.D. Rea and K.M. Wynne). Alaska Sea Grant College Program, University of Alaska: Fairbanks, Alaska.

Andersson, M. (1994) *Sexual Selection*. Princeton University Press: Princeton.

Arnould, J.P.Y. and Hindell, M.A. (2001) Dive behaviour, foraging locations, and maternal-attendance patterns of Australian fur seals *(Arctocephalus pusillus doriferus)*. *Canadian Journal of Zoology*, **79**: 35–48.

Arnould, J.P.Y. and Hindell, M.A. (2002) Milk consumption, body composition and pre-weaning growth rates of Australian fur seal *(Arctocephalus pusillus doriferus)* pups. *Journal of Zoology (London)* **256**: 351–359.

Arnould, J.P.Y., Boyd, I.L. and Speakman, J.R. (1996) The relationship between foraging behaviour and energy expenditure in Antarctic fur seals. *Journal of Zoology* **239**: 769–782.

Ashmole, N.P. (1963) The regulation of numbers of tropical oceanic birds. *Ibis* **103**: 458–473.

Ashmole, N.P. (1968) Body size, prey size and ecological segregation in 5 sympatric tropical terns (Aves: Laridae). *Systematic Zoology* **17**: 292–304.

Bartholomew, G.A. (1970) A model for the evolution of seal polygyny. *Evolution* **24**: 546–549.

Baylis, A.M.M., Page, B. Peters, K. McIntosh, R. McKenzie, J. and Goldsworthy, S.D. (2005) The ontogeny of diving behaviour in New Zealand fur seal pups (*Arctocephalus forsteri*). *Canadian Journal of Zoology* **83**: 1149–1161.

Beals EW. (1984) Bray Curtis ordination: an effective strategy for analysis of multivariate ecological data. *Advances in Ecological Research* **14**: 1–55.

Beck, C.A., Bowen W.D., McMillan J.I. and Iverson S.J. (2003) Sex differences in the diving behaviour of a size-dimorphic capital breeder: the grey seal. *Animal Behaviour* **66**: 777–789.

Berkson, J.M. and DeMaster, D.P. (1985). Use of pup counts in indexing population changes in seals. *Canadian Journal of Fisheries and Aquatic Sciences* **42**: 873–879.

Beverton, R.J.H. (1985). Analysis of marine mammal-fisheries interaction. In ‘Marine Mammals and Fisheries’. Eds J.R. Beddington, R.J.H. Beverton and D.M. Lavigne. pp. 3–33. George Allen and Unwin: London.

Birt, V.L. Birt, T.P. Goulet, D. Cairns, D.K. and Montevecchi, W.A. (1987) Ashmole’s halo: direct evidence for prey depletion by a seabird. *Marine Ecology Progress Series* **40**: 205–208.

Bowen, E.D. Boness, D.J. and Iverson, S.J. (1999) Diving behaviour of lactating harbor seals and their pups during maternal foraging trips. *Canadian Journal of Zoology* **77**: 978–988.

Boyd, I.L., Lunn, N.J. and Barton, T. (1991) Time budgets and foraging characteristics of lactating Antarctic fur seals. *Journal of Animal Ecology* **60**: 577–592.

Boyd, I.L, Lunn, N.J. Duck, C.J. and Barton, T. (1990) Response of Antarctic fur seals to immobilisation with ketamine, a ketamine-diazepam or ketamine-xylazine mixture, and Zoletil. *Marine Mammal Science*, **6**: 135–145.

Boyd, I.L. McCafferty, D.J. Reid, K. Taylor, R. and Walker, T.R. (1998) Dispersal of male and female Antarctic fur seals (*Arctocephalus gazella*). *Canadian Journal of Fisheries and Aquatic Sciences* **55**: 845–852.

Boyd, I.L. Staniland, I.J. and Martin, A.R. (2002) Distribution of foraging by Antarctic fur seals. *Marine Ecology Progress Series* **242**: 285–294.

Boyra, A. Sanchez-Jerez, P. Tuya, F. Espino, F. and Haroun, R. (2004) Attraction of wild coastal fishes to Atlantic subtropical cage fish farms, Gran Canaria, Canary Islands. *Environ Biol Fish* **70**: 393–401.

Brown, C.R. Brown, M.B. and Ives, A.R. (1992) Nest placement relative to food and its influence on the evolution of avian coloniality. *American Naturalist* **139**: 205–217.

Campbell, R. (2003) Demographic and population genetic structure of the Australian sea lion, *Neophoca cinerea*. PhD Thesis, University of Western Australia: Perth, W.A.

Campbell, R.A . (2005) Historical distribution and abundance of the Australian sea lion (*Neophoca cinerea*) on the west coast of Western Australia. In: *Fisheries Research Report No. 148, Department of Fisheries, Western Australia* 42 pp.

Campbell, R.A., Gales, N.J., Lento, G.M. and Baker, C.S. (2007) Islands in the sea: extreme female natal site fidelity in the Australian sea lion, *Neophoca cinerea. Biology letters*, **4**: 139–142.

Carretta, J.V. Forney, K.A., Muto, M.M., Barlow, J., Baker, J. and Lowry. M. (2004) U.S. Pacific marine mammal stock assessments. pp 5–11. NOAA-TM-NMFS-SWFSC-358 Tech. Memo. 295 pp.

Carey, P.W. (1992) Fish prey species of the New Zealand fur seal (*Arctocephalus forsteri* Lesson). *New Zealand Journal of Ecology* **16**: 41–46.

Chernick, M.R. (1999) Bootstrap Methods: A Practitioner’s Guide. Wiley, New York, NY.

Costa, D.P. (1991) Reproductive and foraging energetics of seals: implications for life history patterns. In: Renouf D. (ed), *Behavior of seals*. Chapman and Hall, London: pp 300–338.

Costa, D.P. and Gales, N.J. (2003) Energetics of a benthic diver: Seasonal foraging ecology of the Australian sea lion, *Neophoca cinerea*. *Ecological Monographs* ***73**: 27–43.*

Crespo, E.A. and Pedraza, S.N. (1991) Estado actual y tendencia de la poblacion de lobos marinos de un pelo (*Otaria flavescens*) en el litoral norpatagonico (Spanish). *Ecologia Austral* **1**: 87–95.

Dempster, T., Sanchez-Jerez, P., Bayle-Sempere, J. and Kingsford, M.J. (2004) Extensive aggregations of wild fish at coastal sea cage fish farms. *Marine Ecology Progress Series* **242**: 237–252.

Dempster, T., Sanchez-Jerez, P., Tuya, F., Fernandez-Jover, D., Bayle-Sempere, J. and Boyra, A. Haroun, R. (2006) Coastal aquaculture and conservation can work together. *Marine Ecology Progress Series* **314**: 309–310.

Dennis, T.E. (2005) Australian sea lion survey (and historical) records for South Australia. Report to the Wildlife Conservation Fund, Department for Environment and Heritage, South Australia.

Fea, N.I., Harcourt, R. and Lalas, C. (1999) Seasonal variation in the diet of New Zealand fur seals (*Arctocephalus forsteri*) at Otago Peninsula, New Zealand. *Wildlife Research* **26**: 147–160.

Field, I.C., Bradshaw, C.J.A., Burton, H.R., Sumner, M.D. and Hindell, M.A. (2005) Resource partitioning through oceanographic segregation of foraging juvenile southern elephant seals (*Mirounga leonina*). *Oecologia* **142**: 127–135.

Fletcher, W.J. ,Chesson, J., Sainsbury, K.J., Hundloe, T., Smith, A.D.M. and Whitworth, B. (2002) National ESD reporting Framework for Australian Fisheries: The “How to Guide for Wild Capture Fisheries” FRDC report 2000/145, Canberra, Australia.

Forero, M.G. ,Tella, J.L., Hobson, K.A., Bertellotti, M. and Blanco, G. (2002) Conspecific food competition explains variability in colony size: a test in Magellanic penguins. *Ecology* **83**: 3466–3475.

Fowler, S.L. (2005) Ontongeny of diving in the Australian sea lion. PhD Thesis. University of California, Santa Cruz.

Fowler, S.L. ,Costa, D.P., Arnould, J.P.Y., Gales, N.J. and Kuhn, C.E. (2006) Ontogeny of diving behaviour in the Australian sea lion: trials of adolescence in a late bloomer. *Journal of Animal Ecology* **75**: 358–367.

Fowler, S.L., Costa, D.P. and Gales, N. (2007). Ontogeny of movements and foraging ranges in the Australian sea lion. *Marine Mammal Science* **23**: 598–614.

Gales, N.J. and Cheal, A.J. (1992) Estimating the diet composition of the Australian sea lion (*Neophoca cinerea*) from scat analysis: an unreliable technique. *Wildlife Research* **19**: 405–416.

Gales, N.J. and Costa, D.P. (1997) The Australian sea-lion: a review of an unusual life-history. In: Hindell, M. and Kemper, C. (eds) Marine Mammal Research in the Southern Hemisphere. Surrey Beatty and Sons, Chipping Norton, Sydney, pp. 78–87.

Gales, N.J. and Mattlin, R.H. (1998) Fast, safe, field-portable gas anaesthesia for Otariids. *Marine Mammal Science* **14**: 355–361.

Gales, N.J., Cheal, A.J., Pobar, G.J. and Williamson, P. (1992) Breeding biology and movements of Australian sea-lions, *Neophoca cinerea*, off the west coast of Western Australia. *Wildlife Research* **19**: 405–416.

Gales, N.J., Shaughnessy, P.D. and Dennis, T.E. (1994) Distribution, abundance and breeding cycle of the Australian sea lion *Neophoca cinerea* (Mammalia: Sealia). *Journal of Zoology (London)* **234**: 353–370.

Goldsworthy, S.D. and Shaughnessy, P.D. (1994) Breeding biology and haulout pattern of the New Zealand fur seal, *Arctocephalus forsteri*, at Cape Gantheaume, South Australia. *Wildlife Research* **21**: 365–76.

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

Goldsworthy, S.D. and Page, B (2007) A Risk-Assessment Approach to Evaluating the Significance of Seal Bycatch in two Australian Fisheries. *Biological Conservation* **139**: 269–285.

Goldsworthy, S. D., Bulman, C., He, X., Larcombe, J. and Littnan, C. (2003) Trophic interactions between marine mammals and Australian fisheries: an ecosystem approach. In 'Marine Mammals: Fisheries, Tourism and Management Issues'. (Eds N. Gales, M. Hindell and R. Kirkwood.) pp. 62–99. CSIRO Publishing: Melbourne.

Goldsworthy, S.D. Hamer, D. and Page, B. (2007a) Assessment of the implications of interactions between fur seals and sea lions and the southern rock lobster and gillnet sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF) in South Australia. SARDI Aquatic Sciences Publication Number F2007/000711–1., SARDI Research Report Series Number 225, pp 164.

Goldsworthy, S.D., Shaughnessy, P.D., Page, B., Dennis, T.E., McIntosh, R.R., Hamer, D., Peters, K.J., Baylis, A.M.M., Lowther, A. and Bradshaw, C.J.A. (2007b) Developing population monitoring protocols for Australian sea lions. Report for the Department of the Environment and Water Resources. SARDI Aquatic Sciences Publication Number F2007/000554, SARDI Research Report Series No. 219, pp 75.

Green, K. (1997) Diving behaviour of Antarctic fur seals, *Arctocephalus gazella* Peters, around Heard Island. In: Hindell MA and Kemper C (eds) *Marine mammal research in the southern hemisphere, Vol 1: status ecology and medicine*. Surrey Beatty and Sons, Chipping Norton, Sydney pp 97–104.

Gremillet, D. Dell'Omo, G. Ryan, P.G. Peters, G. Ropert-Coudert, Y. and Weeks, S.J. (2004) Offshore diplomacy, or how seabirds mitigate intra-specific competition: a case study based on GPS tracking of Cape gannets from neighbouring colonies. *Marine Ecology Progress Series* **268**: 265–279.

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

Hamilton, W.J. Gilbert, W.M. Heppner, F.H. and Planck, R.J. (1967) Starling roost dispersal and a hypothetical mechanism regulating rhythmical animal movement to and from dispersal centers. *Ecology* **48**: 825–833.

Harrison, S. Robertson, J. and Carragher, J. (2004) Interactions between seabirds and tuna farms near Port Lincoln. Abstract, Australasian Wildlife Management Society, 17th Conference, Kingscote, South Australia, November-December 2004 p. 48.

Harrison, S. Robertson, J. and Carragher, J. (2005). Silver gull populations in the Port Lincoln area. Abstract, Australasian Wildlife Management Society, 18th Conference, Hobart, Tasmania, November 2005 p. 22.

Harwood, J. and Prime, J.H. (1978) Some factors affecting the size of British grey seal populations. *Journal of Applied Ecology* **15**: 401–11.

Heath, R.B. Calkins, D. McAllister, D. Taylor, W. and Spraker T. (1996) Telazol and Isoflurane field anaesthesia in free-ranging Steller's sea lions (*Eumetopias jubatus*). *Journal of Zoo and Wildlife Medicine* **27**: 35–43.

Higgins, L.V. (1990) Reproductive behaviour and maternal investment of Australian sea lions. PhD Thesis, University of California, Santa Cruz, 126 pp.

Higgins, L.V. and Gass, L. (1993) Birth to weaning - parturition, duration of lactation, and attendance cycles of Australian sea lions (*Neophoca-cinerea*). *Canadian Journal of Zoology.* **71***: 2047–2055.*

Higgins, L.V. and Tedman, R. A. (1990) Effect of attacks by male Australian sea lions, *Neophoca cinerea,* on mortality of pups. *Journal of Mammalogy*, **71**: 617–619.

Hindell, M.A., Bradshaw, C.J.A., Sumner, M.D., Michael K.J. and Burton, H. R. (2003) Dispersal of female southern elephant seals and their prey consumption during the austral summer: relevance to management and oceanographic zones. *Journal of Applied Ecology* **40**: 703–715.

Hoelzel, A.R., Potter, C.W. and Best, P. (1998) Genetic differentiation between parapatric 'nearshore' and 'offshore' populations of the bottlenose dolphin. *Proceedings of the Royal Society of London B* **265**: 1–7.

Hooge, P.N. and Eichenlaub, B. (1997) Animal movement extension to ArcView. ver. 1.1. Alaska Science Center - Biological Science Office, U.S. Geological Survey, Anchorage, AK, USA.

Hulsman, K. (1987) Resource partitioning among sympatric species of tern. *Ardea* **75**: 255–262.

Hunt, G.L., Eppley, Z.A. and Schneider D.C. (1986) Reproductive performance of seabirds: the importance of population and colony size. *Auk* **103**: 306–317.

Kemper, C.M. and Gibbs, S.E. (1997) A study of life history parameters of dolphins and seals entangled in tuna farms near Port Lincoln and comparisons with information from other South Australian dolphin carcasses. Unpublished Report to Environment Australia, Canberra. 47 pp + 25 Fig.

Kemper, C.M., Pemberton, D., Cawthorn, S., Heinrich, J., Mann, J., Wursig, B., Shaughnessy, P. and Gales, R. (2003) Aquaculture and marine mammals: co-existence or conflict? In Gales N, Hindell M and Kirkwood. Marine Mammal: fisheries, tourism and management Issues. pp196–213. CSIRO Publications.

Kemper, C.M. and Gibbs, S.E. (2001) Dolphin interactions with tuna feedlots at Port Lincoln, South Australia and recommendations for minimising entanglements. *Journal of Cetacean Research and Management* **3**: 283–292.

Kirkwood, R.J., Gales, N., Lynch, M. and Dann, P. (2002) Satellite tracker deployments on adult male Australian fur seals, *Arctocephalus pusillus doriferus*: methods and preliminary results. *Australian Mammalogy* **24**: 73–83.

Kirkwood, R., Boren, L., Shaughnessy, P., Szteren, D., Mawson, P., Hückstädt, L., Hofmeyr, G., Oosthuizen, H., Schiavini, A., Campagna, C. and Berris, M. (2003) Seal-focused tourism in the Southern Hemisphere: a review of the industry. In 'Marine Mammals: Fisheries, Tourism and Management Issues'. Eds N. Gales, M. Hindell and R. Kirkwood. pp. 257–276 CSIRO Publishing: Melbourne.

Kirkwood, R., Lynch, M., Gales, N., Dann, P. and Sumner, M. (2006) At-sea movements and habitat use of adult male Australian fur seals (*Arctocephalus pusillus doriferus*). *Canadian Journal of Zoology* **84**: 1781–1788.

Kooyman, G.L. (1989) *Diverse divers: physiology and behaviour*. Springer-Verlag, Berlin.

Kretzmann, M.B., Costa, D.P., Higgins, L.V. and Needham, D.J. (1991) Milk composition of Australian sea lions *Neophoca Cinerea,* variability in lipid content. *Canadian Journal of Zoology* **69**: 2556–2561.

Lalas, C. and Bradshaw, C.J.A. (2003) Expectations for population growth at new breeding locations for the vulnerable New Zealand sea lion (*Phocarctos hookeri*) using a simulation model. *Biological Conservation* **114**: 67–78.

Le Boeuf, B.J., Costa, D.P., Huntley, A.C. and Feldkamp, S.D. (1988) Continuous deep diving in female northern elephant seals, *Mirounga angustirostris. Canadian Journal of Zoology* **66**: 446–458.

Lea, M-A. Hindell, M. Guinet, C. and Goldsworthy, S. (2002) Variability in the diving activity of Antarctic fur seals, *Arctocephalus gazella*, at Iles Kerguelen. *Polar Biology* **25**: 269–279.

Ling, J.K. (1992) *Neophoca cinerea*. *Mammalian Species* **392**: 1–7.

Ling, J.K. (1999) Exploitation of fur seals and sea lions from Australian, New Zealand and adjacent subantarctic Islands during the eighteenth, nineteenth and twentieth centuries. *Australian Zoologist* **31**: 323–350.

Ling, J.K. and Walker, G.E. (1976) Seal studies in South Australia: progress report for the year 1975. *South Australian Naturalist* **50**: 59–68, 72.

Ling, J.K. and Walker, G.E. (1977) Seal studies in South Australia: progress report for the period January 1976 to March (1977) *South Australian Naturalist* **52**: 18, 20–27, 30.

Ling, J.K. and Walker, G.E. (1978) An 18–month breeding cycle in the Australian sea lion? *Search* **9**: 464–465.

Littnan, C.L. and Mitchell, A.T. (2002) Australian and New Zealand fur seals at The Skerries, Victoria: recovery of a breeding colony *Australian Mammalogy* **24**: 57–64.

Littnan, C.L., Arnould, J.P.Y. and Harcourt, R.G. (2007) Effect of proximity to the shelf edge on the diet of female Australian fur seals. *Marine Ecology Progress Series*, **338**: 257–267.

Lowther, A.D. (2007) Maternal Strategies of the Australian sea lion *Neophoca cinerea* at Dangerous Reef, South Australia. Honours Thesis, La Trobe University: Melbourne, Victoria.

Manly B.F.J. (1997) *Randomization, Bootstrap and Monte Carlo Methods in Biology*. Chapman and Hall, London.

Marine Mammal – Marine Protected Area Aquaculture Working Group (2004) Report and recommendations to address the proximity of finfish aquaculture to significant seal and sea lion colonies in South Australia. Primary Industries and Resources South Australia (PIRSA), 11 October 2004, 28 pp.

Marlow, B.J. (1975) The comparative behaviour of the Australasian sea lions *Neophoca cinerea* and *Phocarctos hookeri* (Sealia: Otariidae). *Mammalia* **39**: 159–230.

Mate, B.R. (1982) History and present status of the California sea lion, *Zalophus californianus*. *FAO Fisheries Series* **4**: 303–9.

McConnell, B.J., Chambers, C., Nicholas, K.S. and Fedak, M.A. (1992) Satellite tracking of grey seals (Halichoerus grypus). *Journal of Zoology (London)* **226**: 271–282.

McIntosh, R.R. (2007) Life history and population demographics of the Australian sea lion. PhD thesis. Department of Zoology, La Trobe University, Bundoora Victoria.

McIntosh, R.R., Page, B. and Goldsworthy, S.D. (2006) Dietary analysis of regurgitates and stomach samples from free-living Australian sea lions. *Wildlife Research* **33**: 661–669.

McKenzie, J. (2006) Population dynamics of the New Zealand fur seal *Arctocephalus forsteri*. PhD Thesis, La Trobe University: Melbourne, Victoria.

McKenzie, J., Goldsworthy, S.D. Shaughnessy, P.D. and McIntosh, R. (2005) Understanding the impediments to the growth of Australian sea lion populations. Final report to Department of the Environment and Heritage, Migratory and Marine Species Section. South Australian

Research and Development Institute (Aquatic Sciences), Adelaide, 107 pp. SARDI Publication number RD4/0171.

Mori, Y. (2002) Optimal diving behaviour for foraging in relation to body size. *Journal of Evolutionary Biology* **15**: 269–276.

Morris, D.S. (1996) Seal predation at salmon farms in Maine, an overview of the problem and potential solutions. *Marine Technology Society Journal* **30**: 39–43.

Nams V.O., Mowat G. and Panian M.A. (2006) Determining the spatial scale for conservation purposes – an example with grizzly bears. *Biological Conservation* **128**: 109–119.

Nash C.E., Iwamoto R.N. and Mahnken C.V.W. (2000) Aquaculture risk management and marine mammal interactions in the Pacific Northwest *Aquaculture* **183**: 307–323.

National Seal Strategy Group and Stewardson, C. (2007) National Assessment of Interactions between Humans and Seals: Fisheries, Aquaculture and Tourism. Australian Government Department of Agriculture, Fisheries and Forestry (Bureau of Rural Sciences).

Needham, D.J. (1997) The role of stones in the sea lion stomach: investigations using contrast radiography and fluoroscopy. In: *Marine Mammal Research in the Southern Hemisphere Volume 1: Status, Ecology and Medicine.* Eds M.A. Hindell and C. Kemper. pp 164-169. Surrey Beatty & Sons: Chipping Norton.

Orians, G. H. and Pearson, N. E. (1979) On the theory of central place foraging. In: *Analysis of Ecological Systems.* Eds D.J. Horn, G.R. Stairs and R.D. Mitchell, pp. 155–177. Ohio State University Press: Columbus.

Orsini, J-P. and Newsome, D. (2005) Human perceptions of hauled out Australian sea lions (Neophoca cinerea) and implications for management: A case study from Carnac Island, Western Australia. Tourism in Marine Environments **2**: 23-37.

Page, B., McKenzie, J., McIntosh, R., Baylis, A., Morrissey, A., Calvert, N., Haase, T., Berris, M., Dowie, D., Shaughnessy, P.D. and Goldsworthy, S.D. (2004) Entanglement of Australian sea lions and New Zealand fur seals in lost fishing gear and other marine debris before and after government and industry attempts to reduce the problem. *Marine Pollution Bulletin* **49**: 33–42.

Page, B., McKenzie, J. and Goldsworthy, S.D. (2005a) Dietary resource partitioning among sympatric New Zealand and Australian fur seals. *Marine Ecology Progress Series* **293**: 283–302.

Page, B., McKenzie, J. and Goldsworthy, S. D. (2005b) Inter-sexual differences in New Zealand fur seal diving behaviour. *Marine Ecology Progress Series* **304**: 249–264.

Page, B., McKenzie, J., Hindell, M.A. and Goldsworthy S.D. (2005c) Drift dives by male New Zealand fur seals (*Arctocephalus forsteri*). *Canadian Journal of Zoology* **83**: 293–300

Page, B., McKenzie, J., Sumner, M.D., Coyne, M. and Goldsworthy, S.D. (2006) Spatial separation of foraging habitats among New Zealand fur seals. *Marine Ecology Progress Series* **323**: 263–279.

Pemberton, D. (1996) Port Lincoln Tuna farms, dolphins, seals, sharks, and seabirds. Parks and Wildlife Service Tasmania, Hobart. Unpublished report to Tuna Boat Owners Association of Australia and Primary Industries South Australia. 8 pp.

Pemberton, D. and Shaughnessy, P.D. (1993) Interaction between seals and marine fish-farms in Tasmania, and management of the problem. *Aquatic Conservation: Marine and Freshwater Ecosystems* **3**: 149-158.

Pinaud, D. and Weimerskirch, H. (2005) Scale-dependent habitat use in a long-ranging central place predator. *Journal of Animal Ecology* **74**: 852–863.

Ream, R.R., Sterling, J.T. and Loughlin, T.R. (2005) Oceanographic features related to northern fur seal migratory movements. *Deep-Sea Research II* **52**: 823–843.

Reyes, L.M., Crespo, E.A. and Szapkievich, V. (1999) Distribution and population size of the southern sea lion (*Otaria flavescens*) in central and southern Chubut, Patagonia, Argentina. *Marine Mammal Science* **15**: 478–493.

Richardson, K.C. and Gales, N.J. (1987) Functional morphology of the alimentary tract of the Australian sea lion, *Neophoca cinerea. Australian Journal of Zoology* **35**: 219–236.

Riedman, M. (1990) *The Seals. Seals, Sea Lions and Walruses.* University of California Press, Ltd: Berkley.

Robinson, A.C. and Dennis, T.E. (1988) The status and management of seal populations in South Australia. In: *Marine mammals of Australasia - field biology and captive management.* Ed M. L. Augee, pp. 87–104. Royal Zoological Society of NSW: Sydney.

Robinson, A.C., Canty, P., Mooney, T. and Ruddock, P. (1996) South Australia's offshore islands. Australian Heritage Commission, Canberra.

Robinson, A.C., Armstrong, D.M., Armstrong, G.P., Dalzell, B., Canty, P.B., McDowell, M. and Hall, L.M. (2003) The Encounter 2002 expedition to the Isles of St Francis, South Australia: vertebrate fauna. *Transactions of the Royal Society of South Australia* **127**: 129–139.

Robinson, S., Gales, R., Terauds, A. and Greenwood, M. (2008) Movements of fur seals following relocation from fish farms. *Aquatic conservation: Marine and freshwater ecosystems*. **18**: 1180-1188.

Sargent, B.L., Mann, J., Berggren, P. and Krutzen, M. (2005) Specialization and development of beach hunting, a rare foraging behaviour, by wild bottlenose dolphins (*Tursiops* sp.). *Canadian Journal of Zoology* **83**: 1400–1410.

Schotte, R. and Pemberton, D. (2002) Development of a stock protection system for flexible oceanic pens containing finfish. FRDC Project 99/361. FRDC, Hobart, 85 pp.

Shaughnessy, P. (2004a) Australian sea lions at Nuyts Reef on the west coast of Eyre Peninsula, South Australia. Progress Report to (Commonwealth) Department of the Environment and Heritage, 6 pp.

Shaughnessy, P. (2004b) Population assessment of New Zealand fur seals and Australian sea lions in some South Australian breeding colonies and haulout sites, 2003–2004. Report to Department for Environment and Heritage (South Australia). 49 + ix pp.

Shaughnessy, P. and Dennis, T. (2001) Research on New Zealand fur seals and Australian sea lions in South Australia, 2000–2001. Report to National Parks and Wildlife South Australia, Department for Environment and Heritage. 44 pp.

Shaughnessy, P. and Dennis, T. (2003) Population assessment of New Zealand fur seals and Australian sea lions in some South Australian colonies, 2002–2003. Report to Department for Environment and Heritage. 46 pp.

Shaughnessy, P.D., Gales, N.J., Dennis, T.E. and Goldsworthy, S. D. (1994) Distribution and abundance of New Zealand fur seals, *Arctocephalus forsteri,* in South Australia and Western Australia. *Wildlife Research* **21**: 667–695.

Shaughnessy, P.D., Goldsworthy, S.D. and Libke, J. A. (1995) Changes in the abundance of New Zealand fur seals, *Arctocephalus forsteri,* on Kangaroo Is, South Australia. *Wildlife Research* **22**: 201–215.

Shaughnessy, P. and Dennis, T. (2002) Population assessment of some colonies of New Zealand fur seals and Australian sea lions in South Australia, 2001–2002. Report to National Parks and Wildlife South Australia, Department for Environment and Heritage. 28 pp.

Shaughnessy, P., Kirkwood, R., Cawthorn, M., Kemper, C. and Pemberton, D. (2003) Pinnipeds, cetaceans and Australian fisheries: a review of operational interactions. In: *Marine mammals and humans: towards a sustainable balance.* Eds. N. Gales, M. Hindell and R. Kirkwood, CSIRO Publishing, Melbourne.

Shaughnessy, P. and Dennis, T. (1999) Seal research in South Australia, 1998/99: abundance of New Zealand fur seal pups on Kangaroo Island and Australian sea lion pups at Dangerous Reef. Report to South Australian National Parks and Wildlife, Department of Environment, Heritage and Aboriginal Affairs, October 1999, 39 pp.

Shaughnessy, P.D., Dennis, T.E. and Seager, P.G. (2005) Status of Australian sea lions, *Neophoca cinerea*, and New Zealand fur seals, *Arctocephalus forsteri*, on Eyre Peninsula and the far west coast of South Australia. *Wildlife Research* **32**: 85–101.

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

Shaughnessy, P.D. and Goldsworthy S.D. (2007) Population assessment of fur seals and sea lions at some colonies in South Australia, 2006–07. Final report to the Department for Environment and Heritage, South Australia and the South Australian Wildlife Conservation Fund. 43 pp.

Shaughnessy, P.D., Dennis, T.E. and Berris, M. (2007) Predation on Australian sea lions *Neophoca cinerea* by white sharks *Carcharodon carcharias* in South Australia. *Australian Mammalogy* **29**: 69–76.

Shiavini, A.C.M., Crespo, E.A. and Szapkievich, V. (2004) Status of the population of South American sea lion (*Otaria flavescens* Shaw, 1800) in southern Argentina. *Mammalian Biology* **69**: 108–118.

Sterling, J.T. and Ream, R.R. (2004) At-sea behaviour of juvenile male northern fur seals (*Callorhinus ursinus*). *Canadian Journal of Zoology* **82**: 1621–1637.

Stewart, R.E.A., Stewart, B.E., Stirling, I. and Street, E. (1996) Counts of growth layer groups in cementum and dentine in ringed seals *(Phoca hispida)*. *Marine Mammal Science* **12**: 383–401.

Sunderland Marine Mutual Insurance Company Limited (2000) Aquaculture Risk Management Limited Newsletter, September 2000.

Szteren, D., Aurioles, D. and Gerber, L.R. (2006) Population Status and Trends of the California Sea Lion (*Zalophus californianus californianus*) in the Gulf of California, Mexico. In ‘Sea Lions of the World’. Eds A.W. Trites, S.K. Atkinson, D.P. DeMaster, L.W. Fritz, T.S. Gelatt, L.D. Rea and K.M. Wynne). Alaska Sea Grant College Program, University of Alaska: Fairbanks, Alaska.

Thompson, D., Strange, I., Riddy, M. and Duck, C.D. (2004) The size and status of the population of southern sea lions *Otaria flavescens* in the Falkland Islands. *Biological Conservation* **121**: 357-367.

Thompson, P.M., Mackay A., Tollit D.J., Enderby S. and Hammond P.S. (1998) The influence of body size and sex on the foraging characteristics of harbour seal foraging trips. *Canadian Journal of Zoology* **76**: 1044–1053.

Tilzey, R.D.J., Goldsworthy, S., Cawthorn, M., Calvert, N., Hamer, D., Russell, S., Shaughnessy, P.D., Wize, B. and Stewardson, C (2006) Assessment of seal-fishery interactions in the winter blue grenadier fishery off west Tasmania and the development of fishing practices and Seal Exclusion Devices to mitigate seal bycatch by factory trawlers. Final Report to the FRDC. Project no. 2001/008. February 2006. 69pp.

Tinker, M.T., Costa, D.P., Estes, J.A. and Wieringa, N. (2007) Individual dietary specialization and dive behaviour in the California sea otter: Using archival time-depth data to detect alternative foraging strategies. *Deep-Sea Research II* **54**: 330–342.

Trites, A.W., Miller, A.J., Maschner, H.D.G., Alexander, M.A., Bograd, S.J., Calder, J.A., Capotondi, A., Coyle, K.O., Lorenzo, E.D., Finney, B.P., Gregr, E.J., Grosch, C.E., Hare, S.R., Hunt, G.L., Jahncke, J., Kachel, N.B., Kim, H-J., Ladd, C., Mantua, N.J., Marzban, C., Maslowski, W., Mendelssohn, R., Neilson, D.J., Okkonen, S.R., Overland, J.E., Reedy-Maschner, K.L., Royer, T.C., Schwing, F.B., Wang, J.X.L. and Winship, A.J. (2007) Bottom-up forcing and the decline of Steller sea lions (*Eumetopias jubatus*) in Alaska: assessing the ocean climate hypothesis. *Fisheries Oceanography* **16**: 46–67.

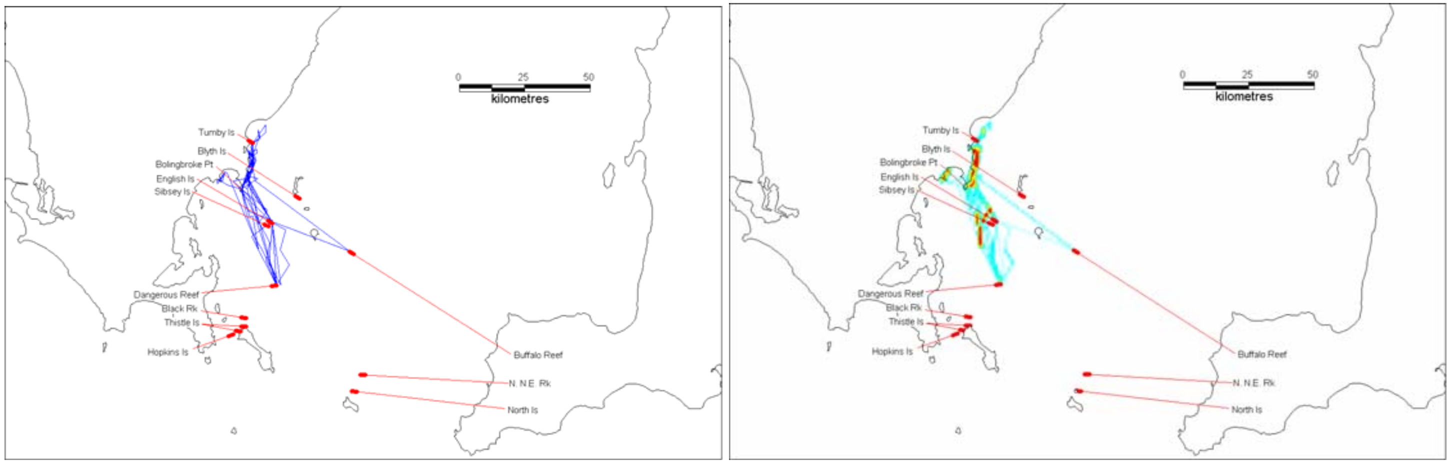
Troy, S.K. (1997) Territorial behaviour and mating success in male New Zealand fur seals, *Arctocephalus forsteri*. PhD thesis, University of Melbourne, Australia.

Walker, G.E. and Ling, J.K. (1981) Australian sea lion *Neophoca cinerea* (Péron, 1816). In: *Handbook of marine mammals Volume 1; the walrus, sea lions, fur seals and sea otter.* Eds S. H. Ridgway and R. J. Harrison pp. 99–118. Academic Press: London.

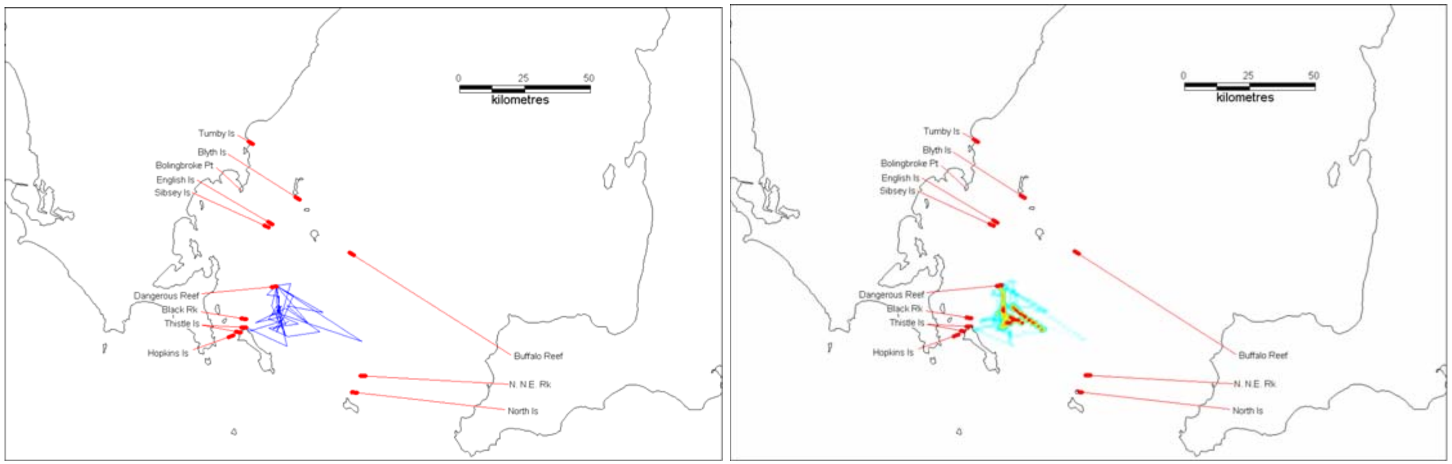
White, G.C. and Garrott, R.A. (1990) 'Analysis of Wildlife Radio-tracking Data'. Academic Press: San Diego.

15 APPENDIX

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

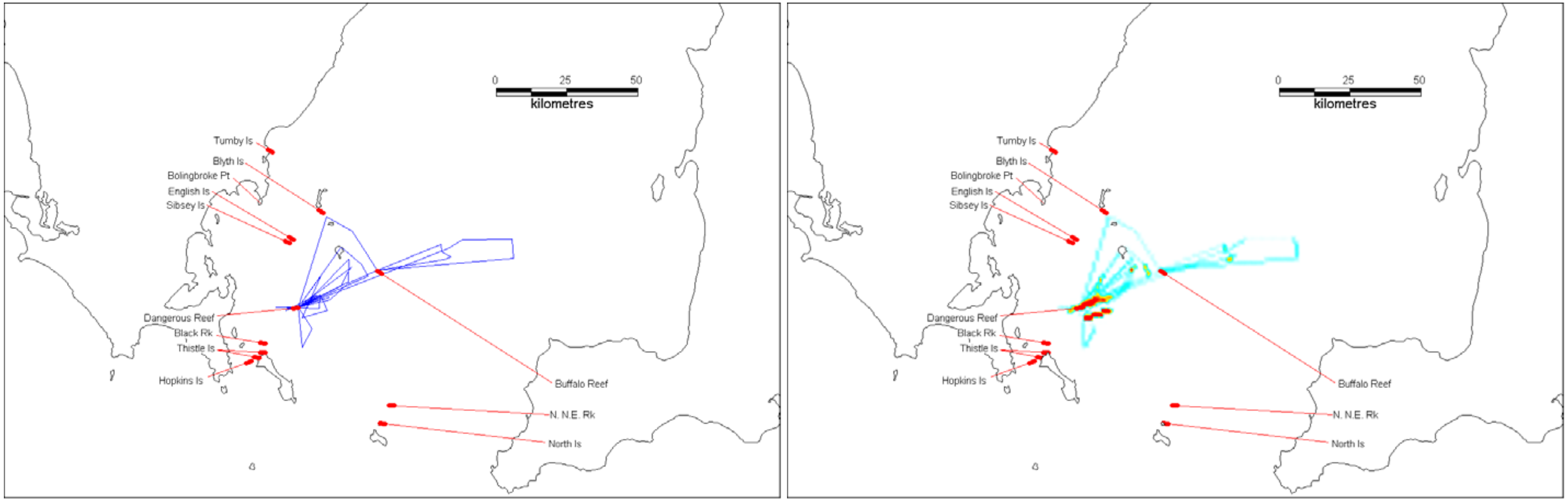


Adult female 10011 from Dangerous Reef. Tracks of 19 foraging trips (left) and time spent in 1 x 1 km areas (right).



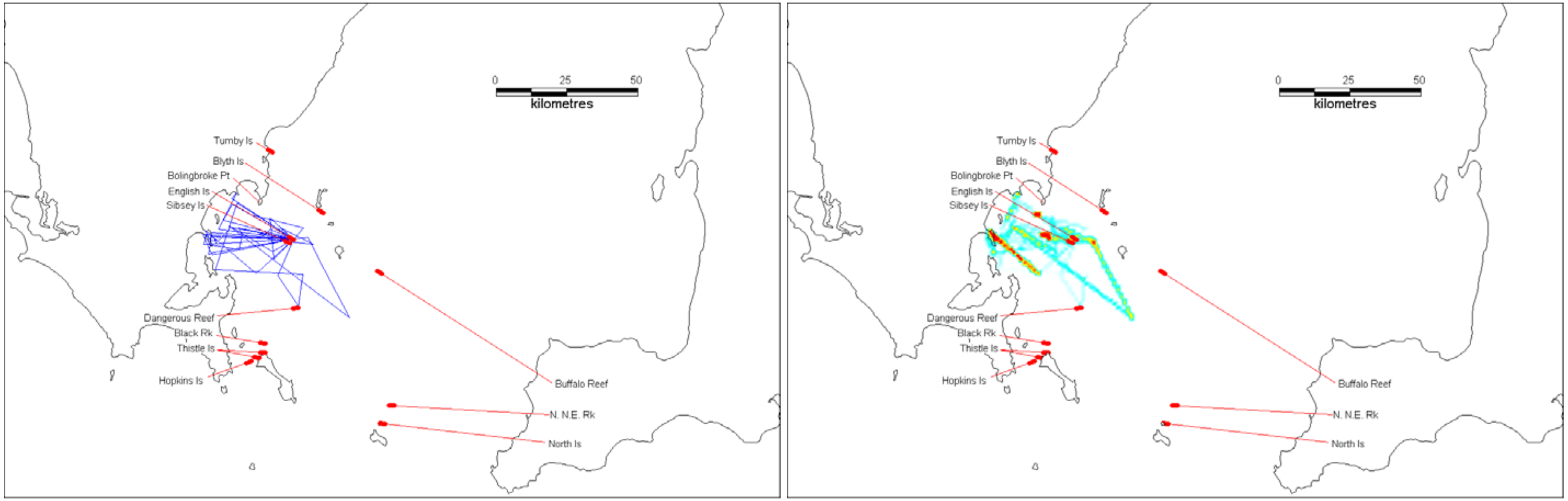
Adult female 10111 from Dangerous Reef. Tracks of 6 foraging trips (left) and time spent in 1 x 1 km areas (right).

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

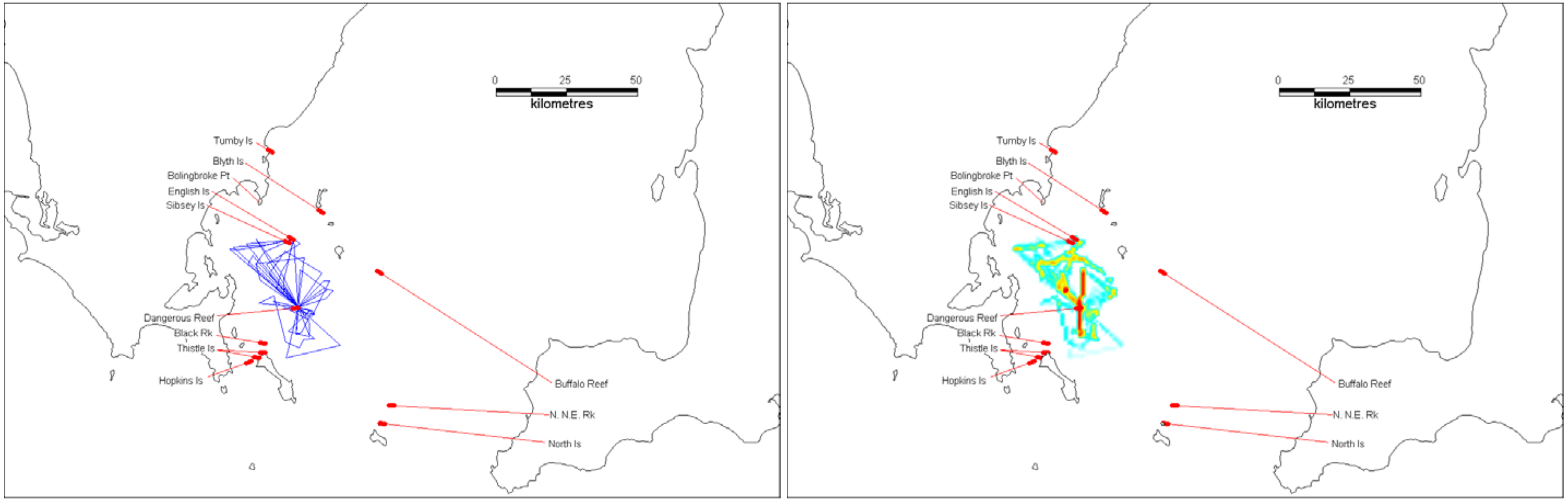


Adult female 10411 from Dangerous Reef. Tracks of 11 foraging trips (left) and time spent in 1 x 1 km areas (right).

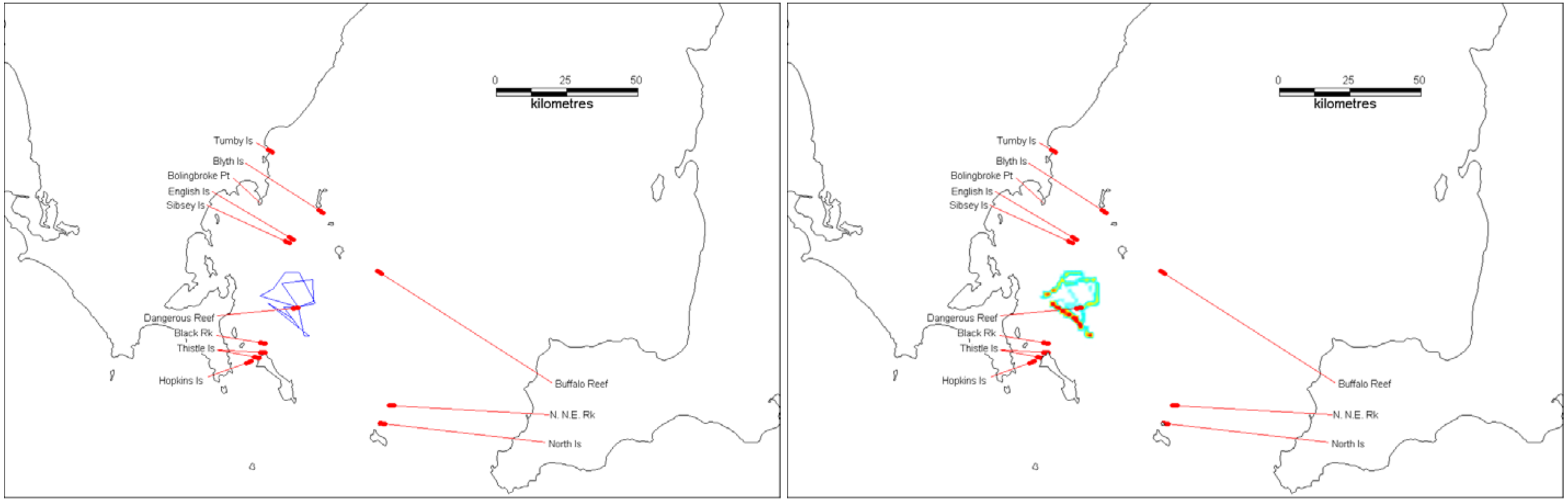
Adult female 10511 from Dangerous Reef. Tracks of 7 foraging trips (left) and time spent in 1 x 1 km areas (right).



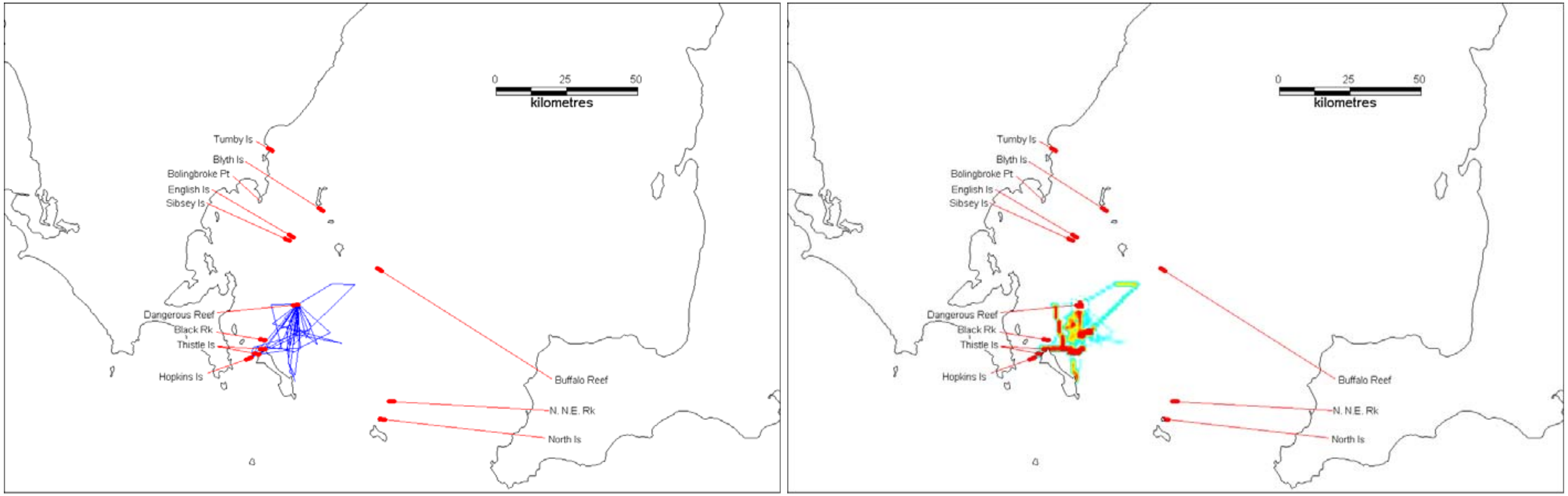
Adult female 10611 from Dangerous Reef. Tracks of 13 foraging trips (left) and time spent in 1 x 1 km areas (right).



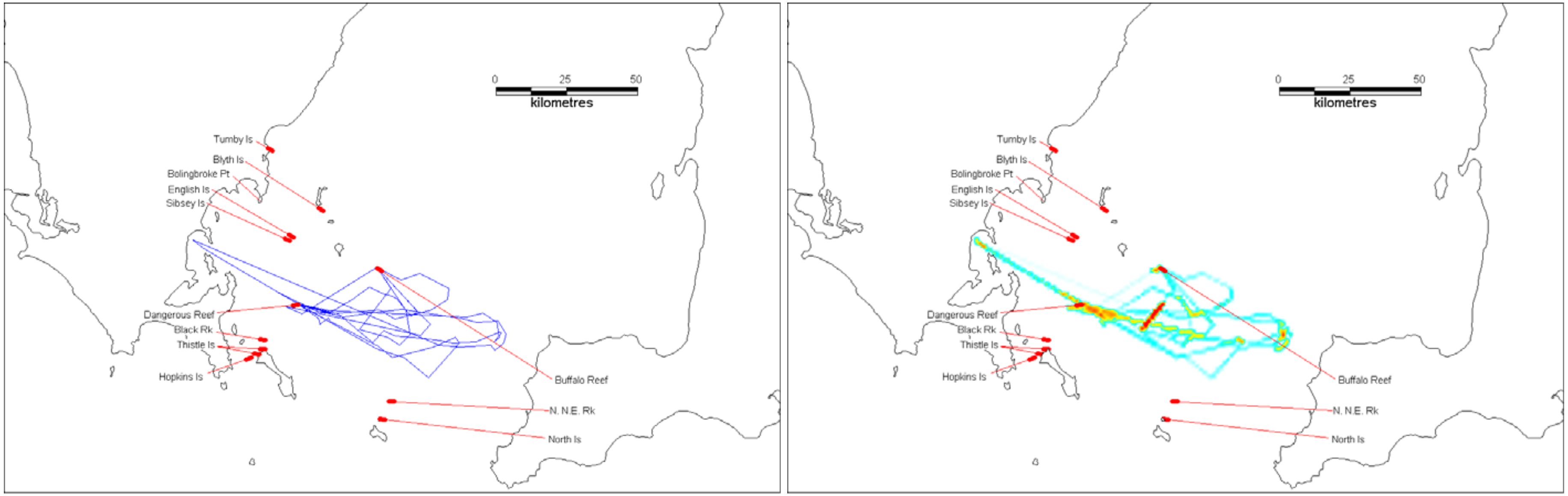
Adult female 10711 from Dangerous Reef. Tracks of 20 foraging trips (left) and time spent in 1 x 1 km areas (right).



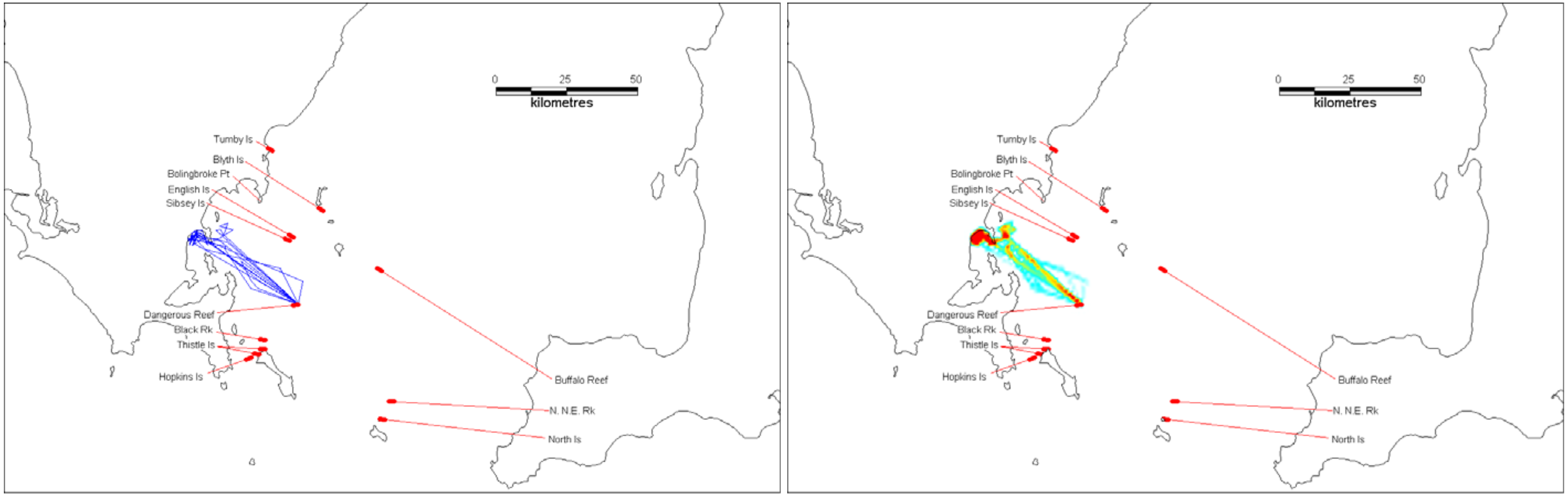
Adult female 10811 from Dangerous Reef. Tracks of 3 foraging trips (left) and time spent in 1 x 1 km areas (right).



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

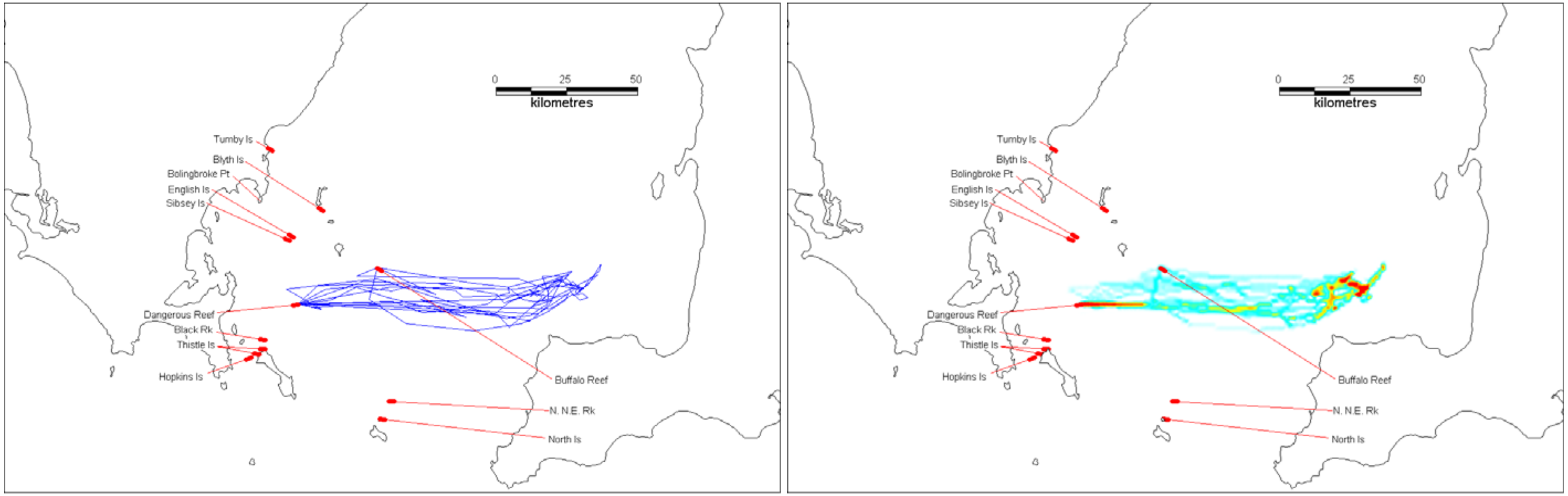


Adult female 11011 from Dangerous Reef. Tracks of 8 foraging trips (left) and time spent in 1 x 1 km areas (right).



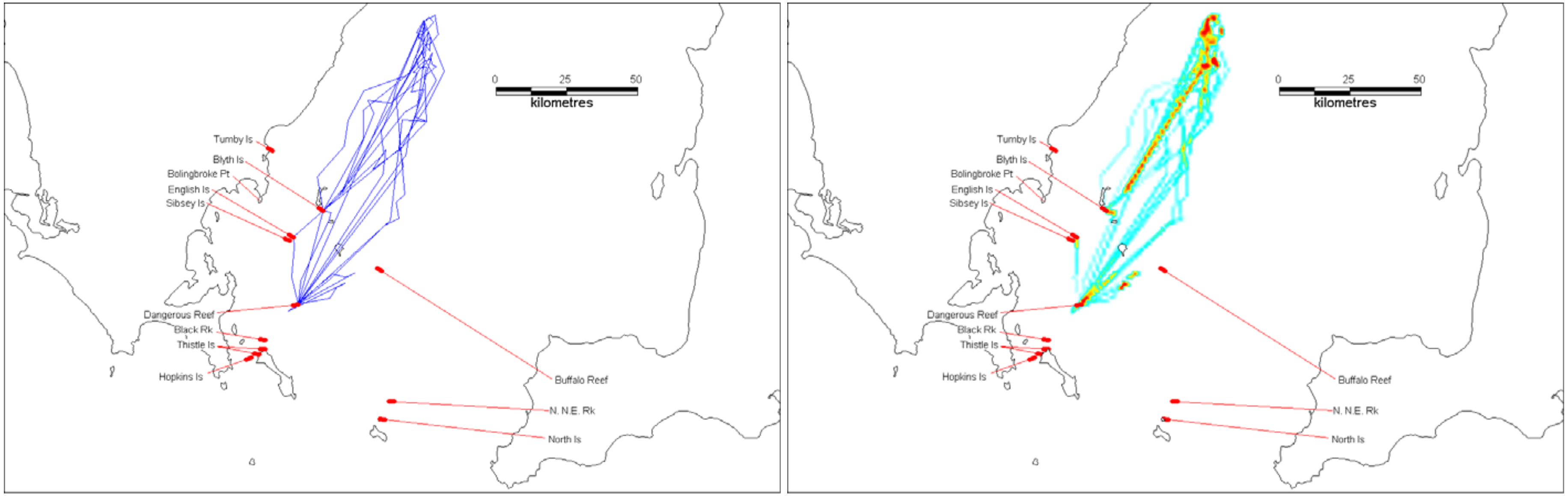
Adult female 11111 from Dangerous Reef. Tracks of 7 foraging trips (left) and time spent in 1 x 1 km areas (right).

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



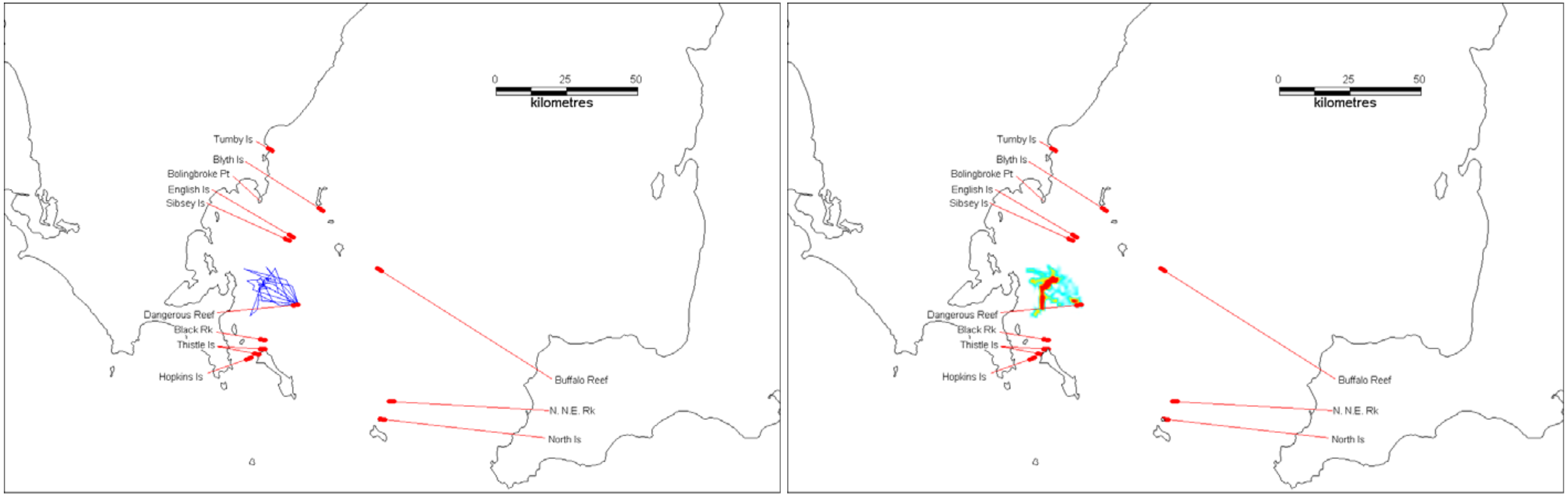
Adult female 11311 from Dangerous Reef. Tracks of 8 foraging trips (left) and time spent in 1 x 1 km areas (right).

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

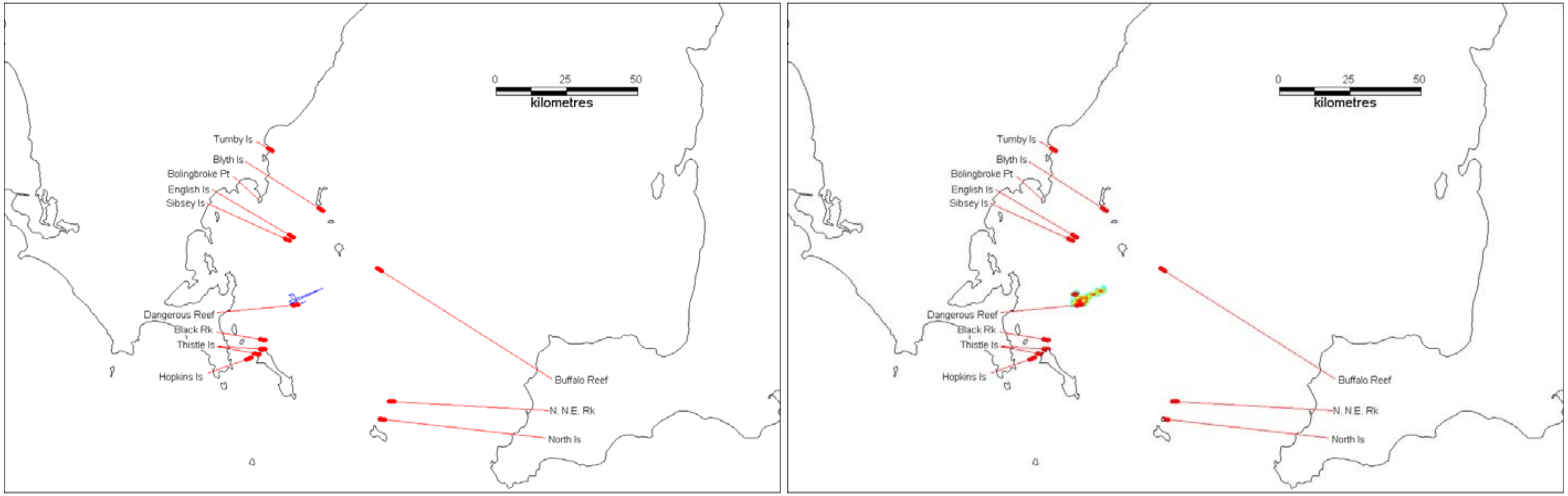


Adult female 11511 from Dangerous Reef. Tracks of 9 foraging trips (left) and time spent in 1 x 1 km areas (right).

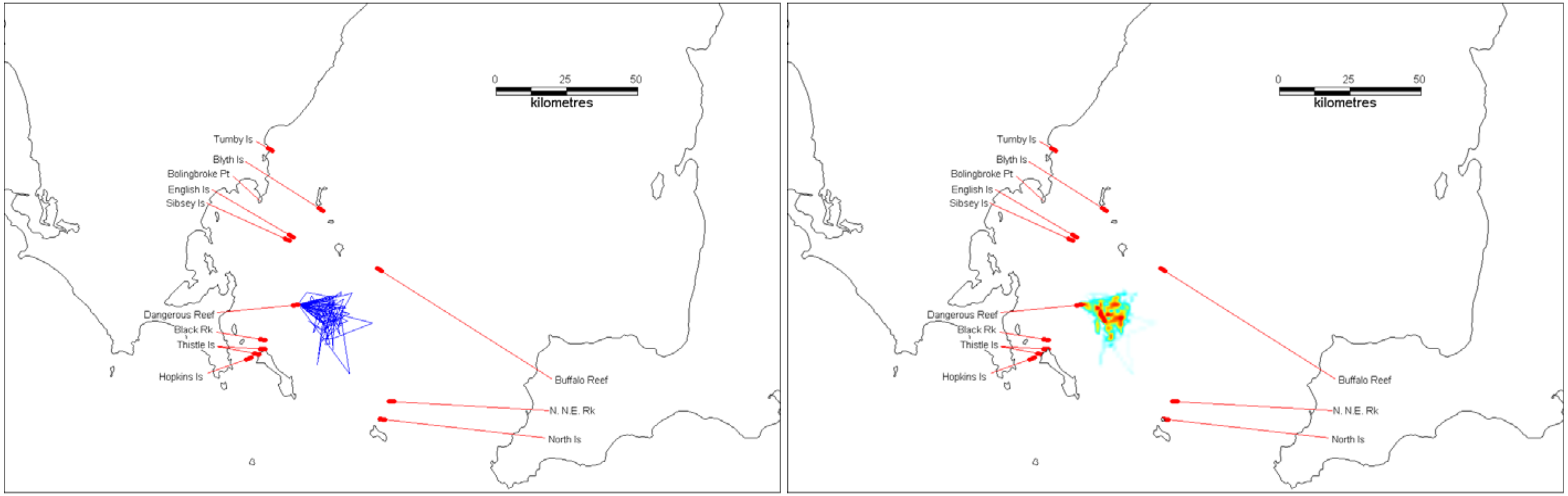
Adult female 11611 from Dangerous Reef. Tracks of 18 foraging trips (left) and time spent in 1 x 1 km areas (right).



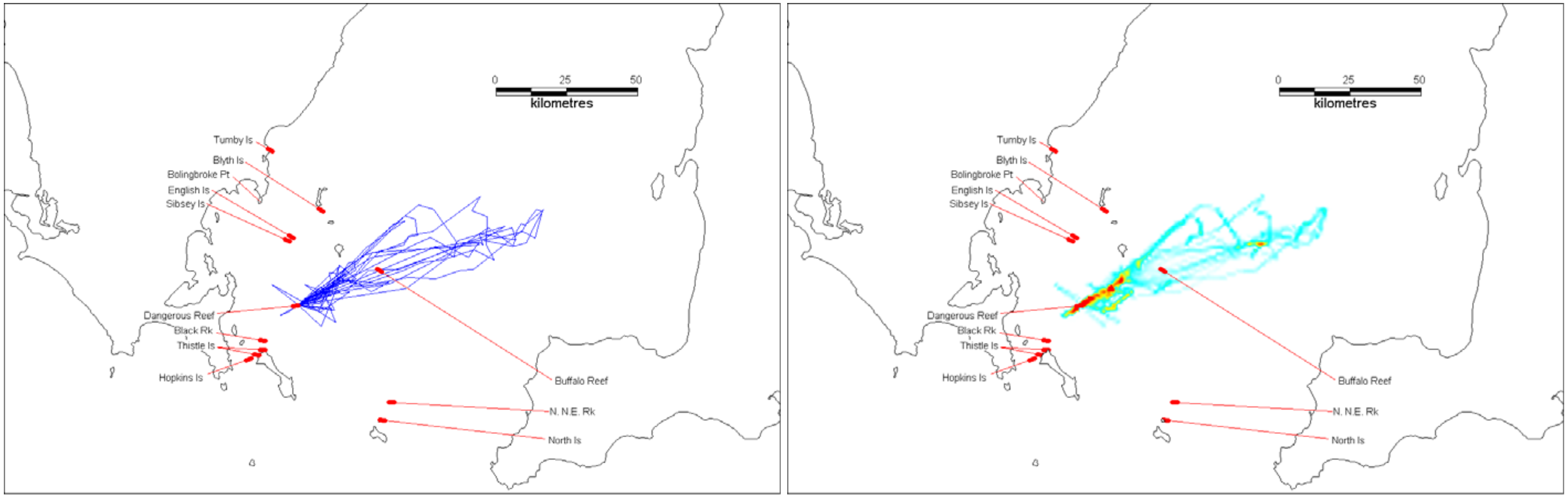
Adult female 11711 from Dangerous Reef. Tracks of 6 foraging trips (left) and time spent in 1 x 1 km areas (right).



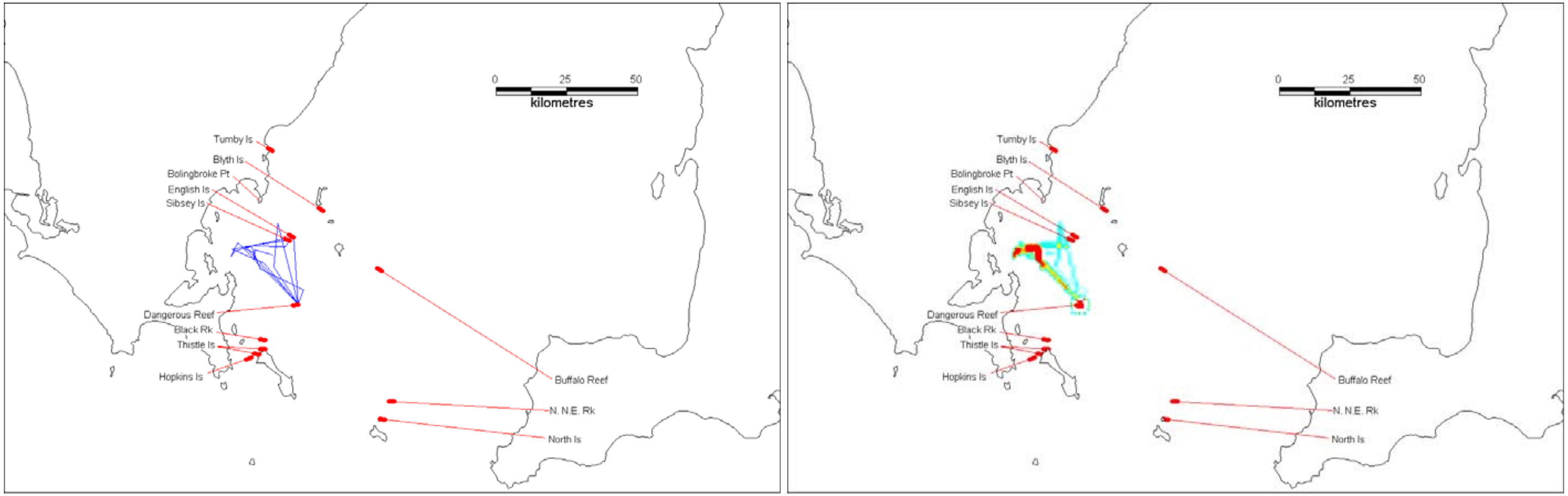
Adult female 11811 from Dangerous Reef. Tracks of 3 foraging trips (left) and time spent in 1 x 1 km areas (right).



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

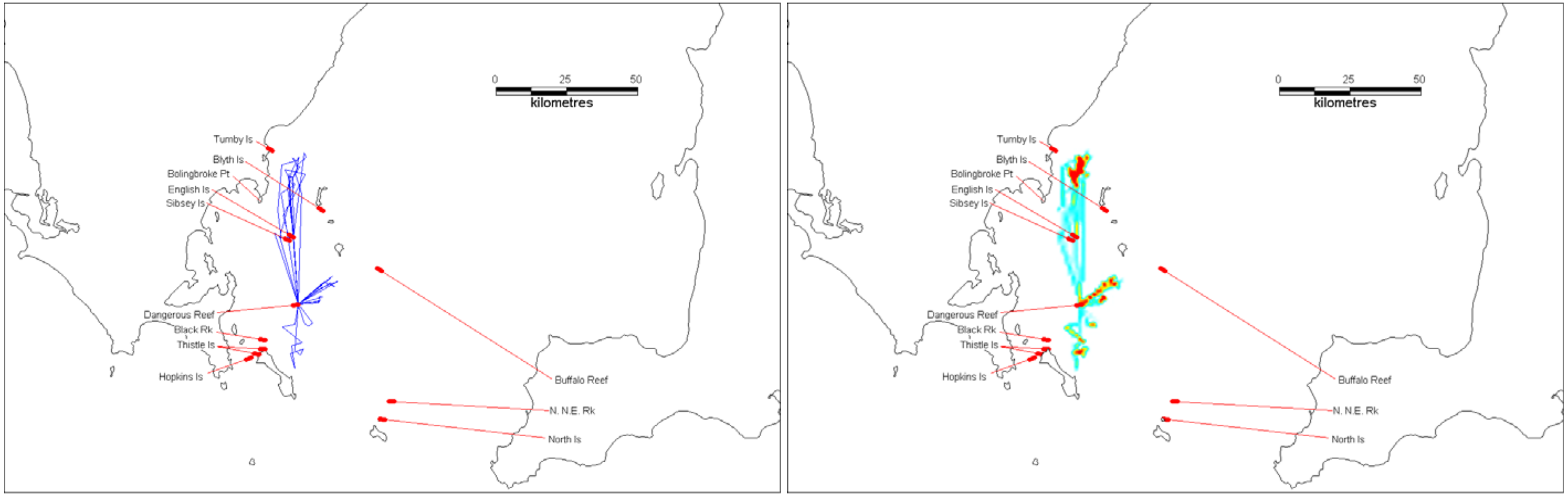


Adult female 12011 from Dangerous Reef. Tracks of 23 foraging trips (left) and time spent in 1 x 1 km areas (right).



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).

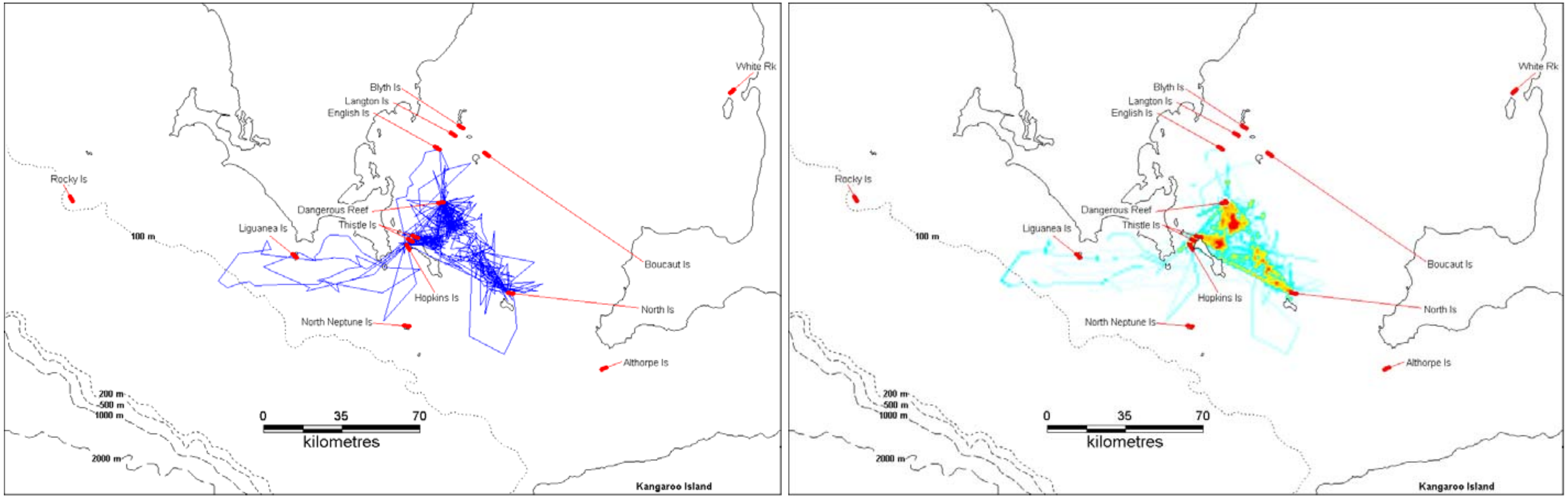
Adult female 1411 from Dangerous Reef. Tracks of 20 foraging trips (left) and time spent in 1 x 1 km areas (right).

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

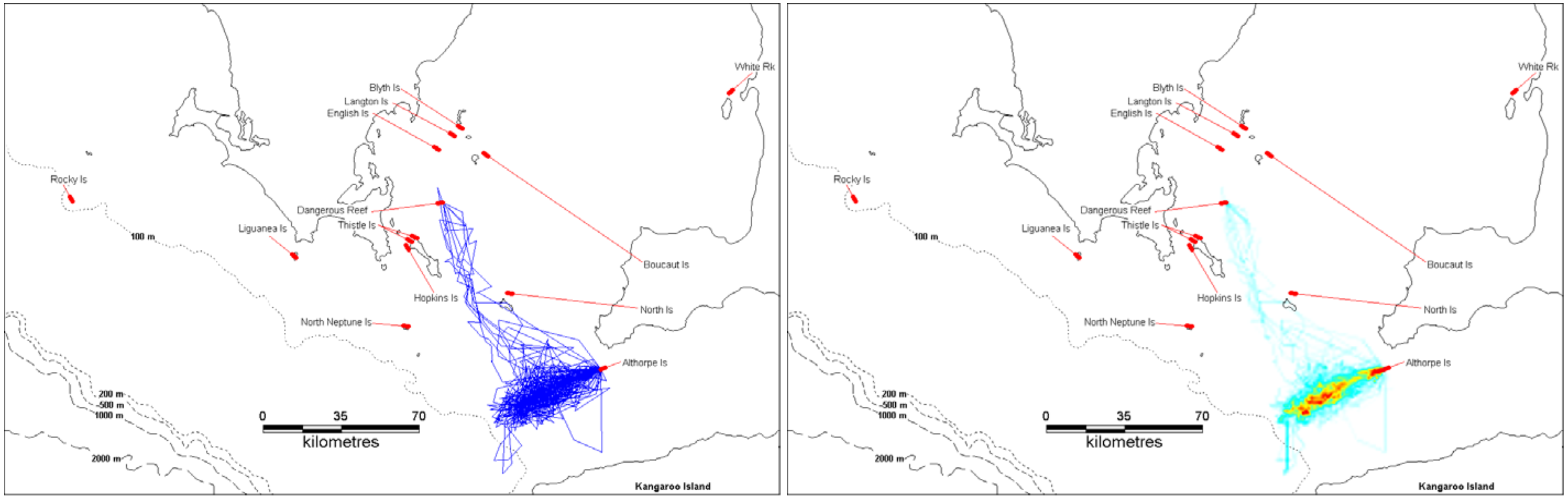
Adult female 1611 from Dangerous Reef. Tracks of 18 foraging trips (left) and time spent in 1 x 1 km areas (right).

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

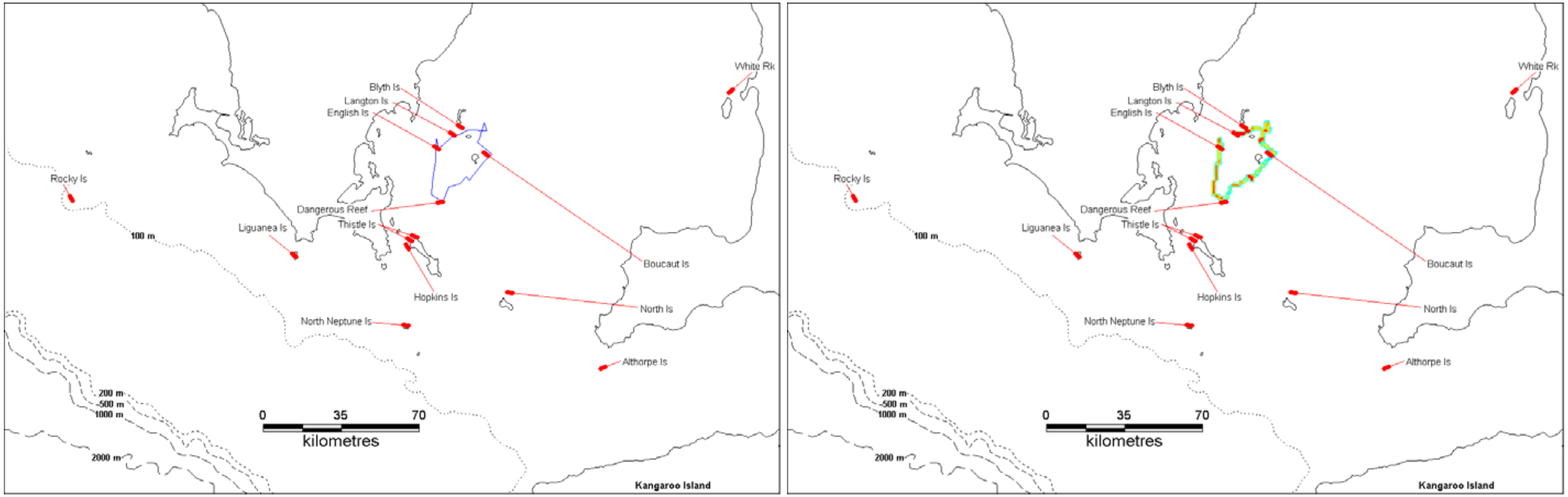
Adult female 1811 from Dangerous Reef. Tracks of 19 foraging trips (left) and time spent in 1 x 1 km areas (right).



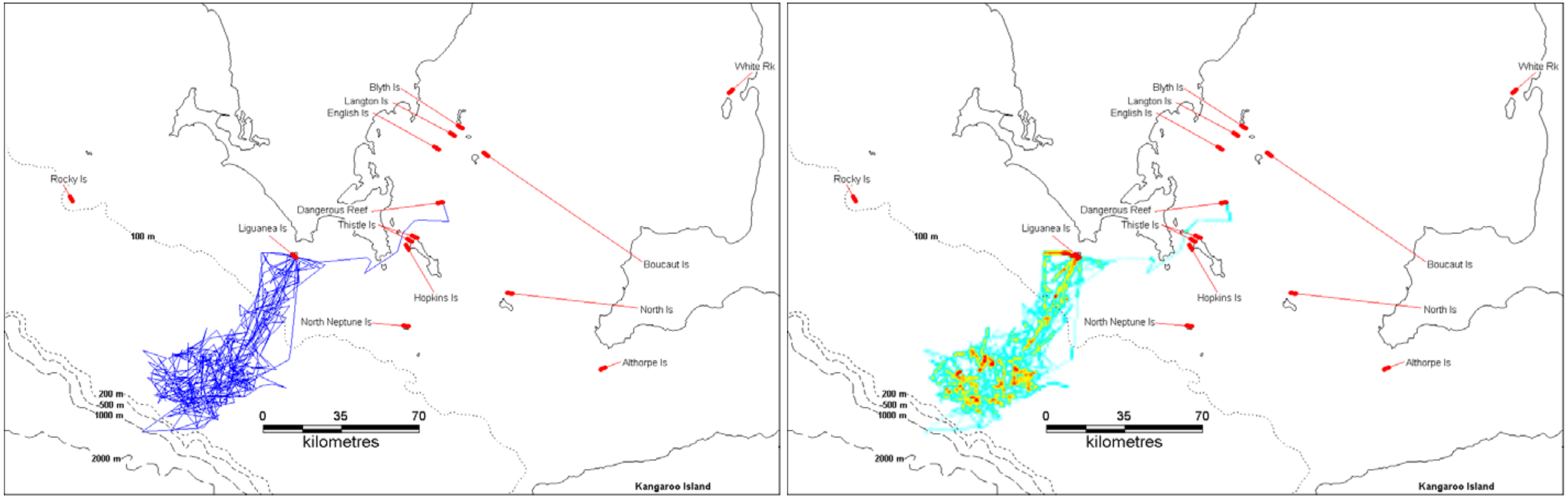
Adult male 212 from Dangerous Reef. Tracks of 46 foraging trips (left) and time spent in 1 x 1 km areas (right).



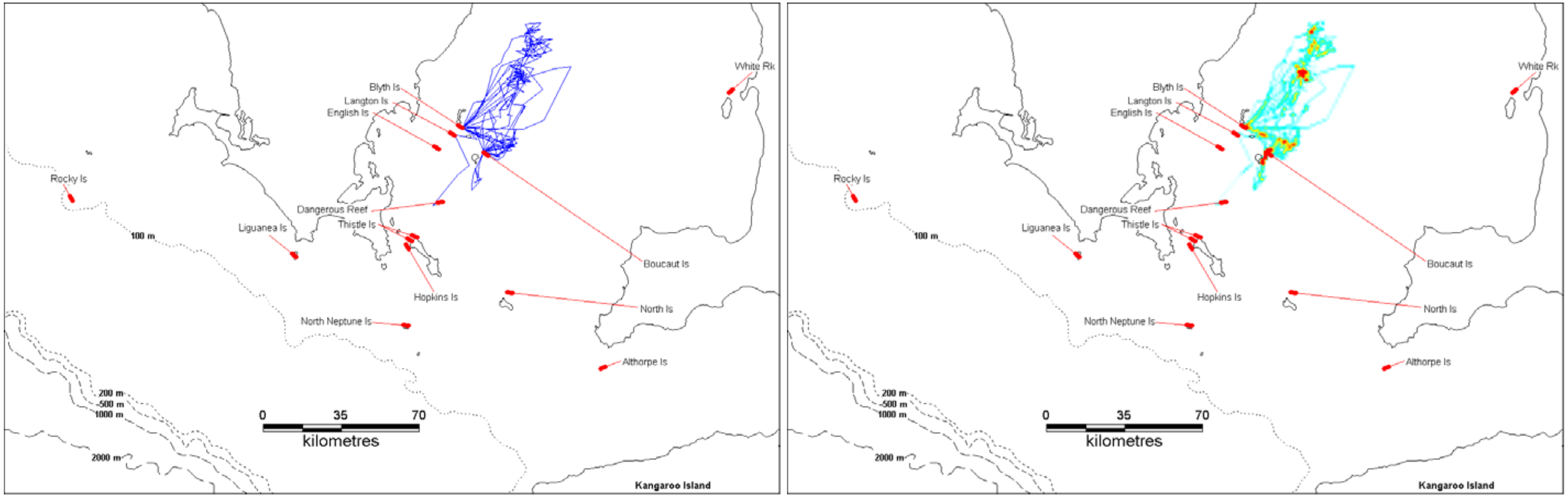
Adult male 412 from Dangerous Reef. Tracks of 44 foraging trips (left) and time spent in 1 x 1 km areas (right).



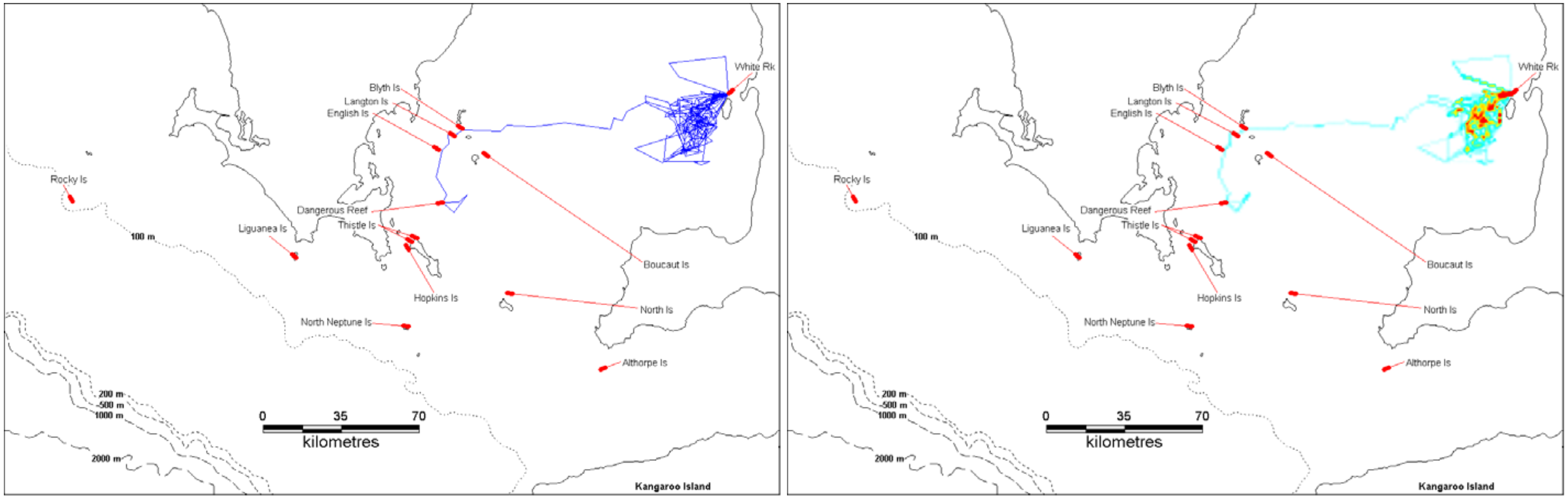
Adult male 512 from Dangerous Reef. Tracks of 2 foraging trips (left) and time spent in 1 x 1 km areas (right).



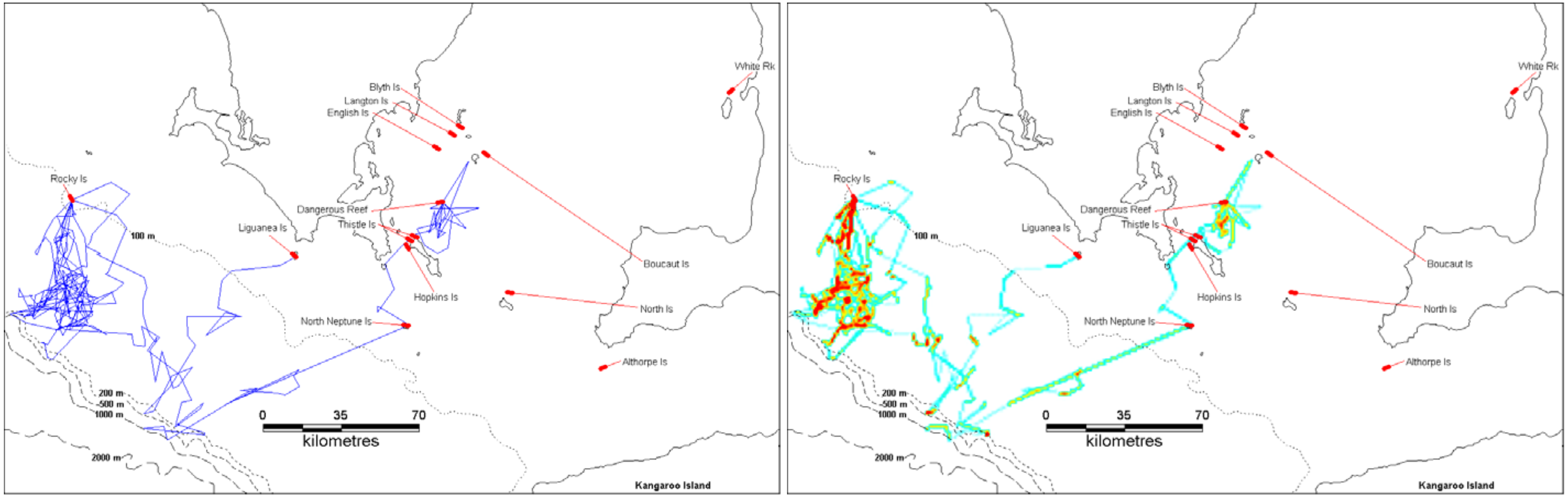
Adult male 3012 from Dangerous Reef. Tracks of 11 foraging trips (left) and time spent in 1 x 1 km areas (right).



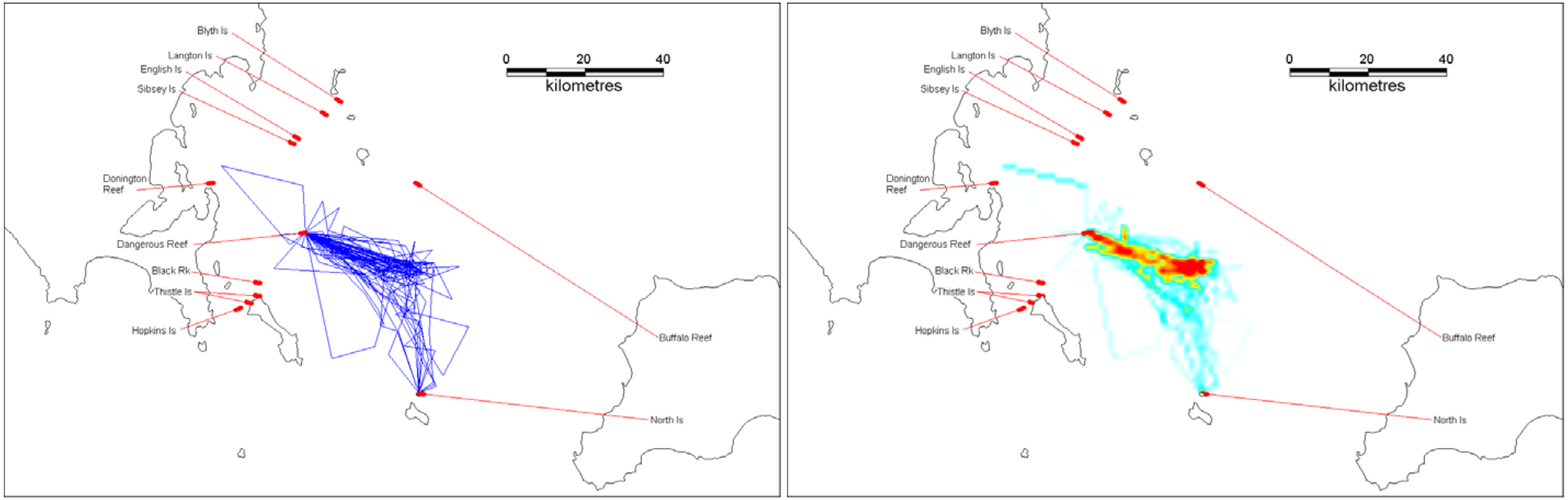
Adult male 3112 from Dangerous Reef. Tracks of 21 foraging trips (left) and time spent in 1 x 1 km areas (right).



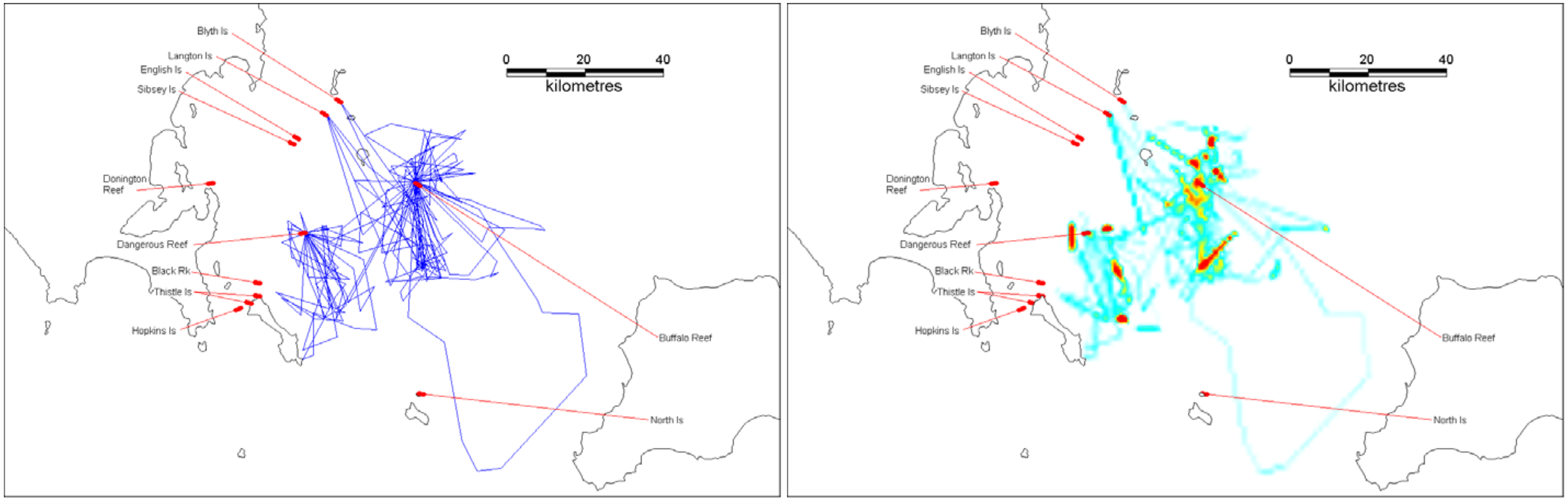
Adult male 3212 from Dangerous Reef. Tracks of 17 foraging trips (left) and time spent in 1 x 1 km areas (right).



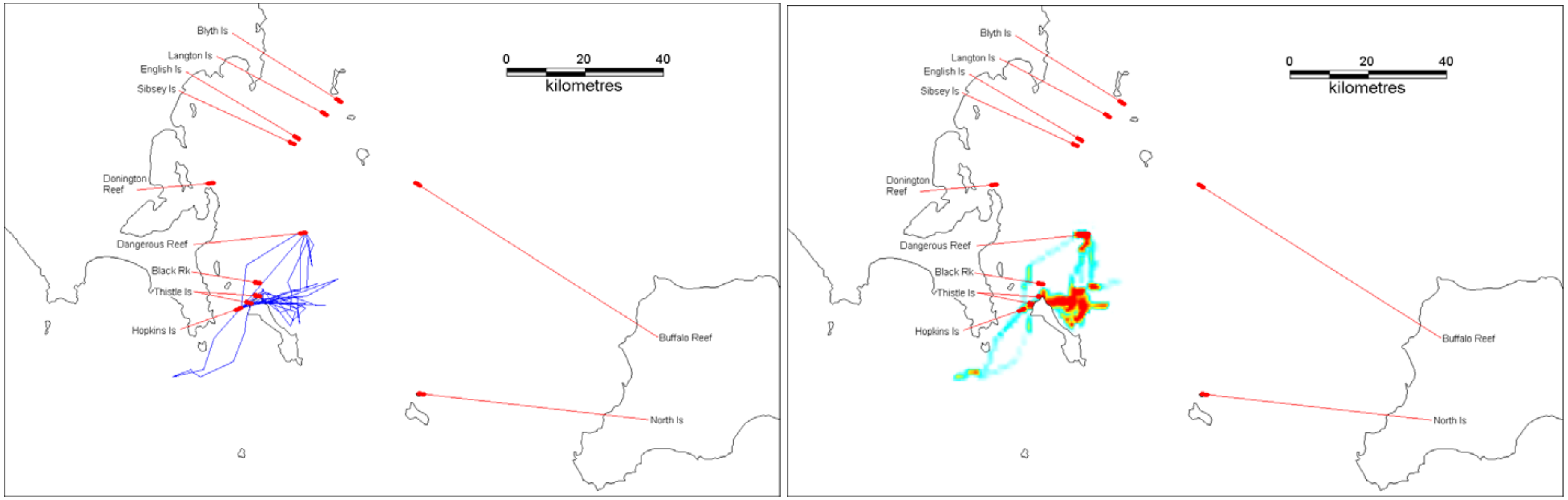
Adult male 3312 from Dangerous Reef. Tracks of 11 foraging trips (left) and time spent in 1 x 1 km areas (right).



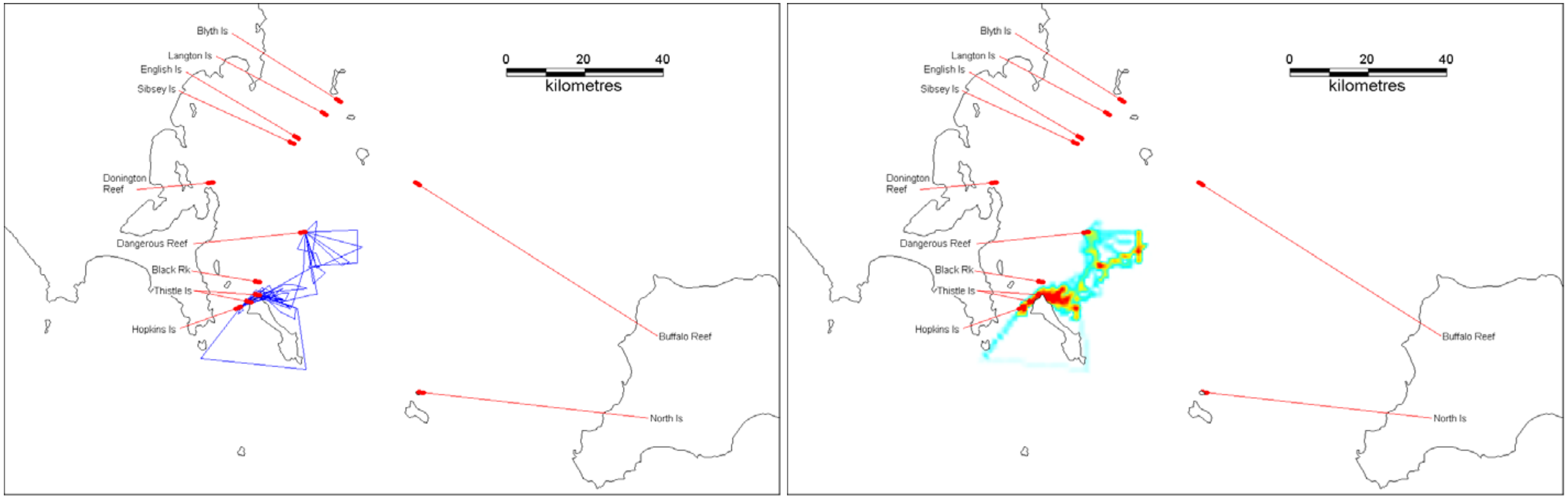
Juvenile male 10314 from Dangerous Reef. Tracks of 38 foraging trips (left) and time spent in 1 x 1 km areas (right).



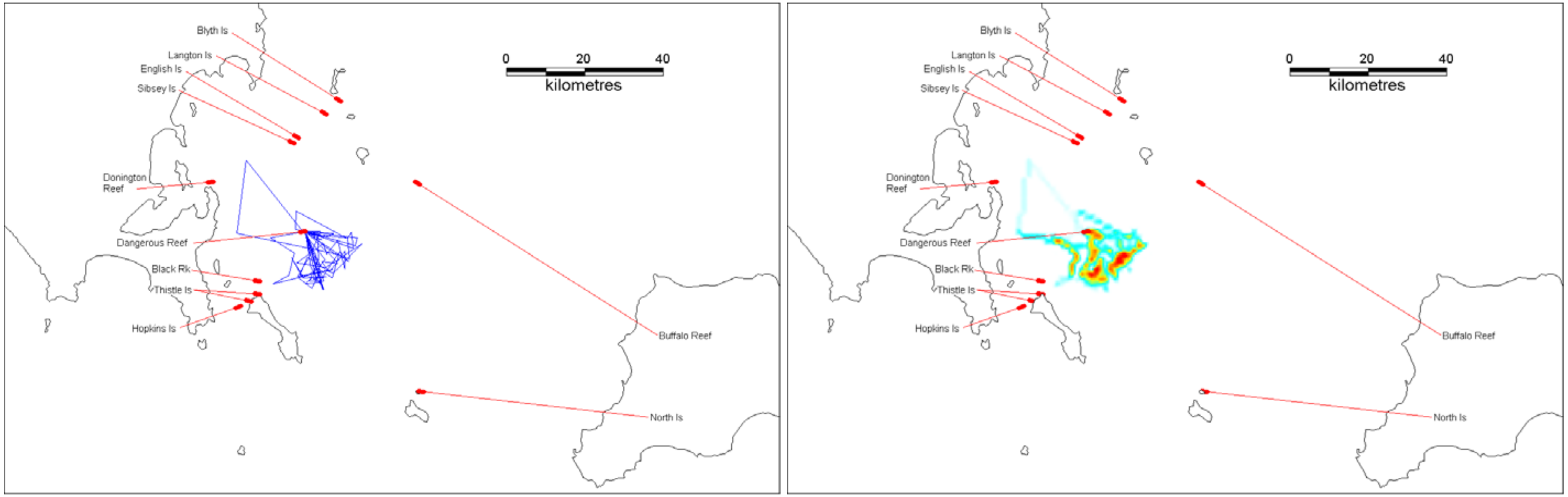
Juvenile male 12514 from Dangerous Reef. Tracks of 40 foraging trips (left) and time spent in 1 x 1 km areas (right).



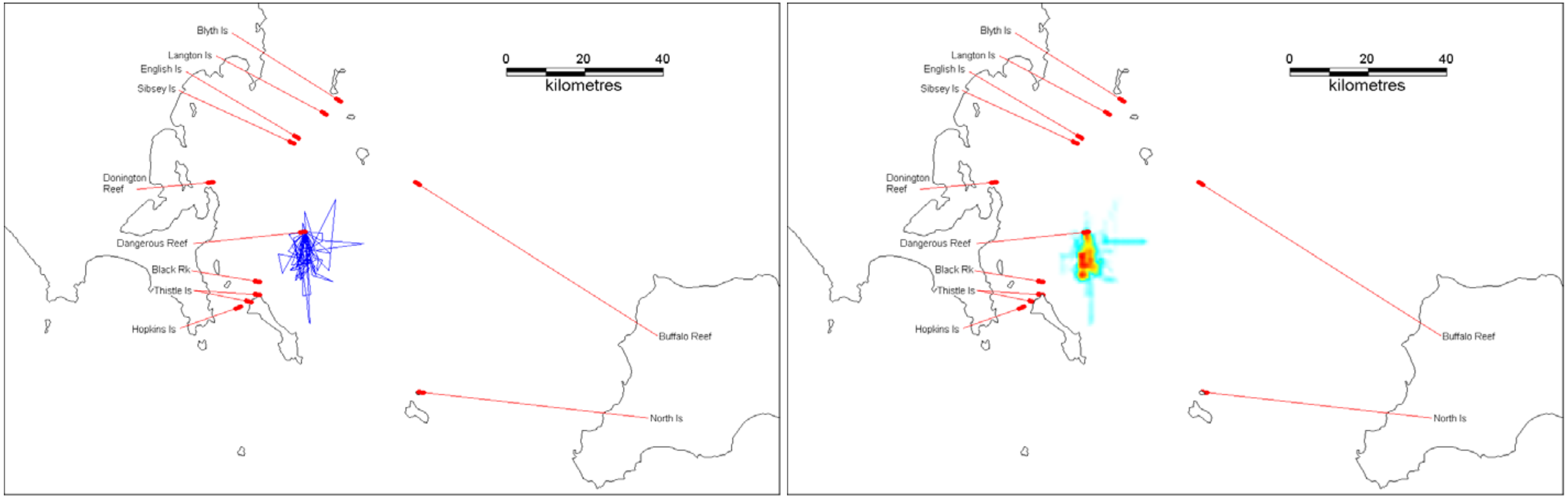
Juvenile male 614 from Dangerous Reef. Tracks of 11 foraging trips (left) and time spent in 1 x 1 km areas (right).



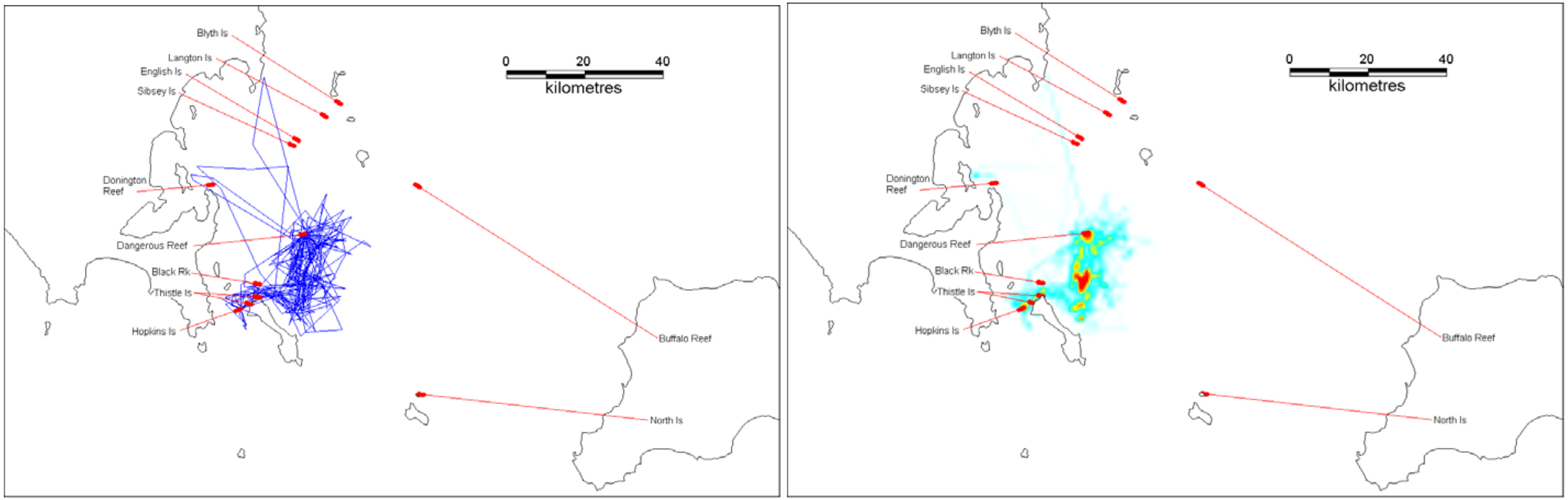
Juvenile male 714 from Dangerous Reef. Tracks of 17 foraging trips (left) and time spent in 1 x 1 km areas (right).



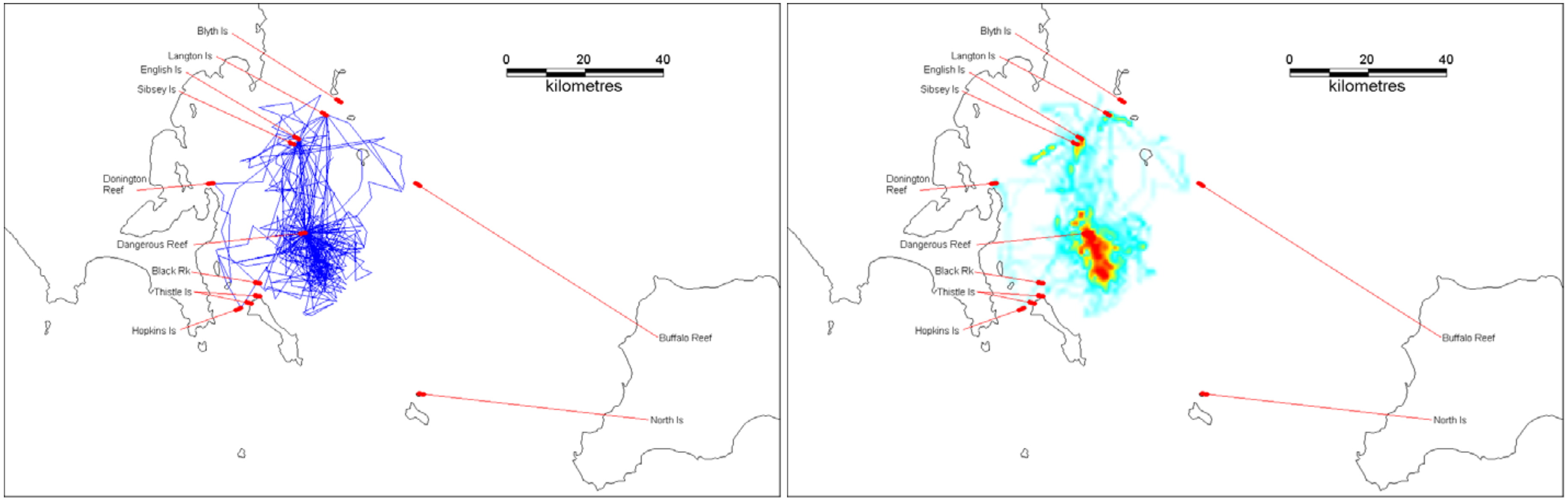
Juvenile male 914 from Dangerous Reef. Tracks of 12 foraging trips (left) and time spent in 1 x 1 km areas (right).



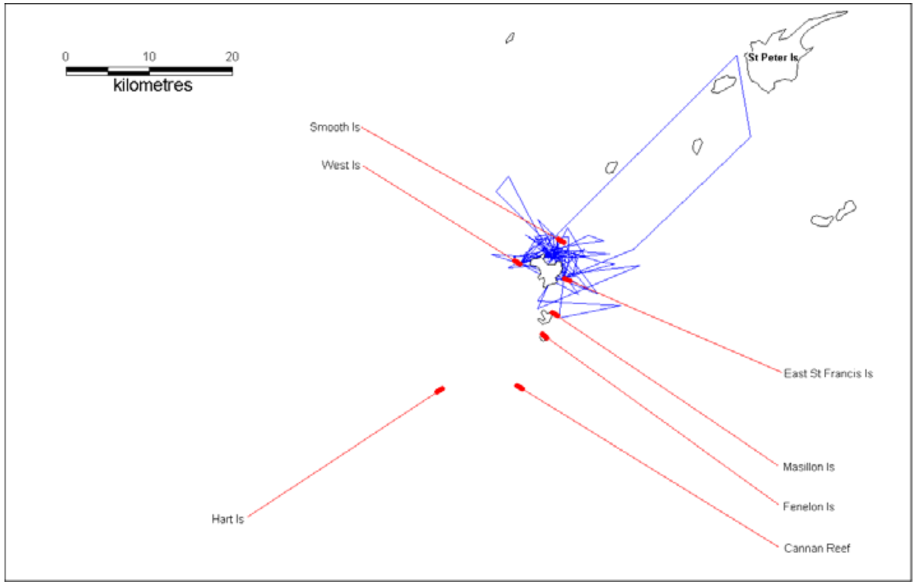
Juvenile male 1914 from Dangerous Reef. Tracks of 19 foraging trips (left) and time spent in 1 x 1 km areas (right).

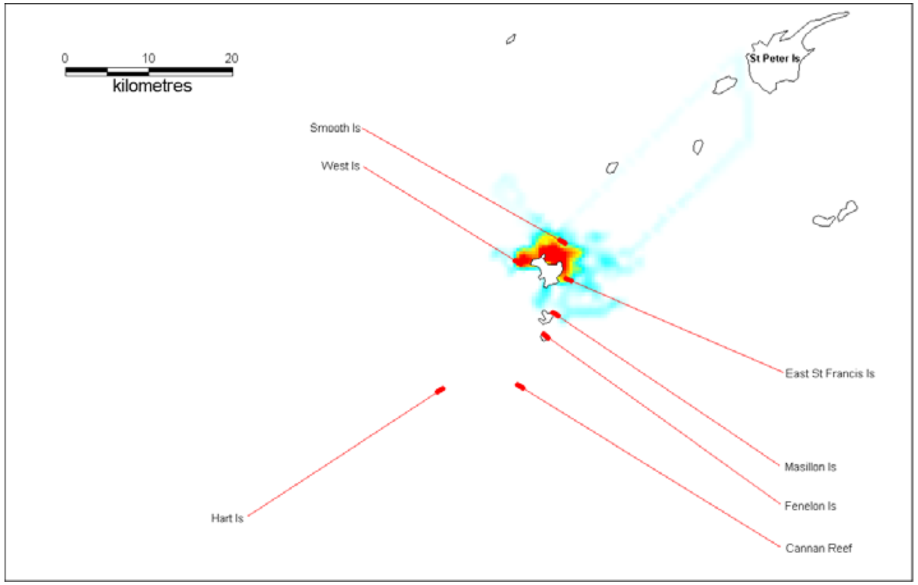


Juvenile male 2014 from Dangerous Reef. Tracks of 34 foraging trips (left) and time spent in 1 x 1 km areas (right).

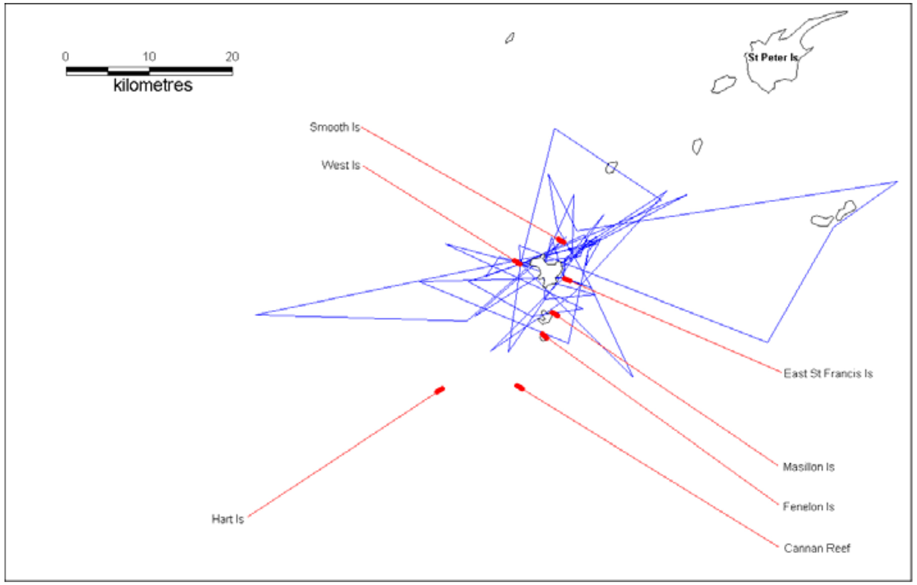


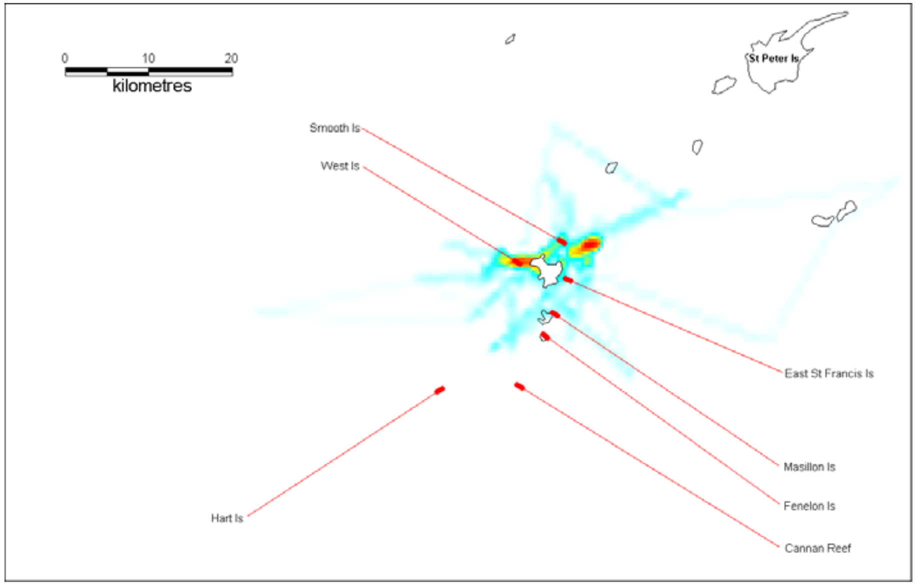
Subadult male 1015 from Dangerous Reef. Tracks of 78 foraging trips (left) and time spent in 1 x 1 km areas (right).



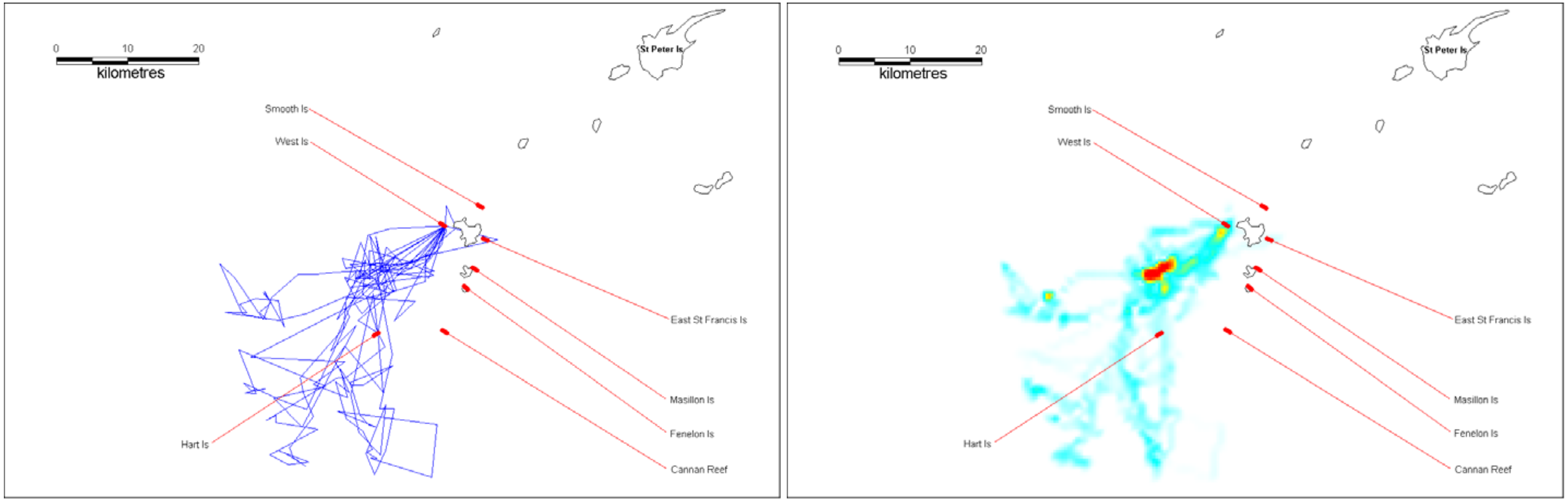


Adult female 121 from West Is. Tracks of 15 foraging trips (left) and time spent in 1 x 1 km areas (right).

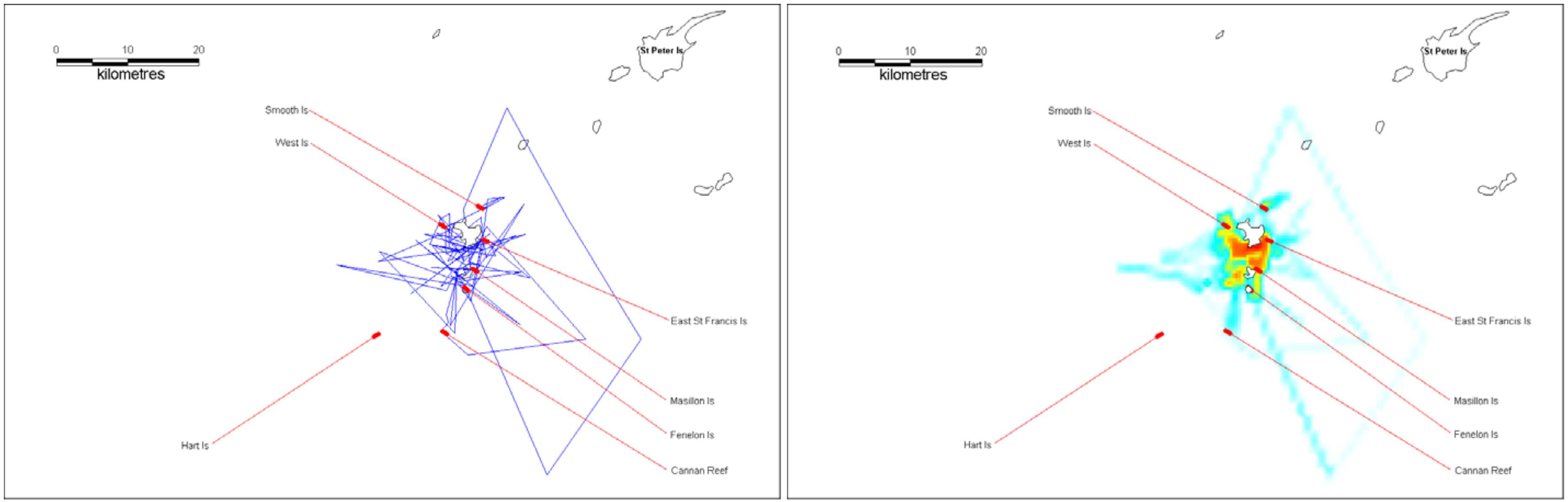




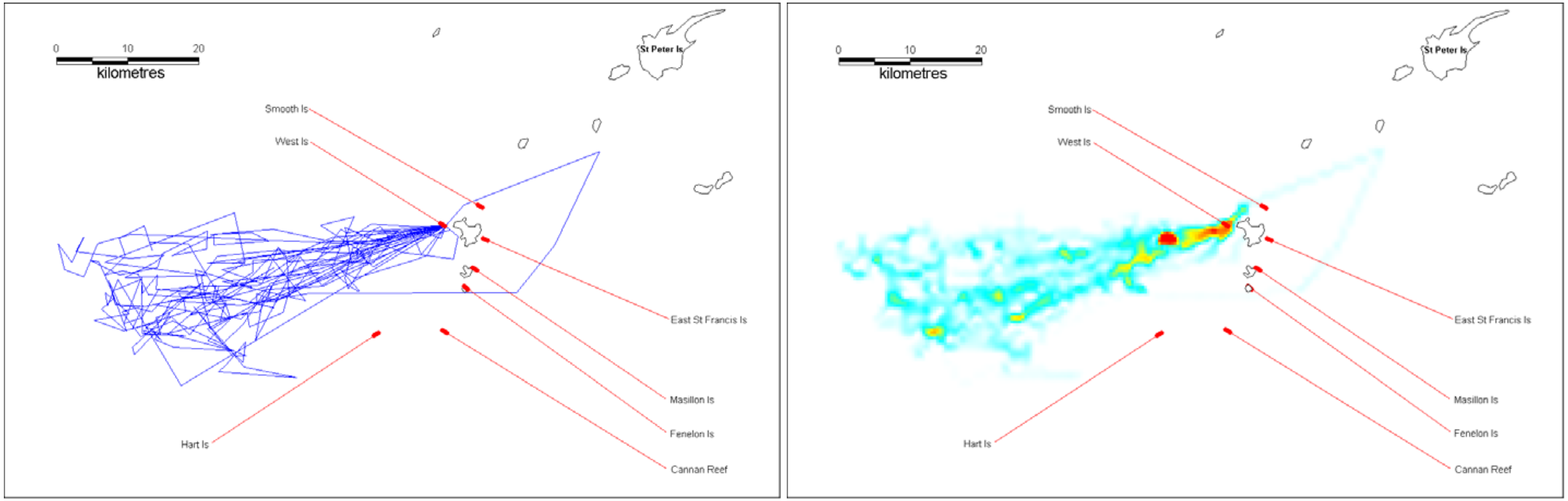
Adult female 321 from West Is. Tracks of 11 foraging trips (left) and time spent in 1 x 1 km areas (right).



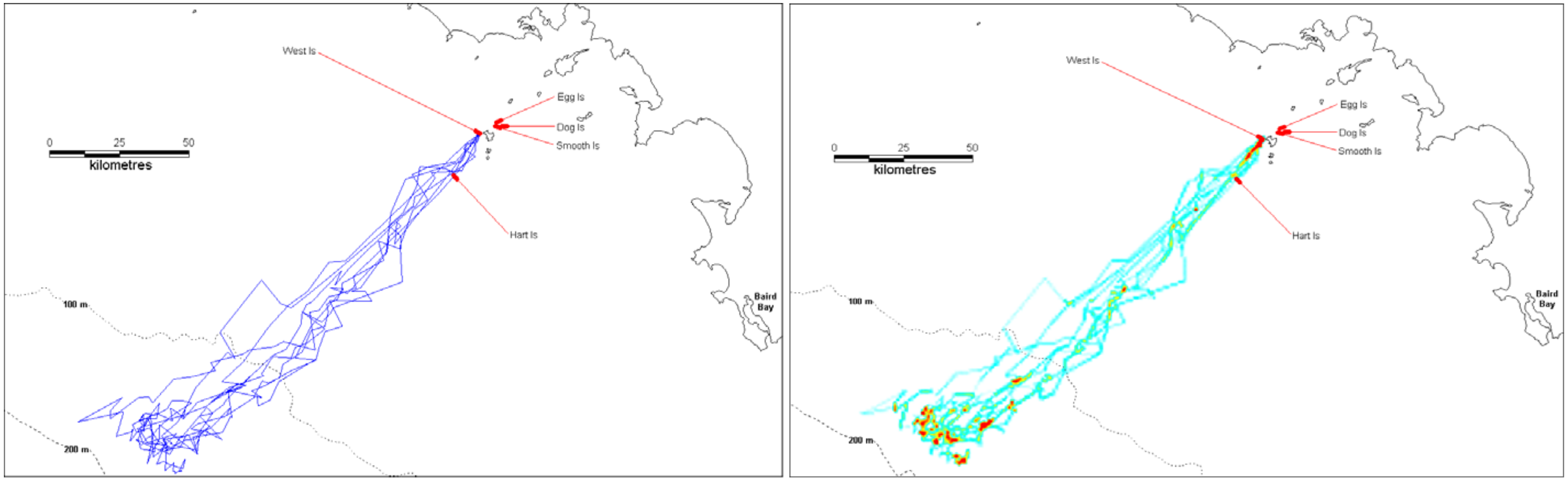
Adult female 421 from West Is. Tracks of 12 foraging trips (left) and time spent in 1 x 1 km areas (right).



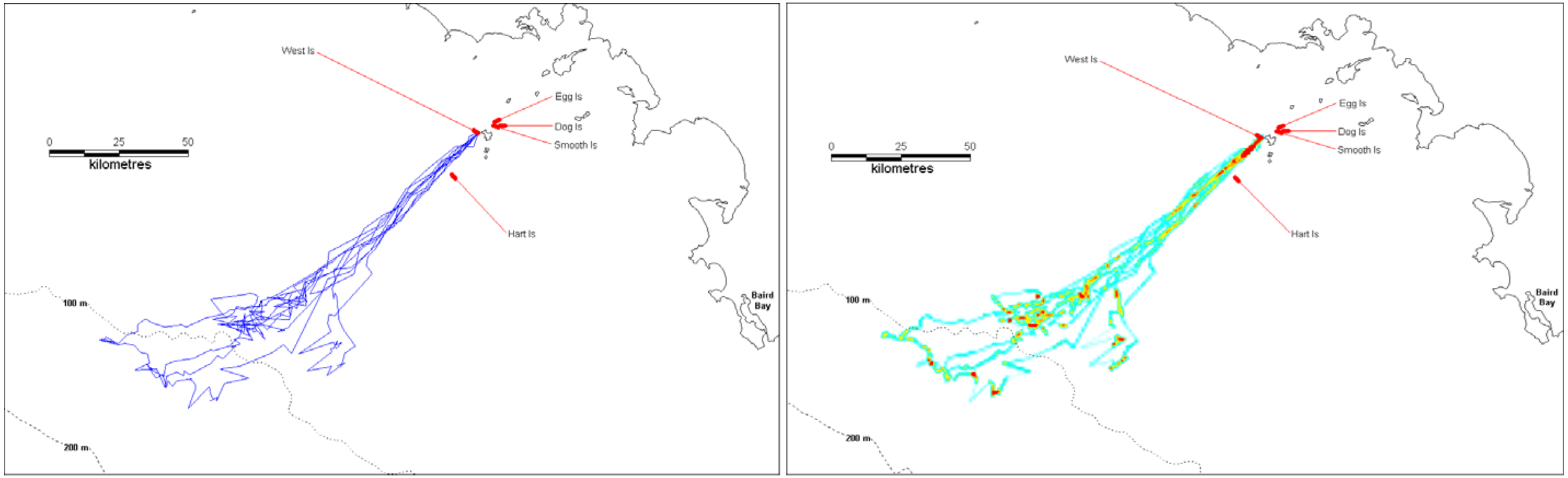
Adult female 521 from West Is. Tracks of 16 foraging trips (left) and time spent in 1 x 1 km areas (right).



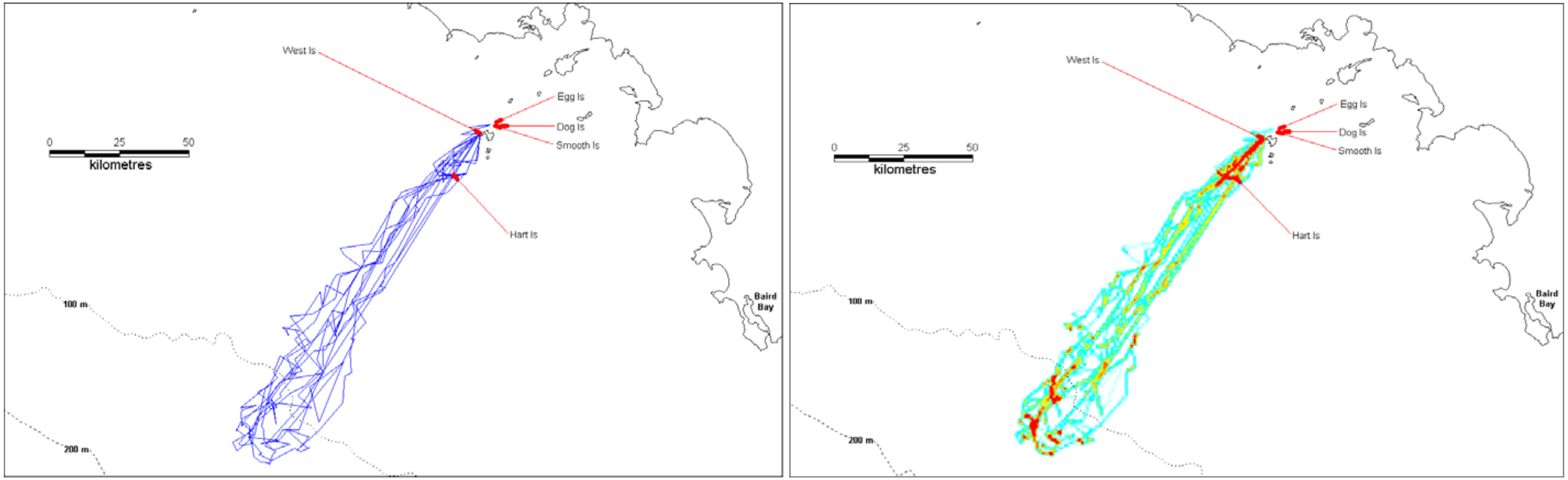
Adult female 621 from West Is. Tracks of 12 foraging trips (left) and time spent in 1 x 1 km areas (right).



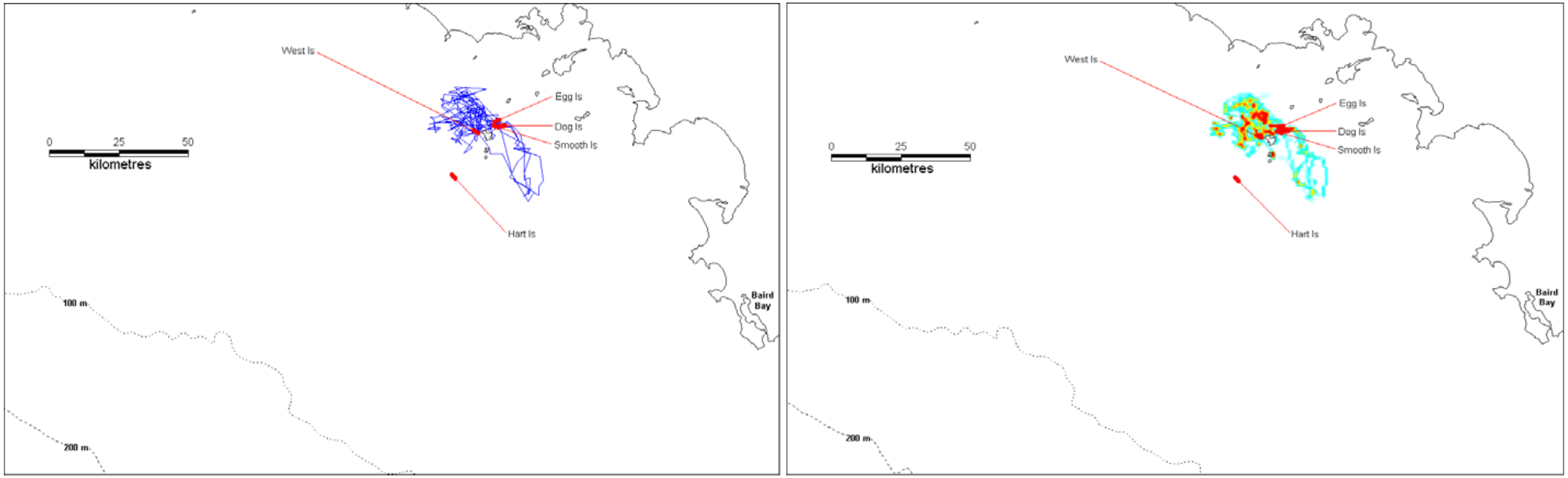
Adult male 1222 from West Is. Tracks of 4 foraging trips (left) and time spent in 1 x 1 km areas (right).



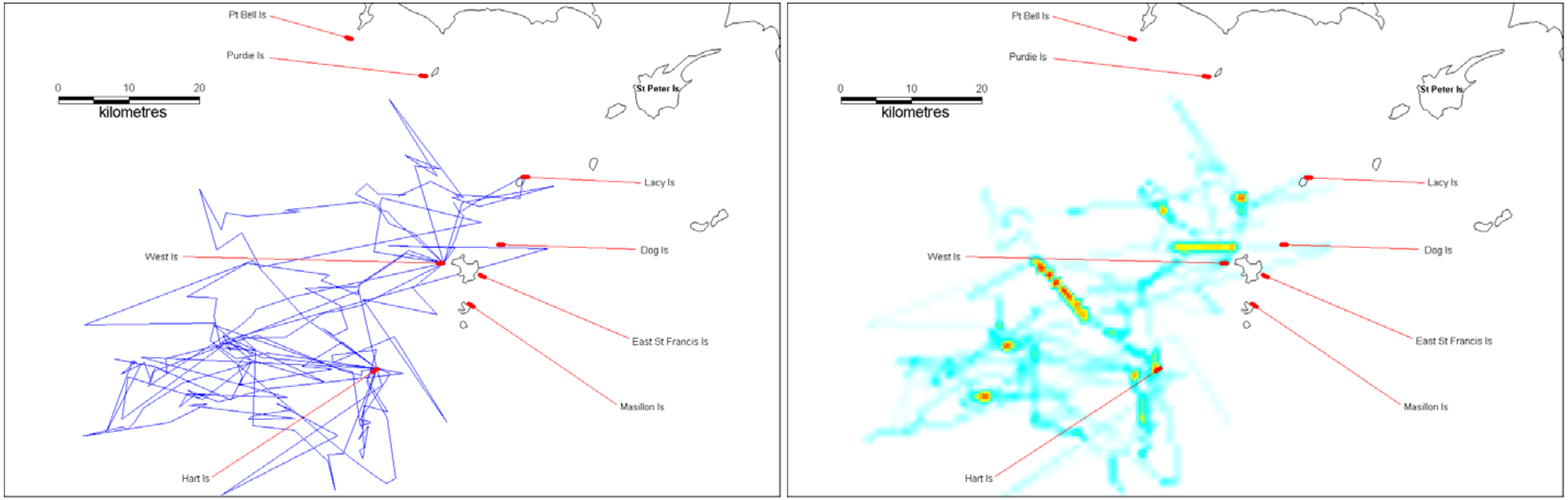
Adult male 1322 from West Is. Tracks of 5 foraging trips (left) and time spent in 1 x 1 km areas (right).



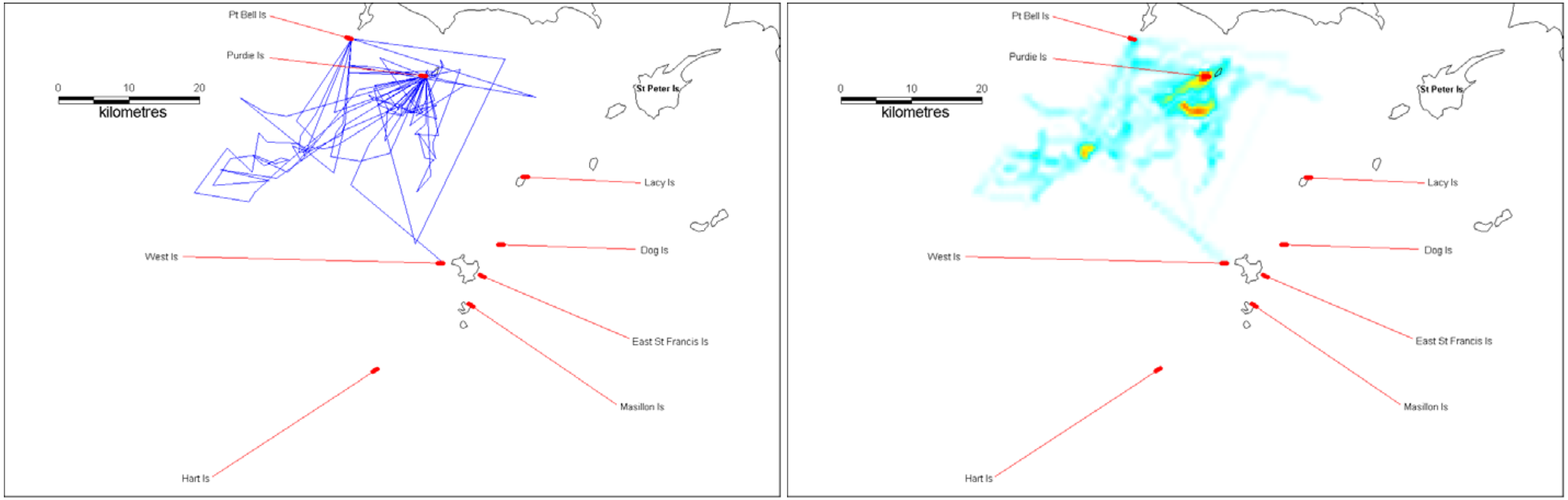
Adult male 1422 from West Is. Tracks of 9 foraging trips (left) and time spent in 1 x 1 km areas (right).



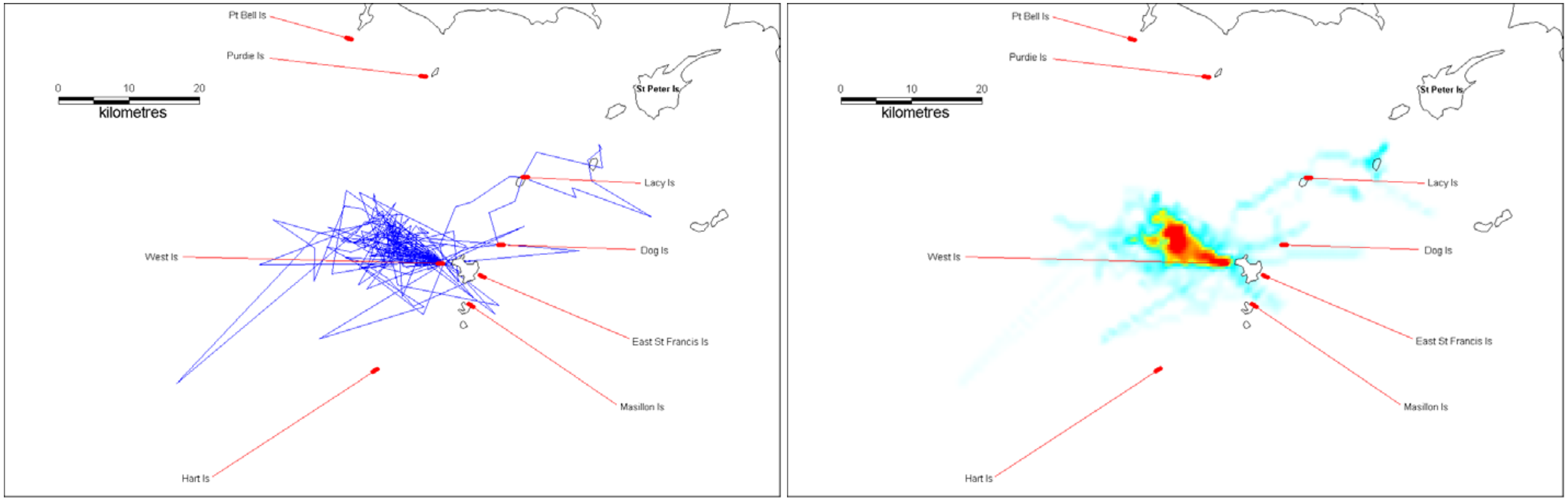
Adult male 1522 from West Is. Tracks of 18 foraging trips (left) and time spent in 1 x 1 km areas (right).



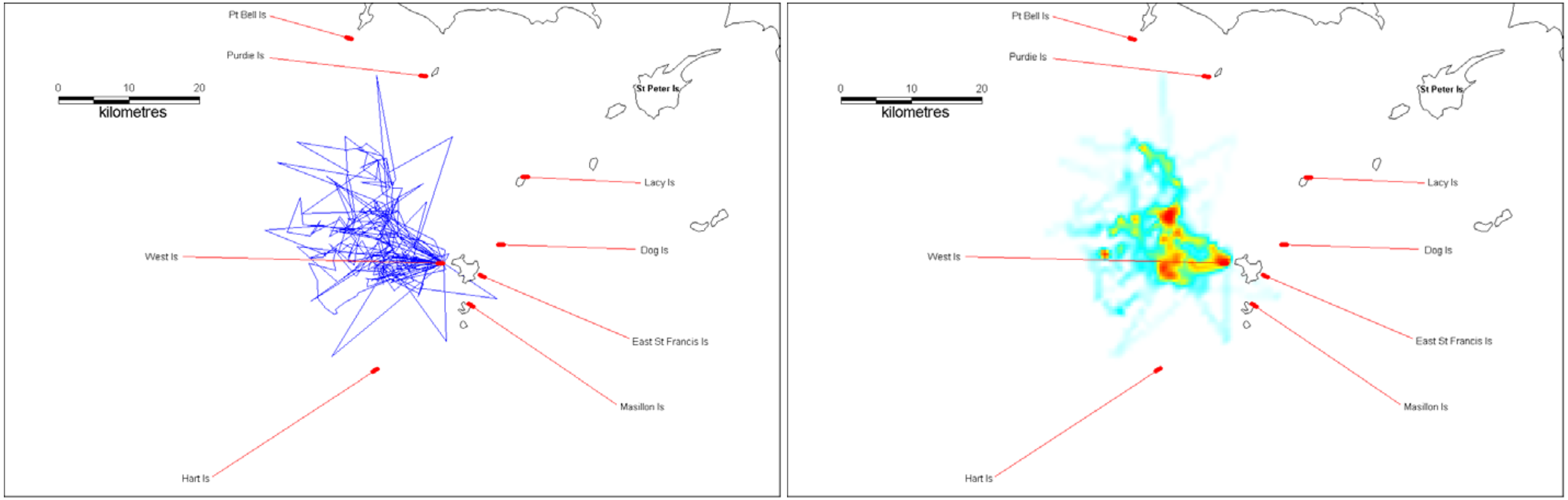
Juvenile female 723 from West Is. Tracks of 14 foraging trips (left) and time spent in 1 x 1 km areas (right).



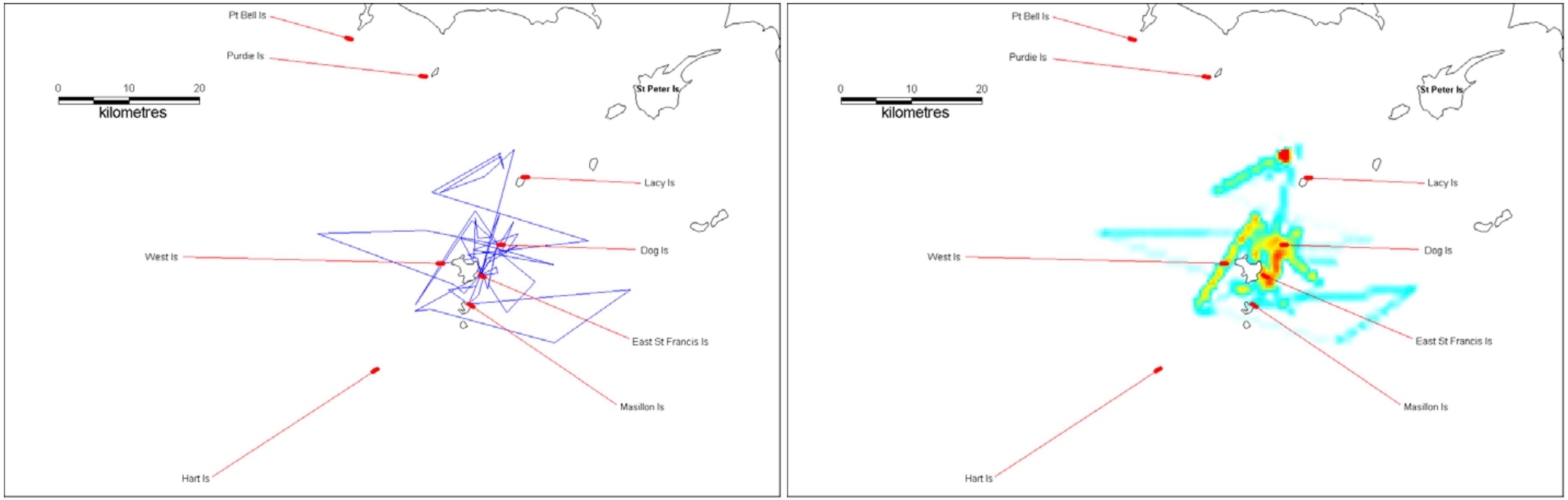
Juvenile female 923 from West Is. Tracks of 20 foraging trips (left) and time spent in 1 x 1 km areas (right).



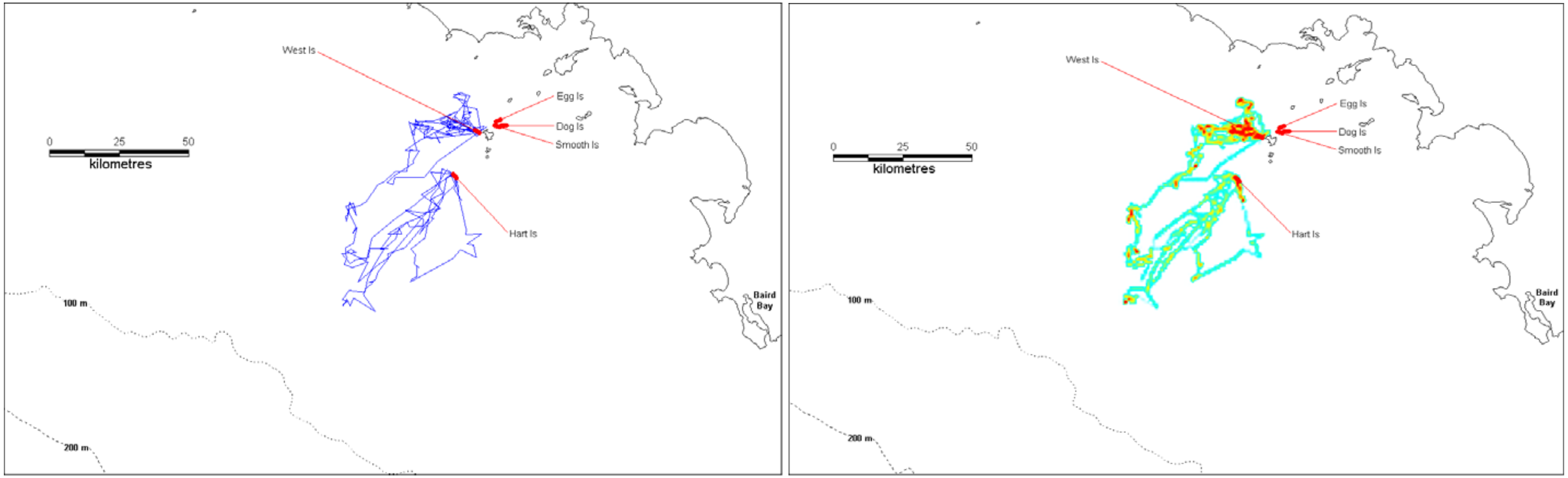
Juvenile male 224 from West Is. Tracks of 29 foraging trips (left) and time spent in 1 x 1 km areas (right).



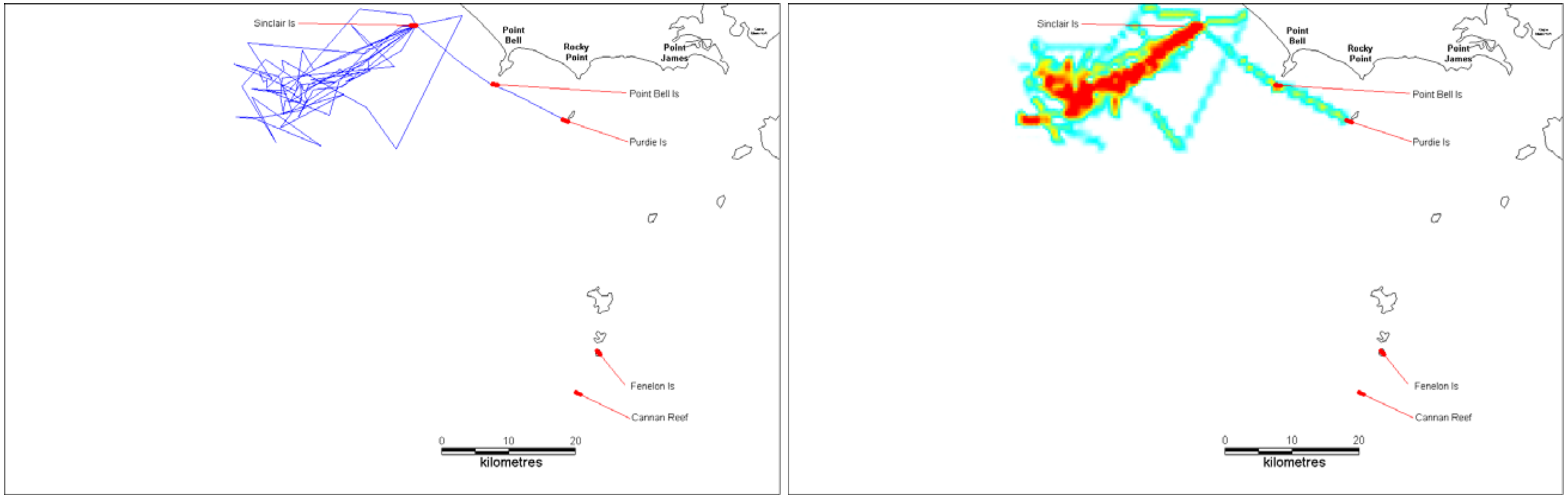
Juvenile male 824 from West Is. Tracks of 17 foraging trips (left) and time spent in 1 x 1 km areas (right).



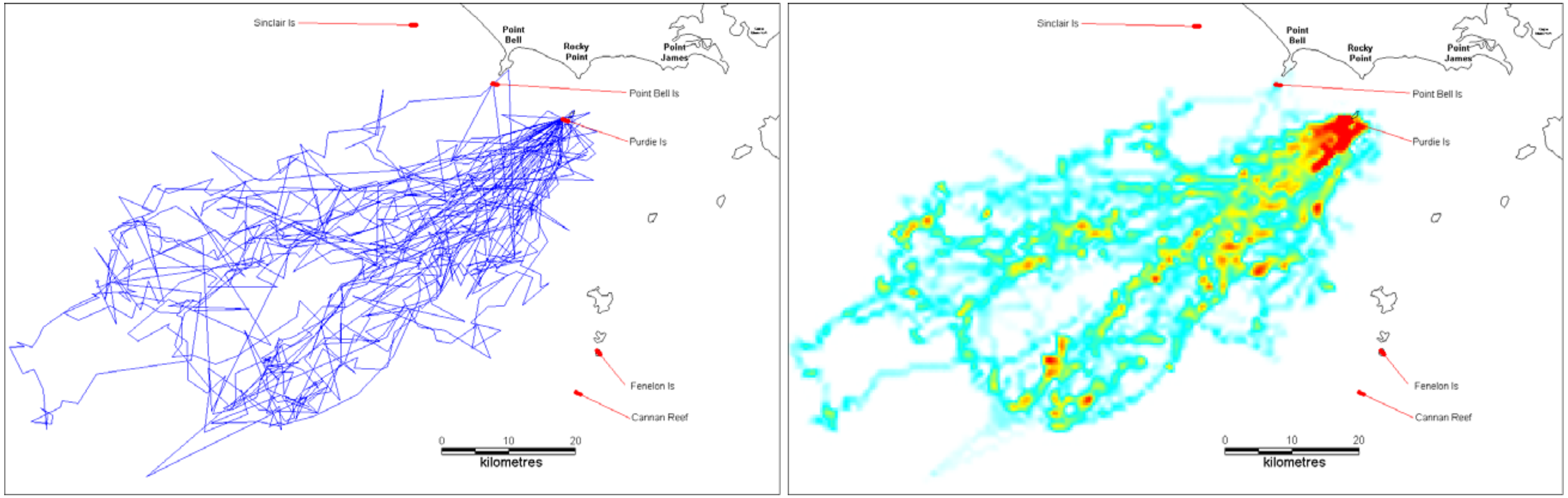
Juvenile male 1124 from West Is. Tracks of 11 foraging trips (left) and time spent in 1 x 1 km areas (right).



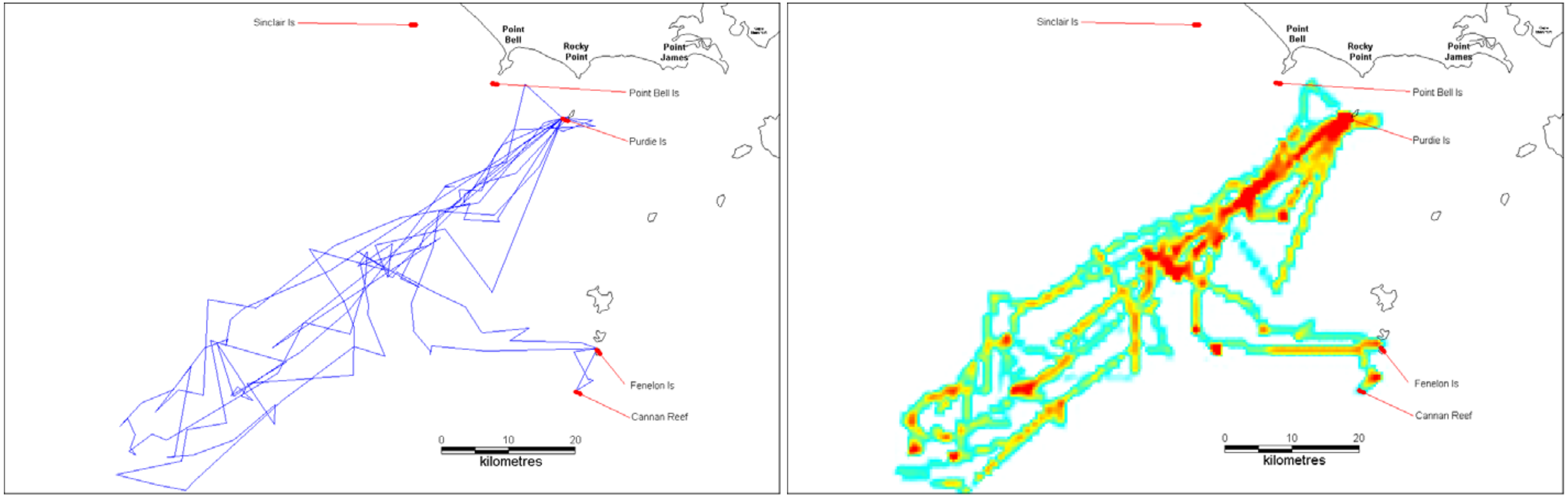
Subadult male 1025 from West Is. Tracks of 12 foraging trips (left) and time spent in 1 x 1 km areas (right).



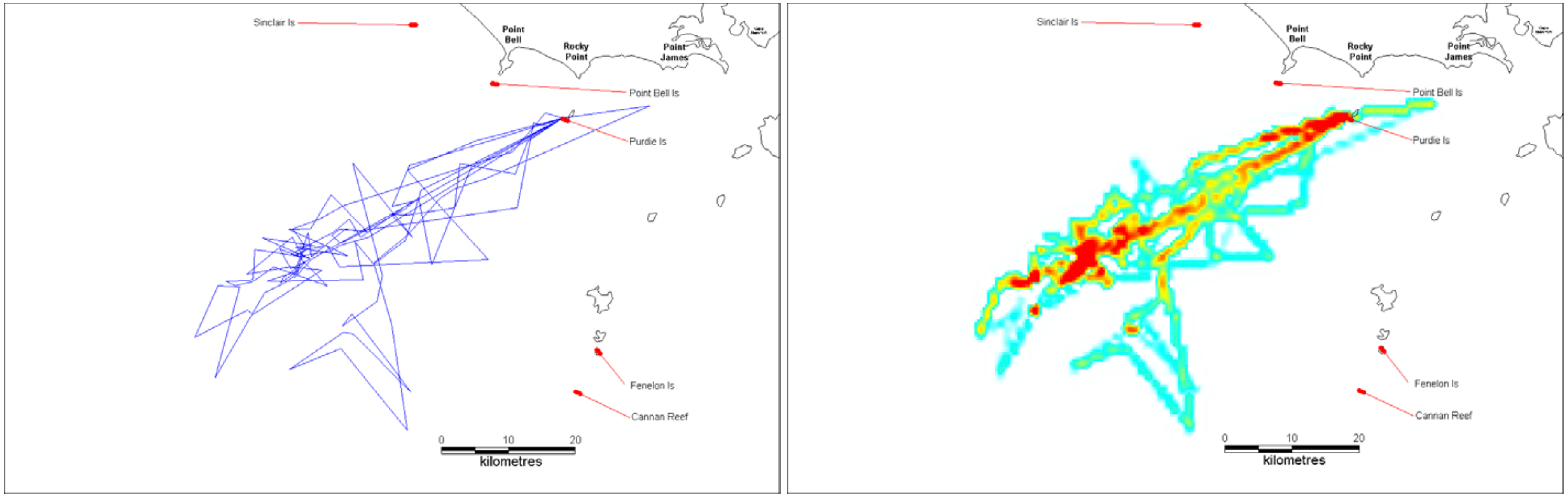
Adult female 131 from Purdie Is. Tracks of 8 foraging trips (left) and time spent in 1 x 1 km areas (right).



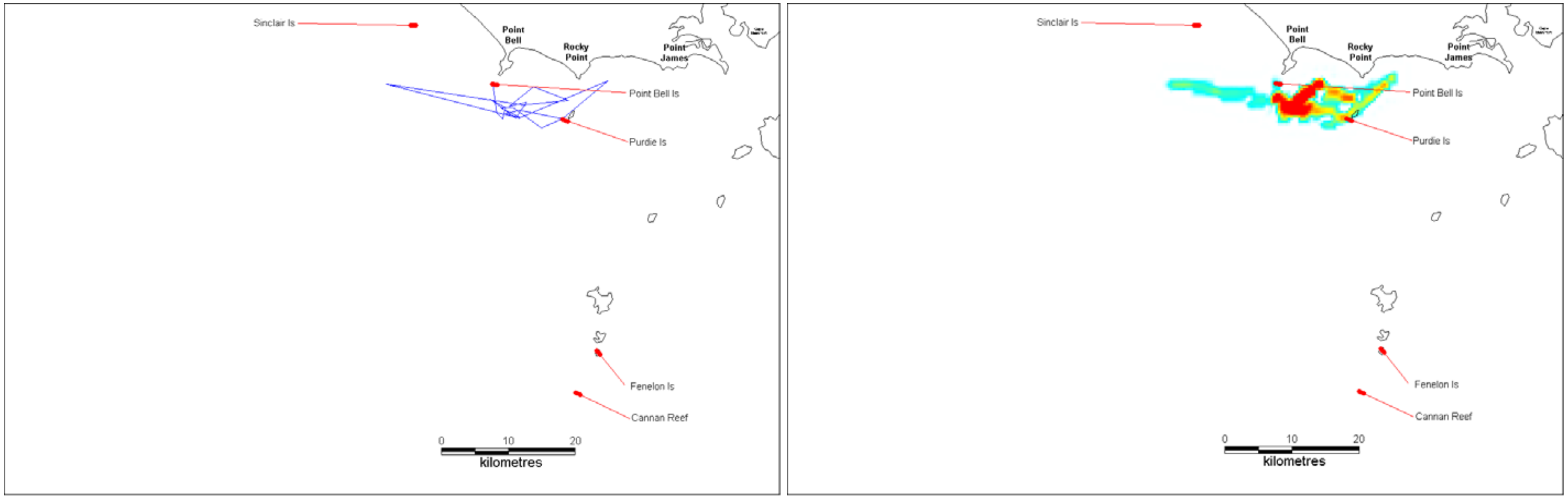
Adult female 331 from Purdie Is. Tracks of 25 foraging trips (left) and time spent in 1 x 1 km areas (right).



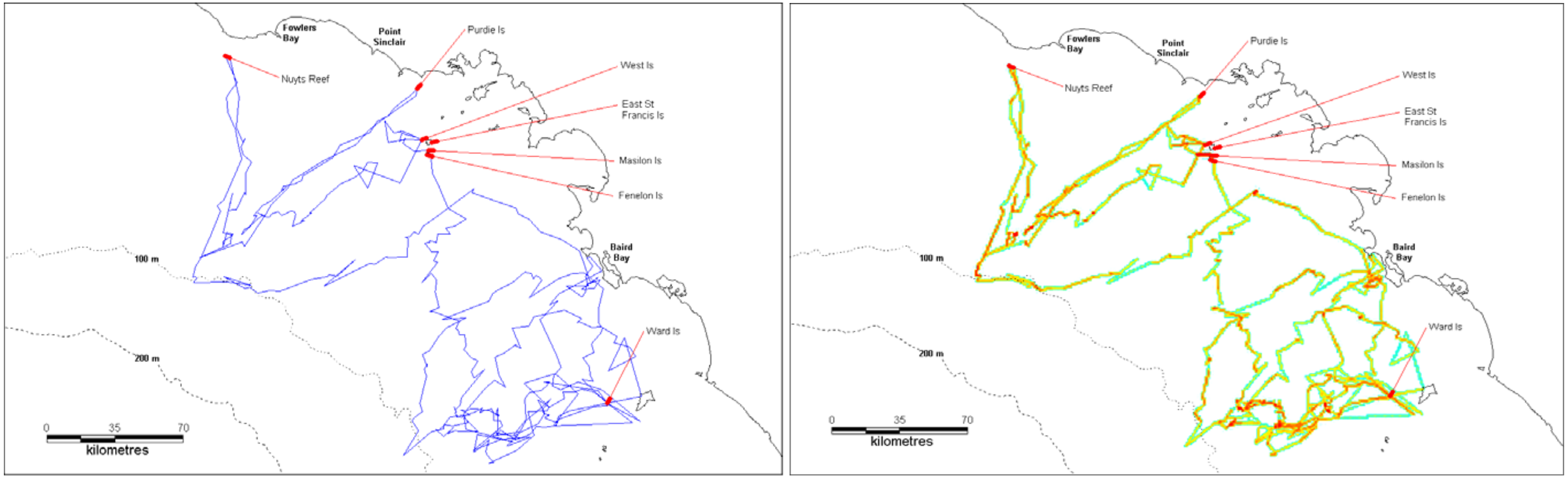
Adult female 431 from Purdie Is. Tracks of 9 foraging trips (left) and time spent in 1 x 1 km areas (right).



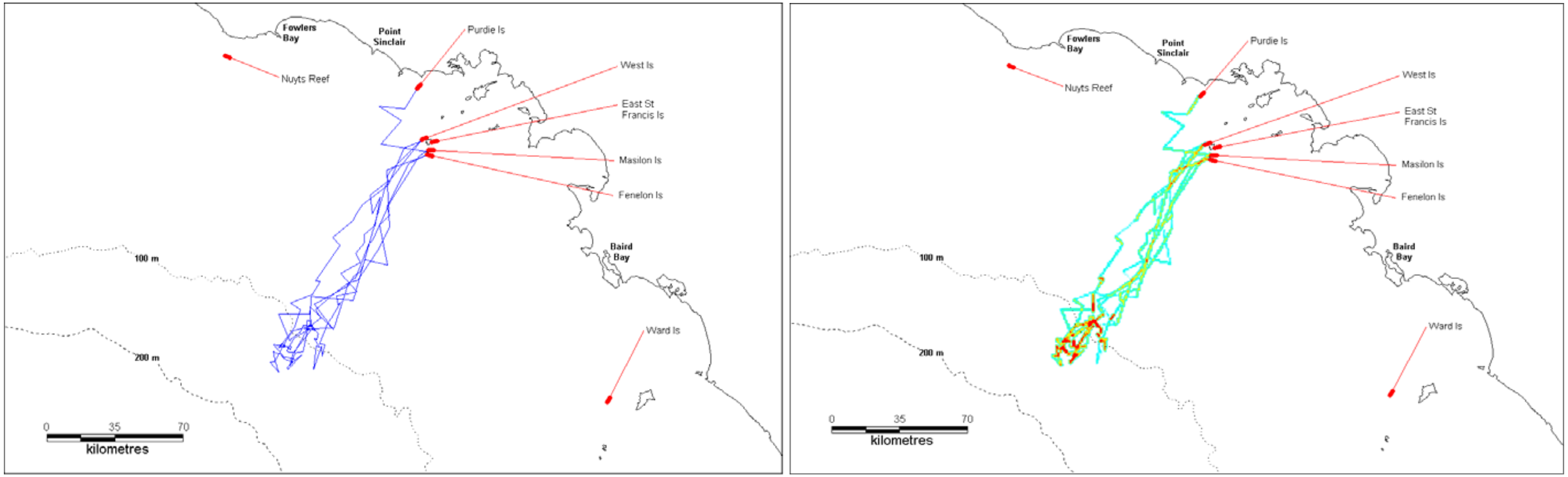
Adult female 531 from Purdie Is. Tracks of 5 foraging trips (left) and time spent in 1 x 1 km areas (right).



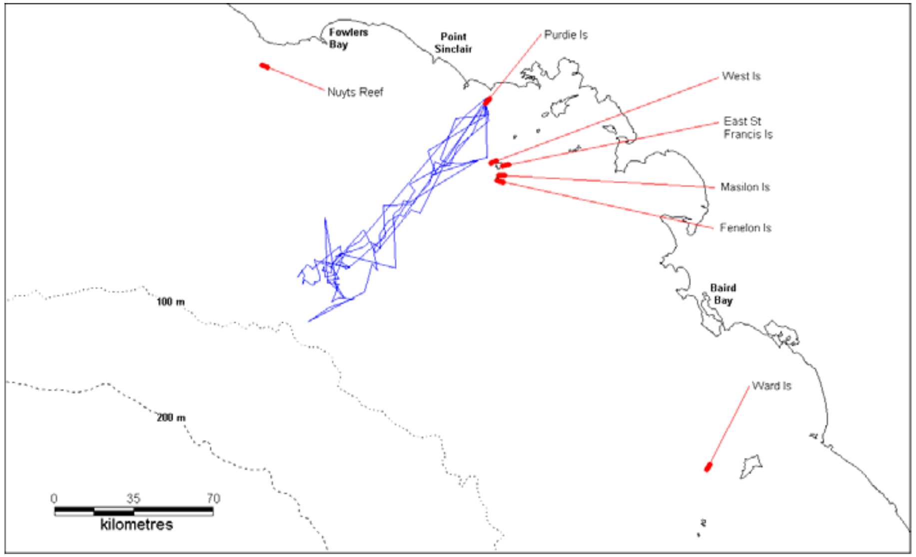
Adult female 731 from Purdie Is. Tracks of 2 foraging trips (left) and time spent in 1 x 1 km areas (right).

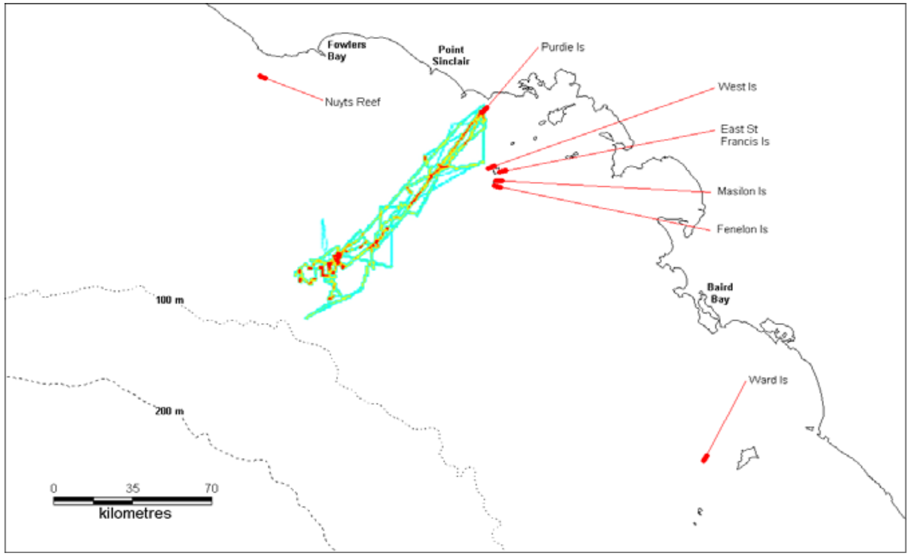


Adult male 1132 from Purdie Is. Tracks of 9 foraging trips (left) and time spent in 1 x 1 km areas (right).

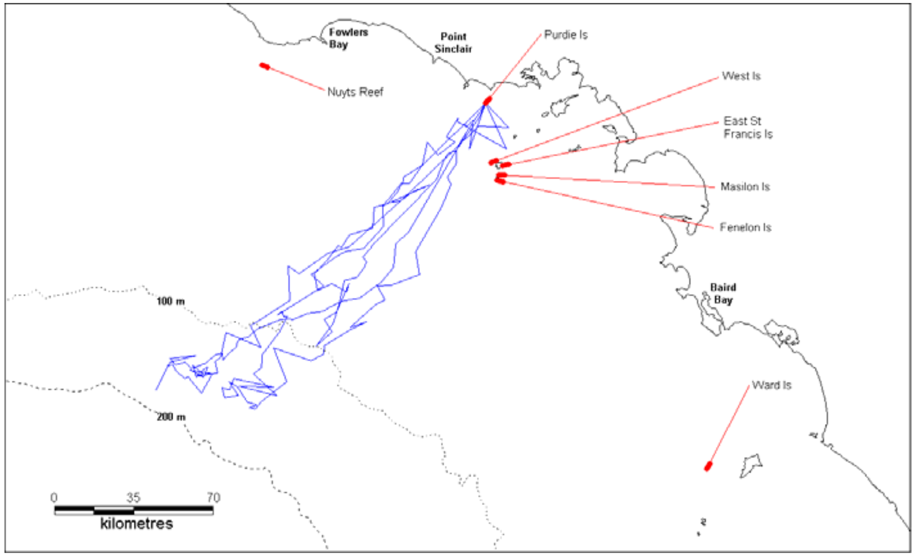


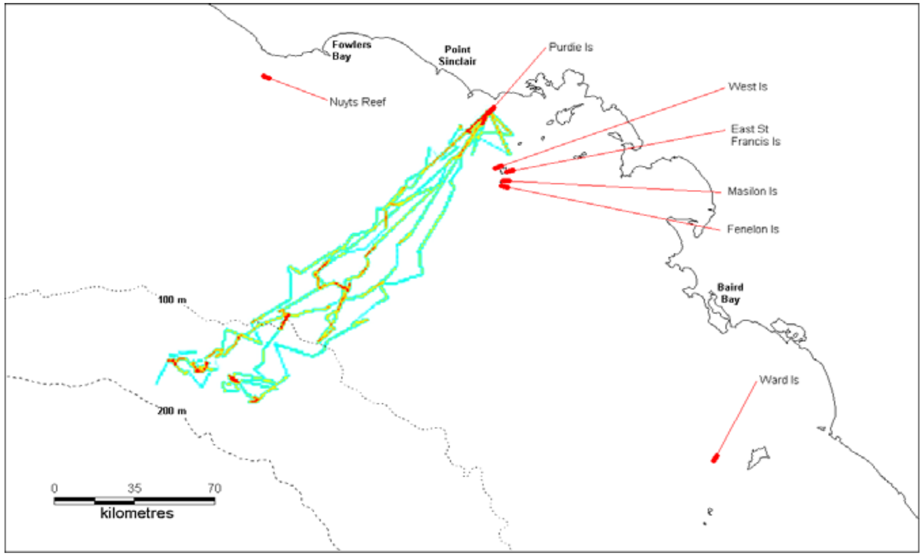
Adult male 1232 from Purdie Is. Tracks of 4 foraging trips (left) and time spent in 1 x 1 km areas (right).



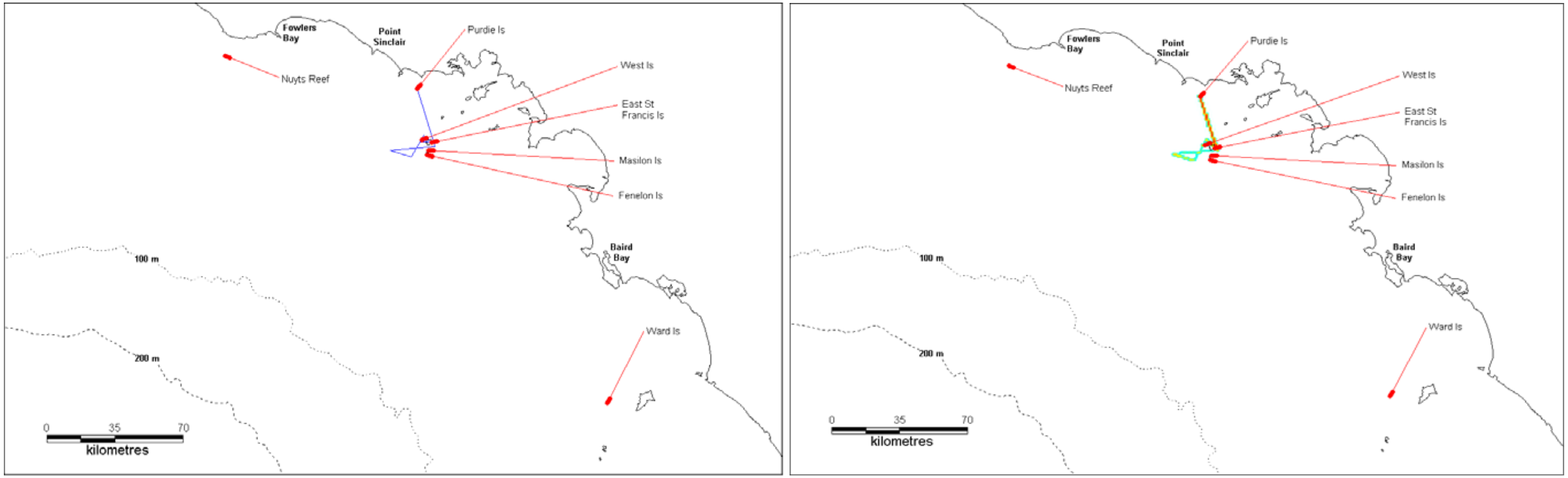


Adult male 1332 from Purdie Is. Tracks of 4 foraging trips (left) and time spent in 1 x 1 km areas (right).

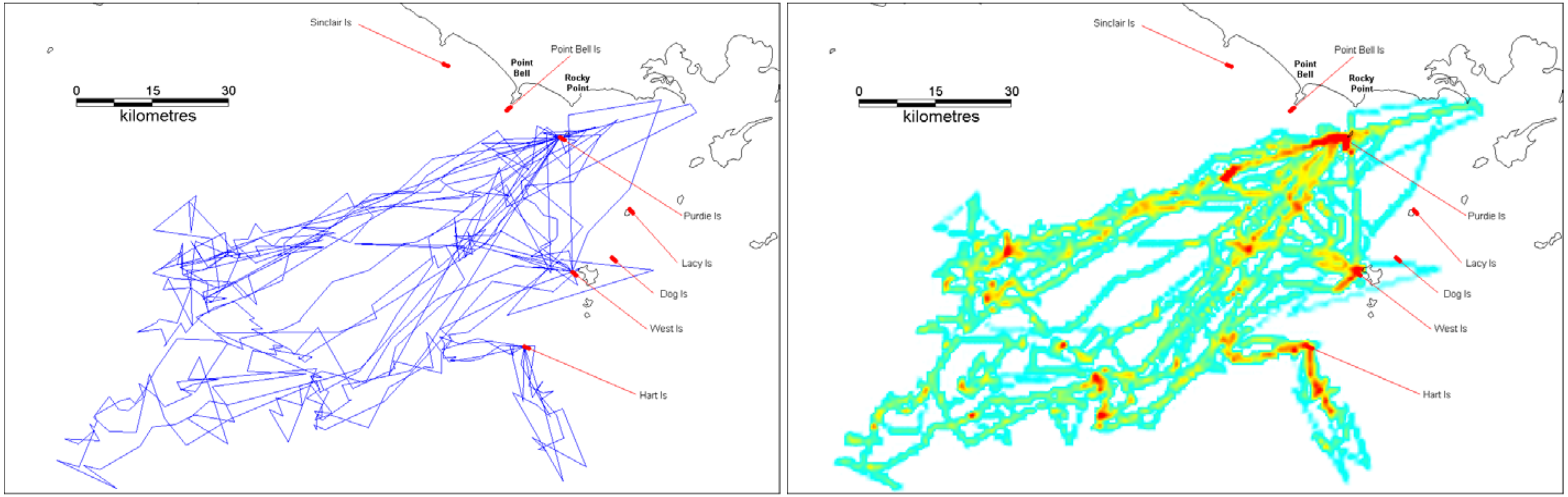




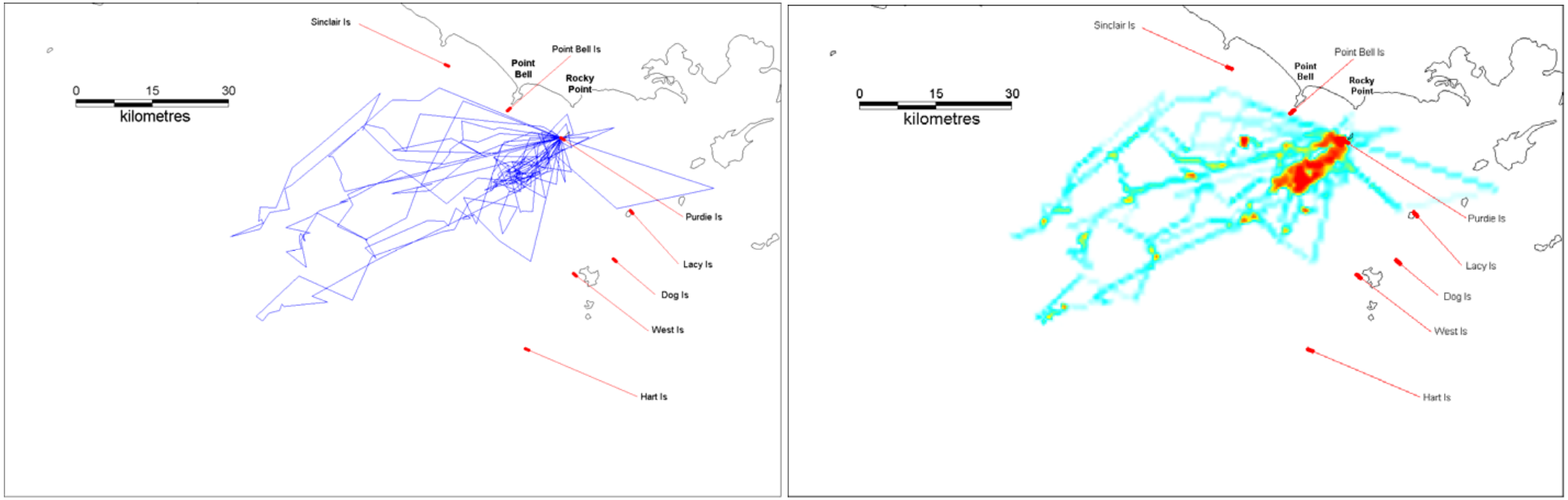
Adult male 1432 from Purdie Is. Tracks of 4 foraging trips (left) and time spent in 1 x 1 km areas (right).



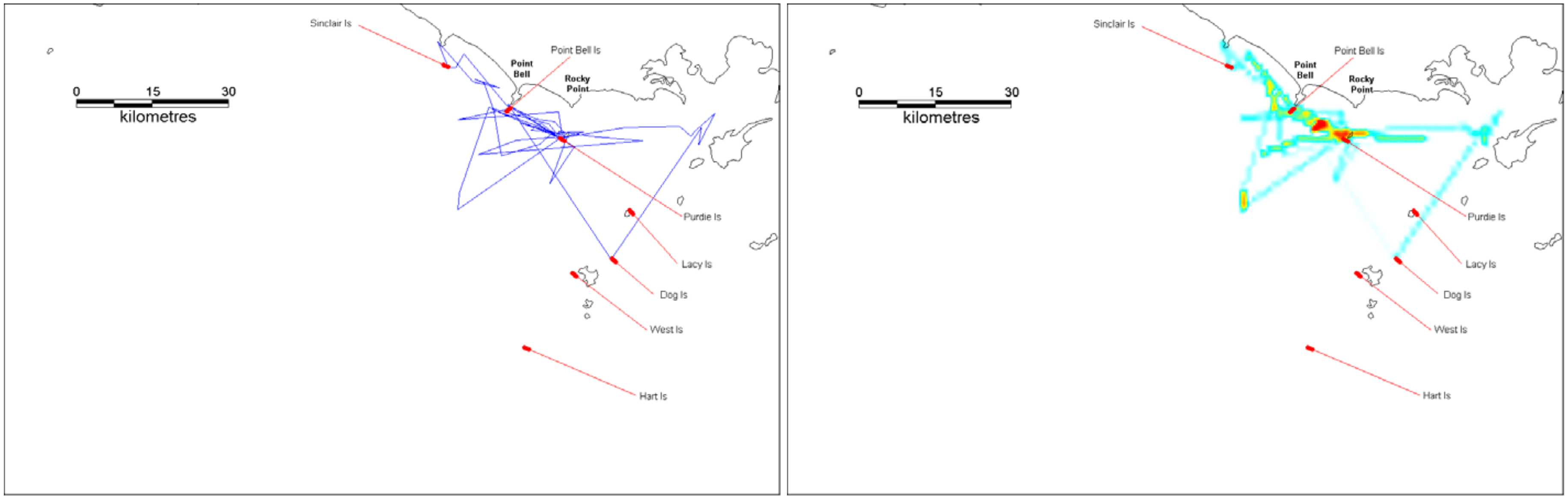
Adult male 1532 from Purdie Is. Tracks of 2 foraging trips (left) and time spent in 1 x 1 km areas (right).



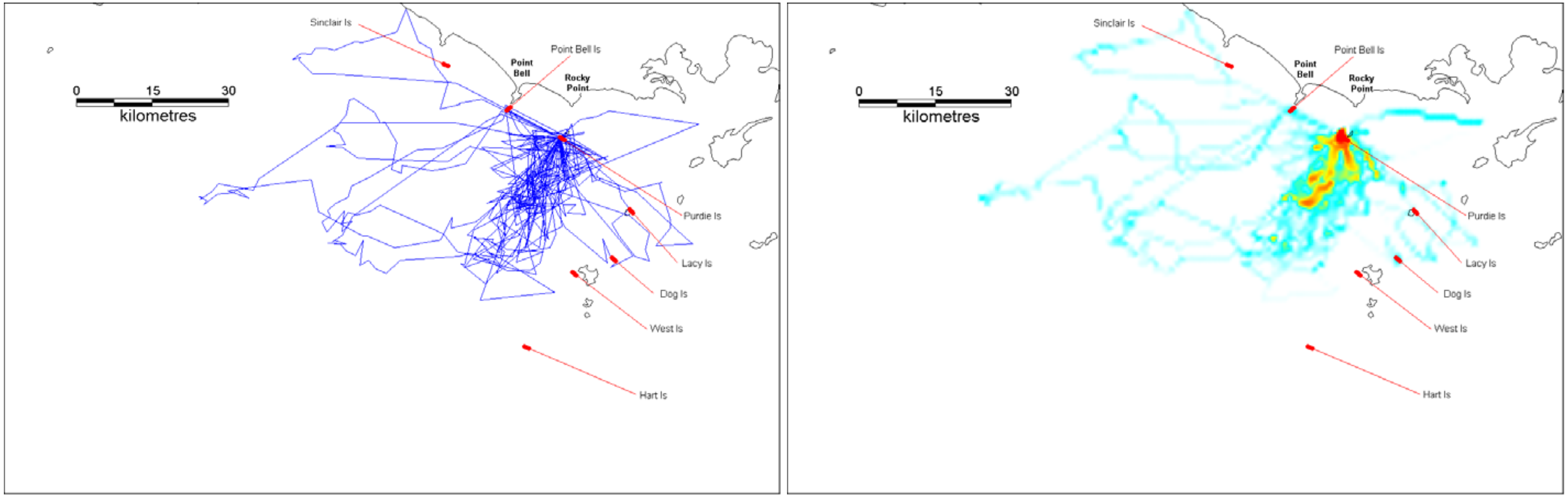
Juvenile male 234 from Purdie Is. Tracks of 21 foraging trips (left) and time spent in 1 x 1 km areas (right).



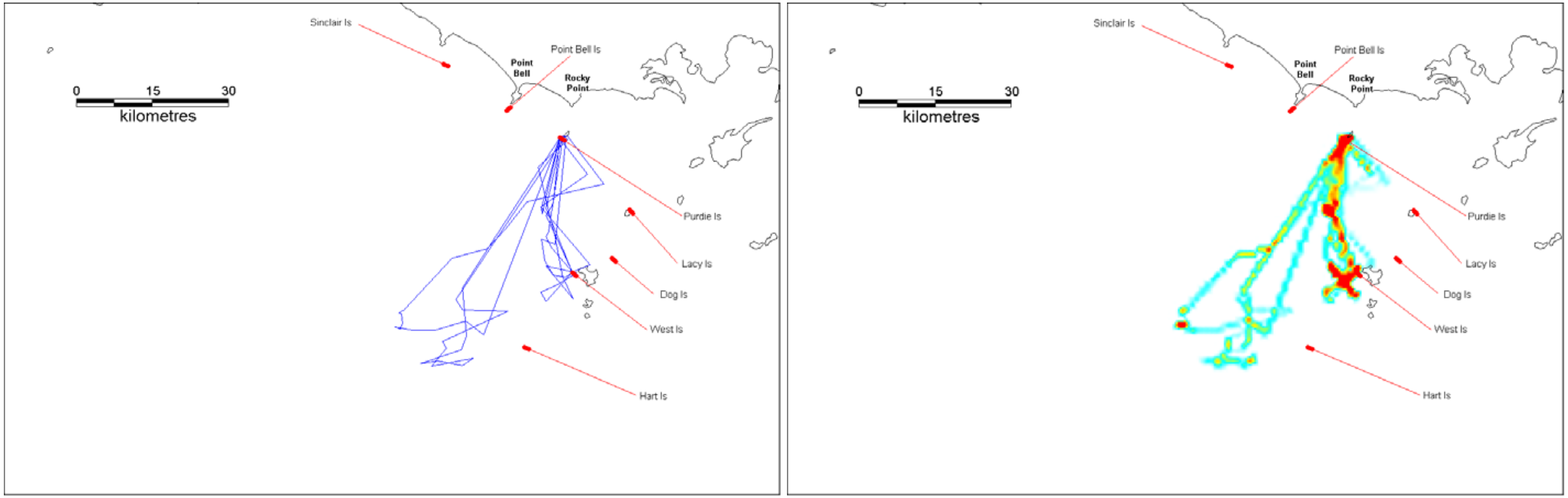
Juvenile male 634 from Purdie Is. Tracks of 21 foraging trips (left) and time spent in 1 x 1 km areas (right).



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



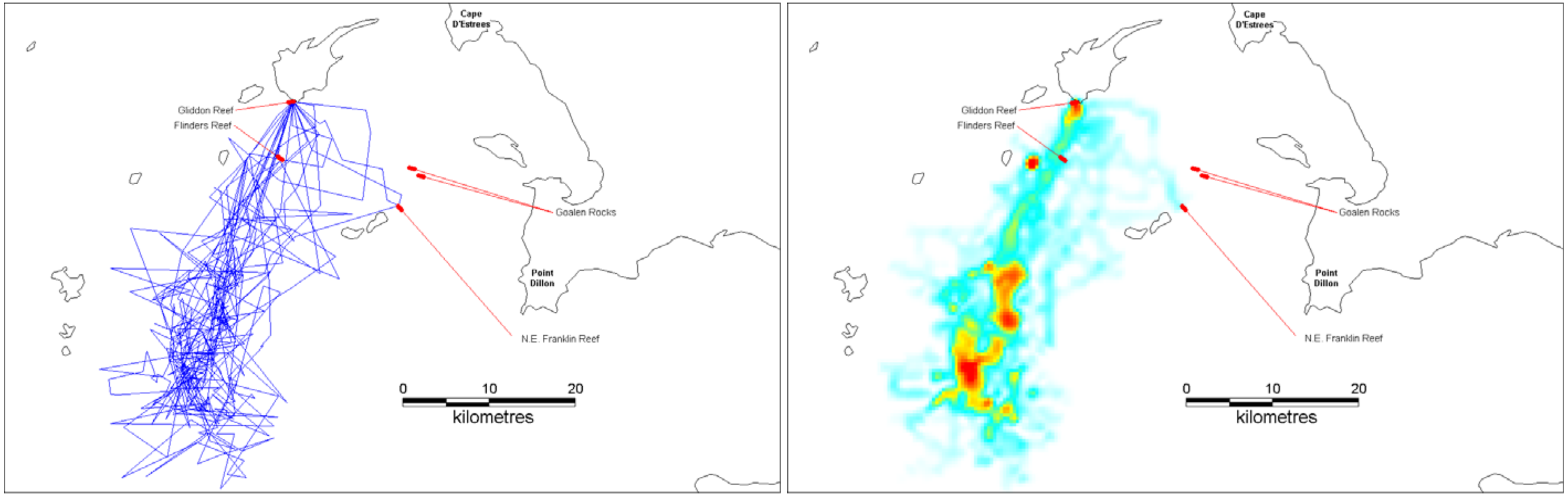
Juvenile male 934 from Purdie Is. Tracks of 38 foraging trips (left) and time spent in 1 x 1 km areas (right).



Juvenile male 1034 from Purdie Is. Tracks of 10 foraging trips (left) and time spent in 1 x 1 km areas (right).

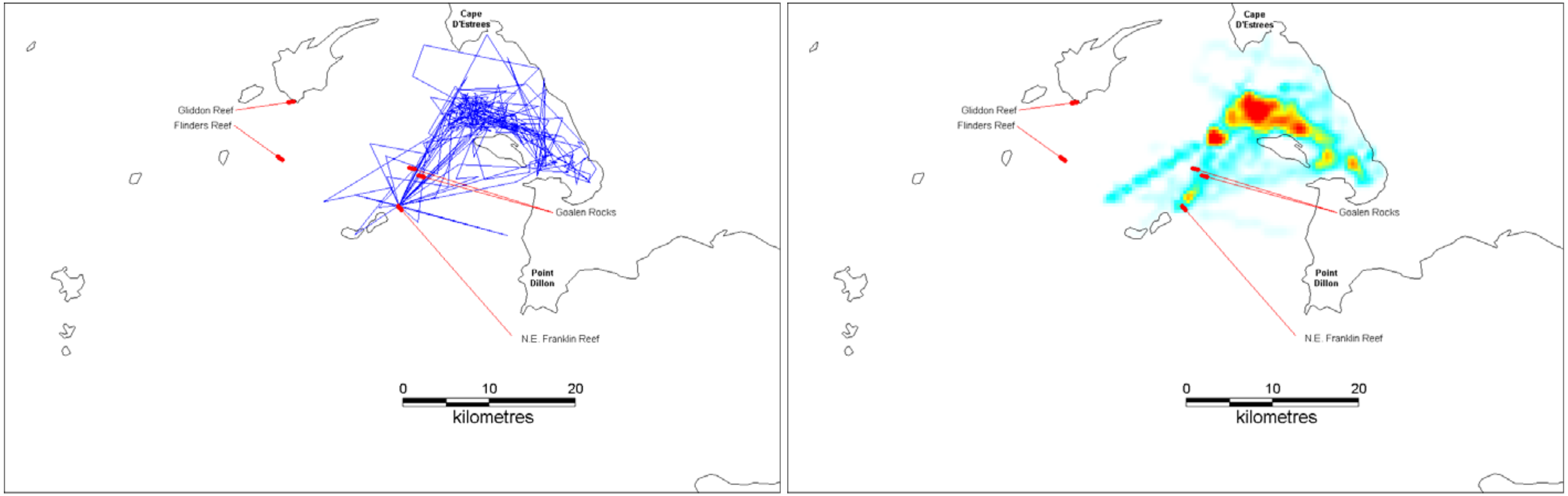
Adult female 241 from NE Franklin Is. Tracks of 5 foraging trips (left) and time spent in 1 x 1 km areas (right).

Adult female 341 from NE Franklin Is. Tracks of 33 foraging trips (left) and time spent in 1 x 1 km areas (right).

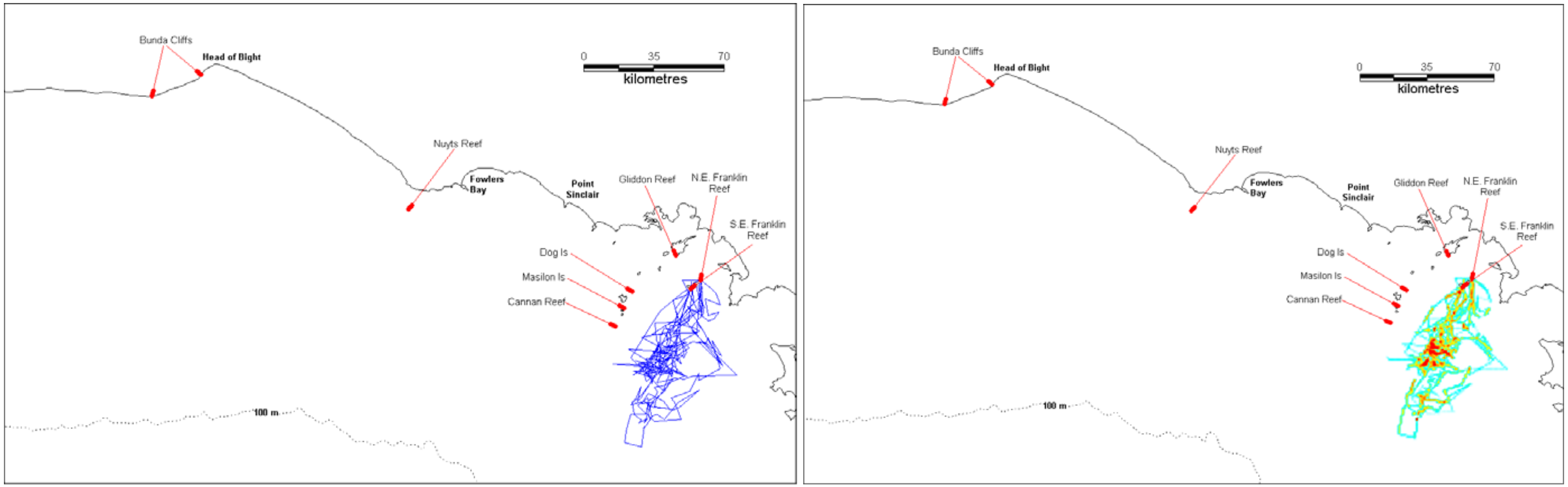


Adult female 441 from NE Franklin Is. Tracks of 16 foraging trips (left) and time spent in 1 x 1 km areas (right).

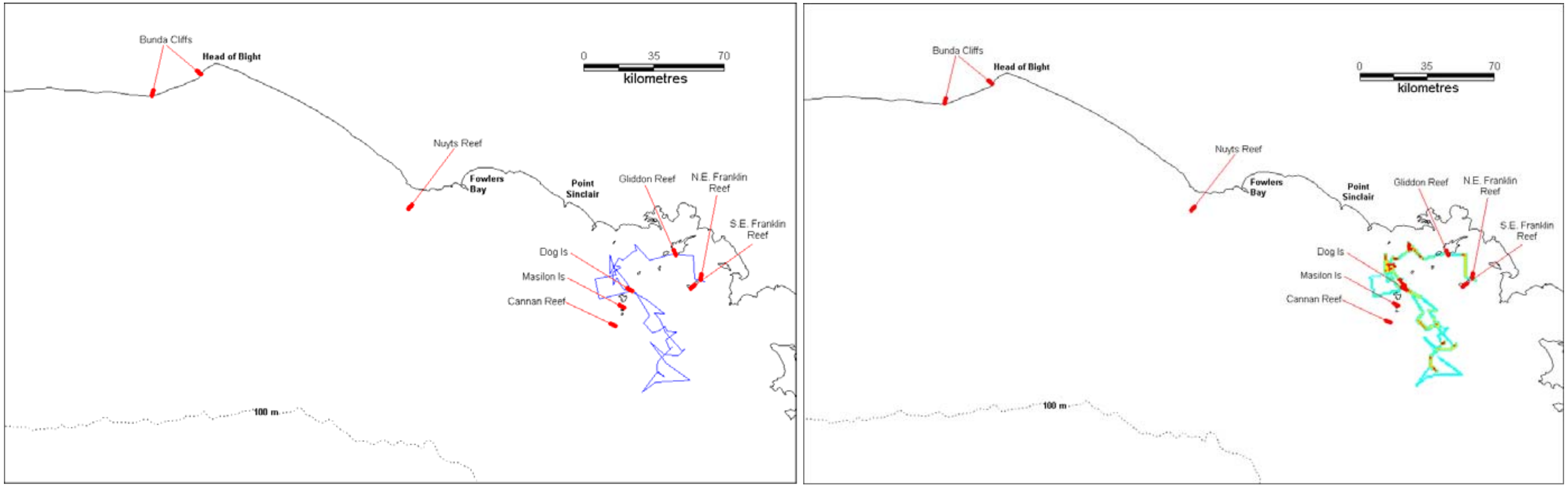
Adult female 641 from NE Franklin Is. Tracks of 3 foraging trips (left) and time spent in 1 x 1 km areas (right).



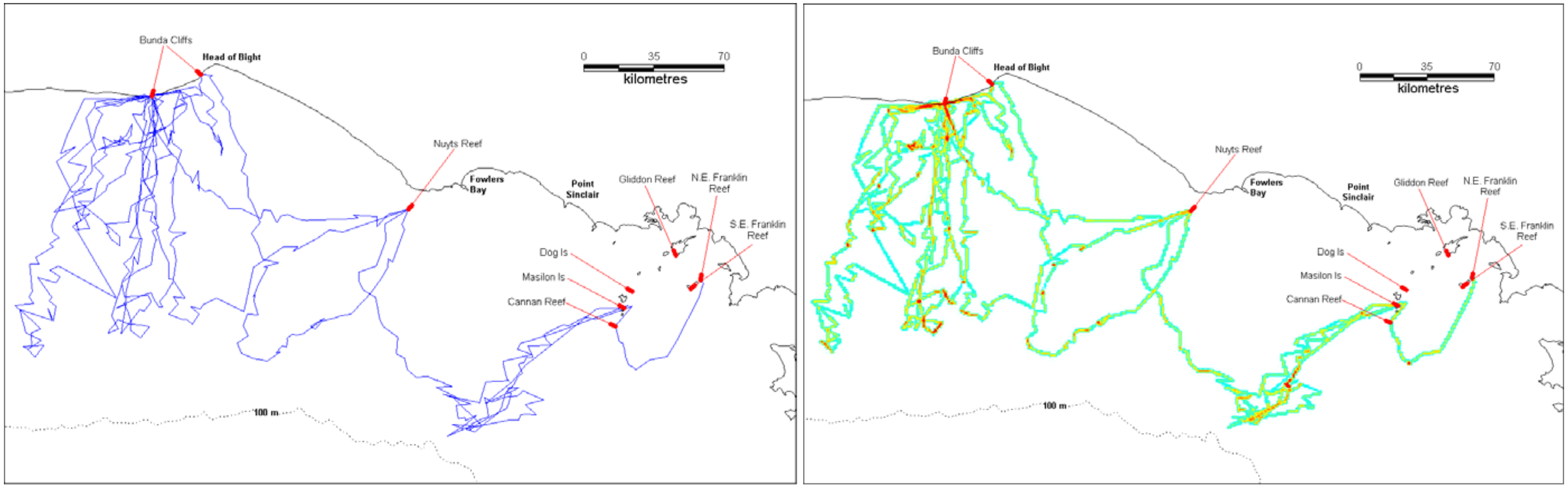
Adult female 941 from NE Franklin Is. Tracks of 14 foraging trips (left) and time spent in 1 x 1 km areas (right).



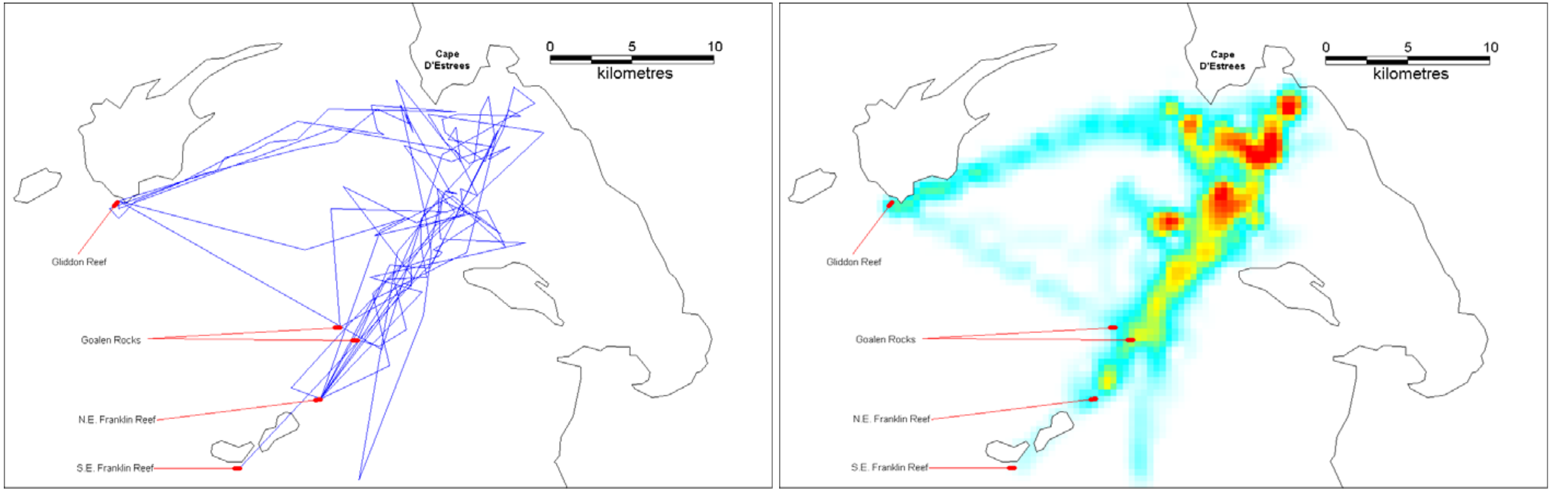
Adult male 142 from NE Franklin Is. Tracks of 8 foraging trips (left) and time spent in 1 x 1 km areas (right).



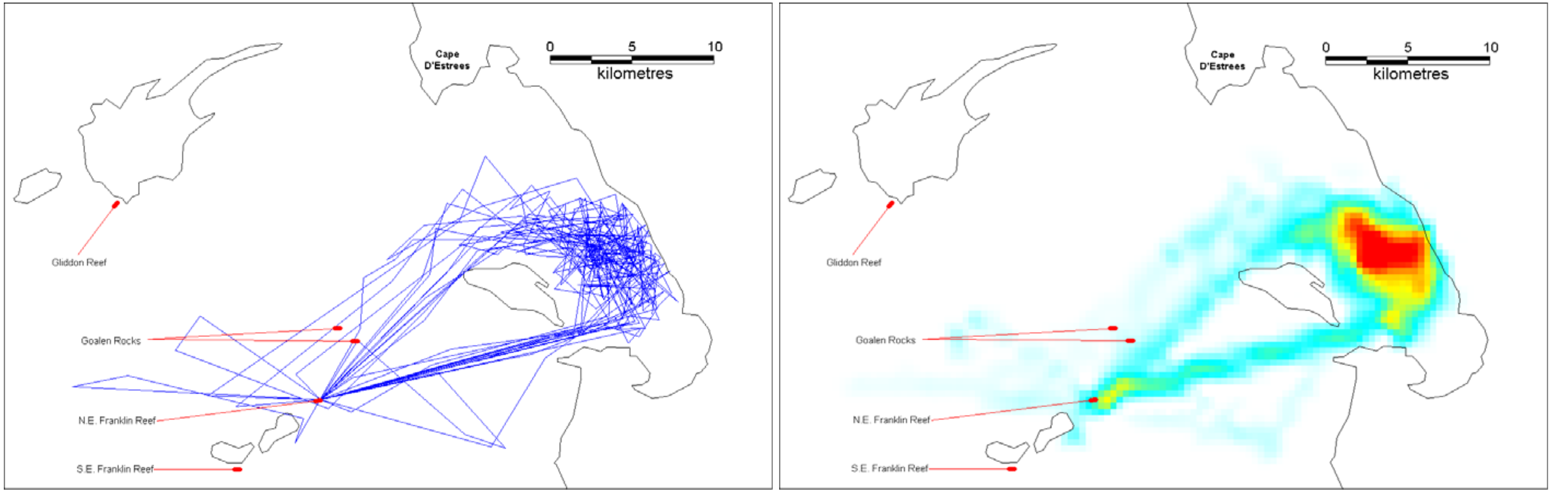
Adult male 742 from NE Franklin Is. Tracks of 4 foraging trips (left) and time spent in 1 x 1 km areas (right).



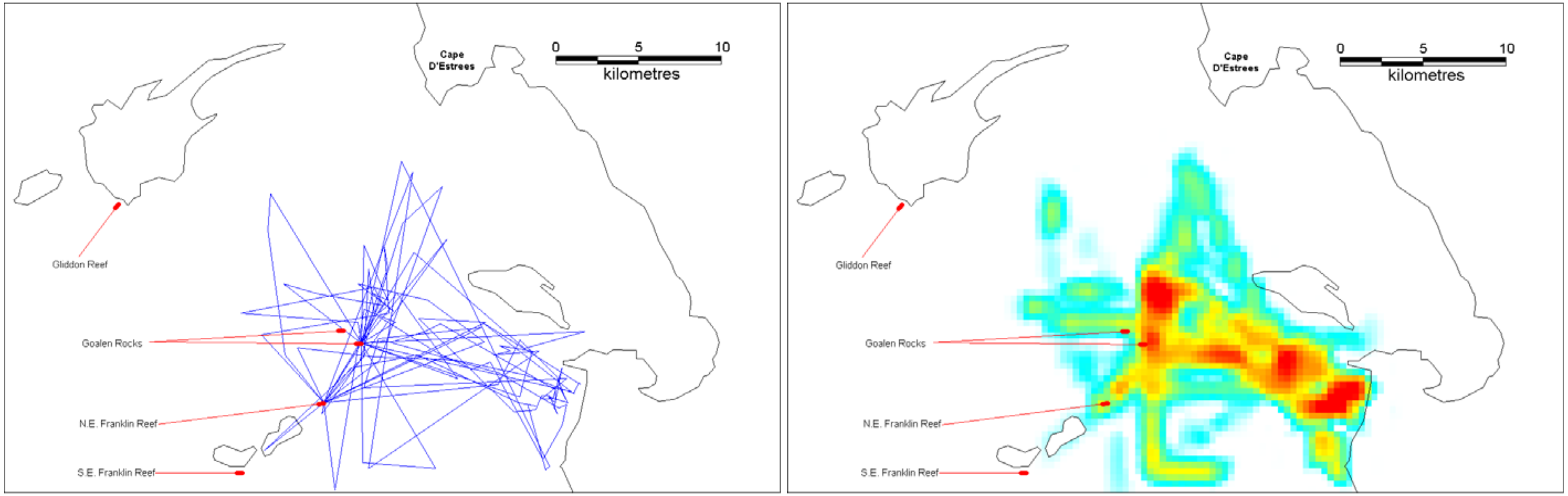
Adult male 842 from NE Franklin Is. Tracks of 15 foraging trips (left) and time spent in 1 x 1 km areas (right).



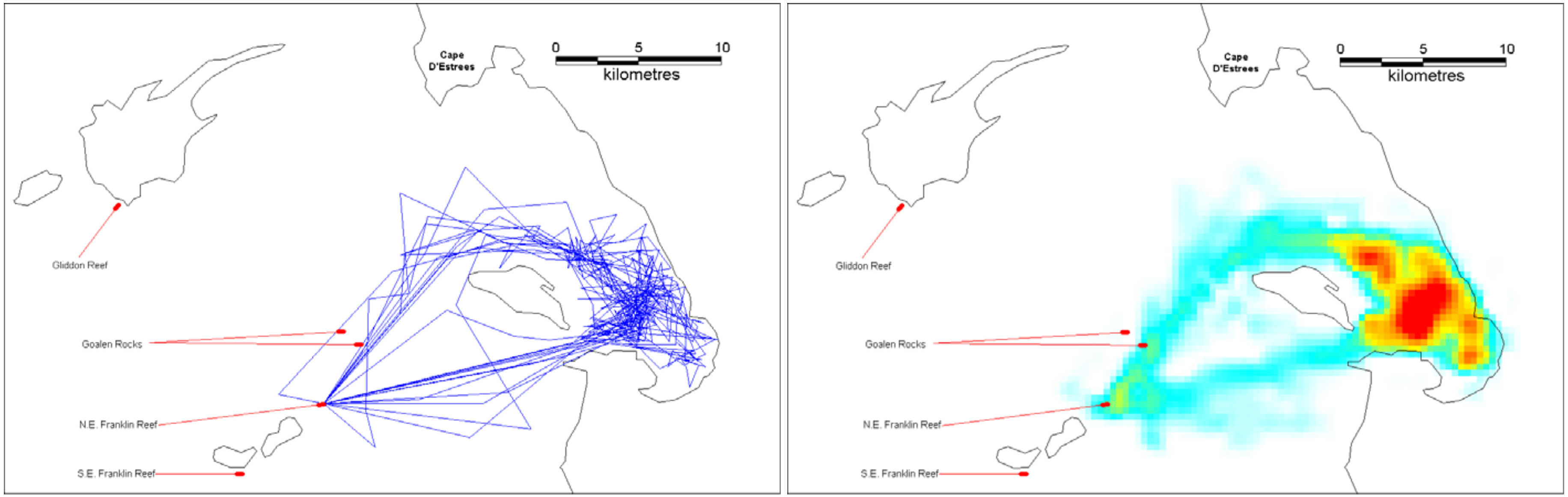
Juvenile female 543 from NE Franklin Is. Tracks of 10 foraging trips (left) and time spent in 1 x 1 km areas (right).



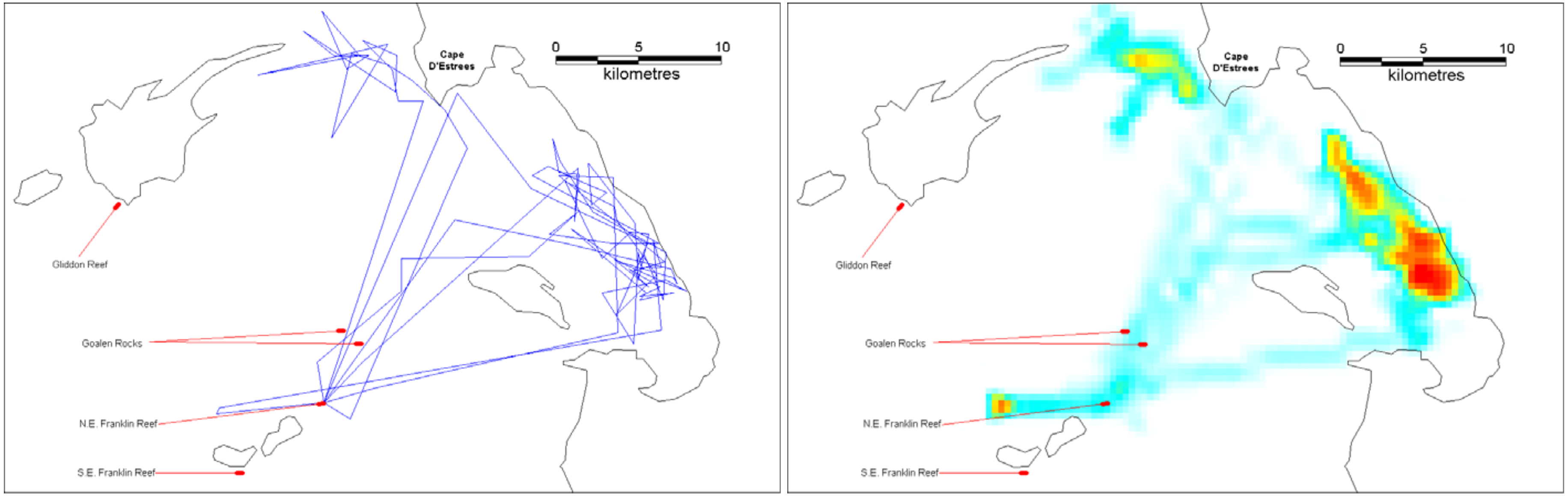
Juvenile female 1043 from NE Franklin Is. Tracks of 15 foraging trips (left) and time spent in 1 x 1 km areas (right).



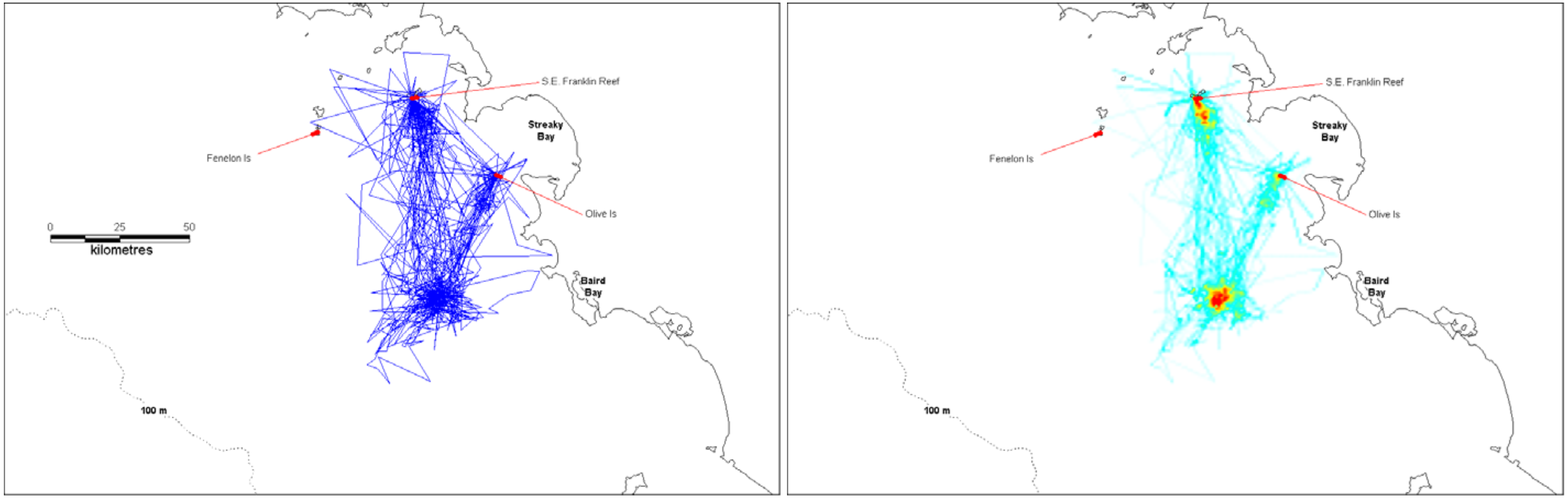
Juvenile female 1243 from NE Franklin Is. Tracks of 17 foraging trips (left) and time spent in 1 x 1 km areas (right).



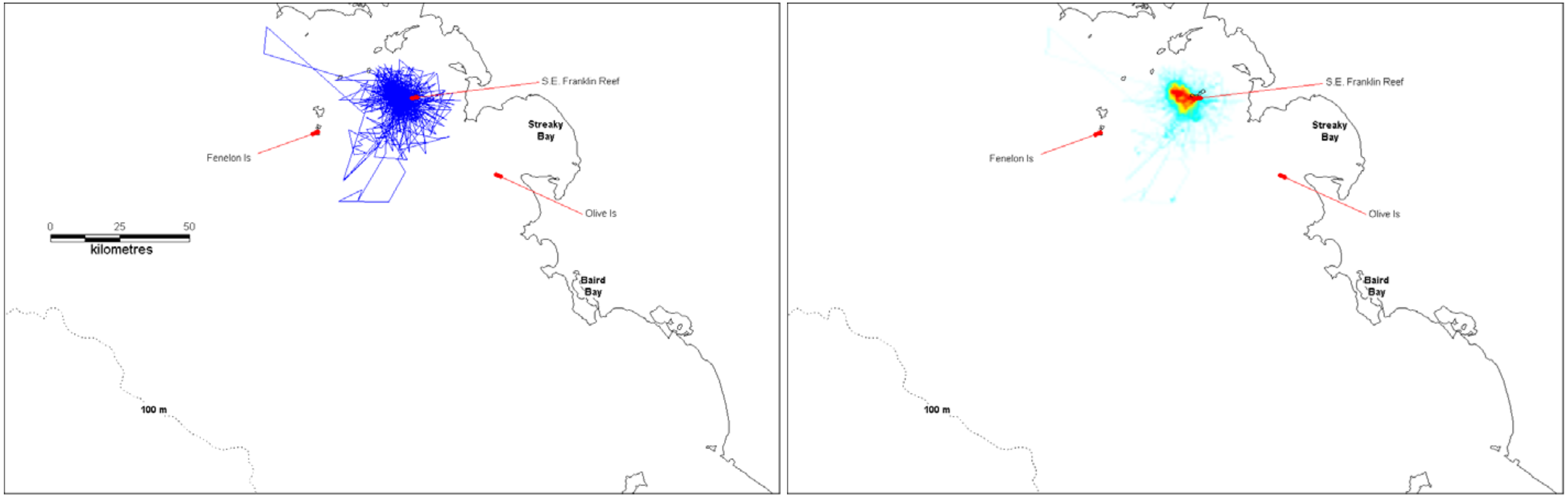
Juvenile female 1343 from NE Franklin Is. Tracks of 12 foraging trips (left) and time spent in 1 x 1 km areas (right).



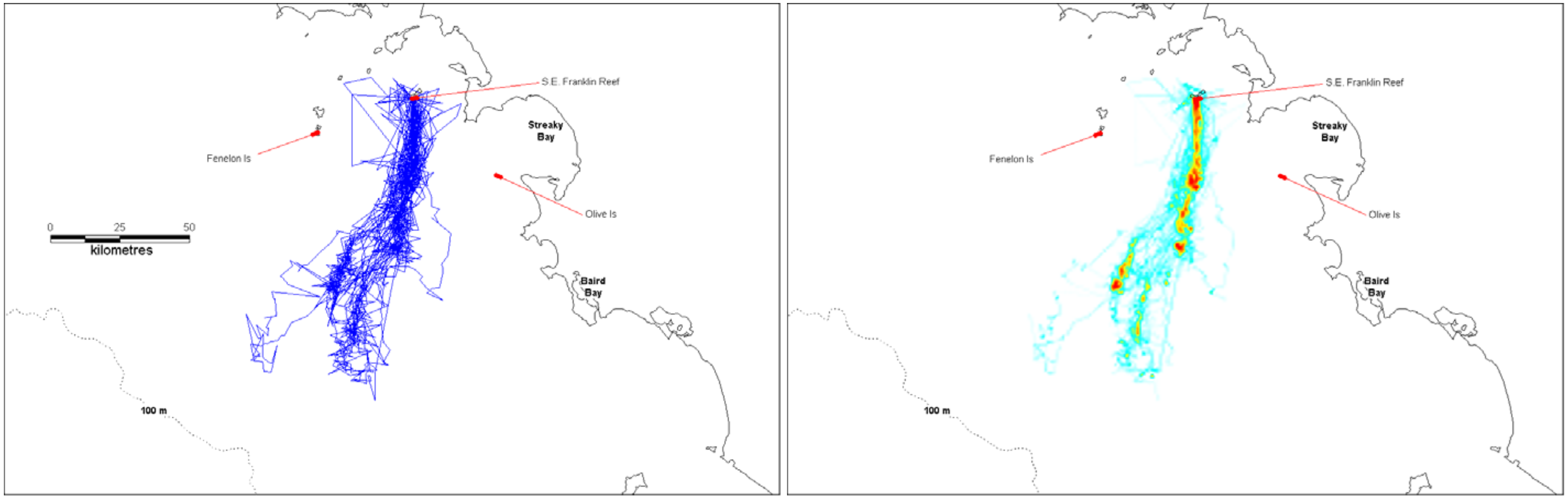
Juvenile male 1144 from NE Franklin Is. Tracks of 4 foraging trips (left) and time spent in 1 x 1 km areas (right).



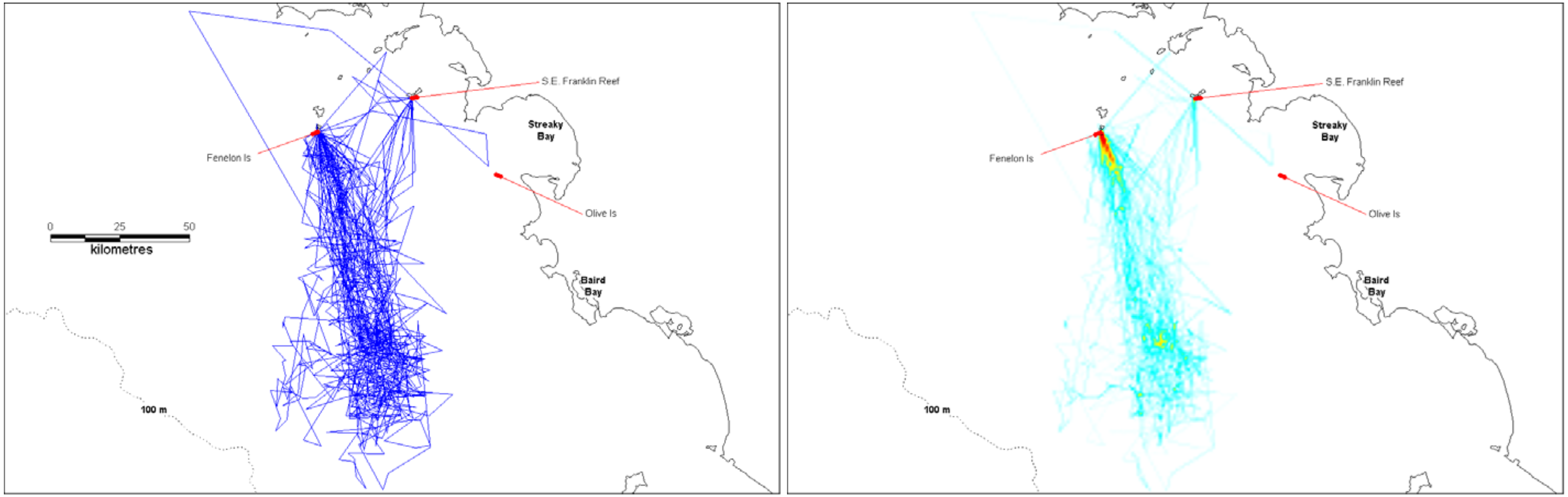
Adult female 251 from SE Franklin Is. Tracks of 67 foraging trips (left) and time spent in 1 x 1 km areas (right).



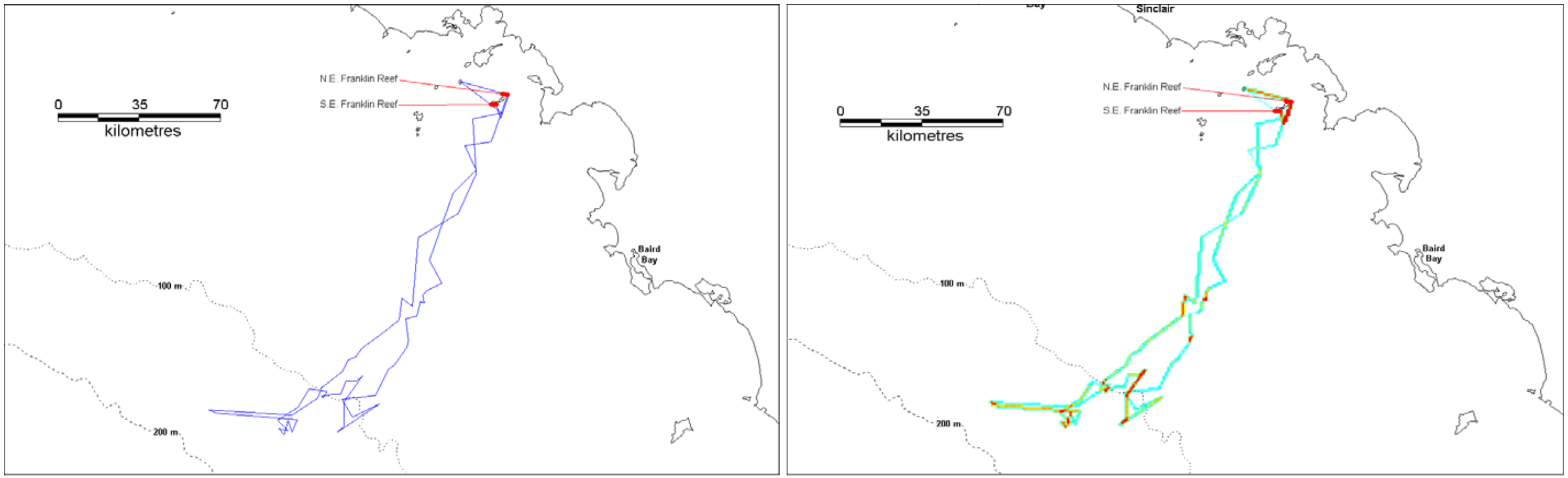
Adult female 351 from SE Franklin Is. Tracks of 38 foraging trips (left) and time spent in 1 x 1 km areas (right).



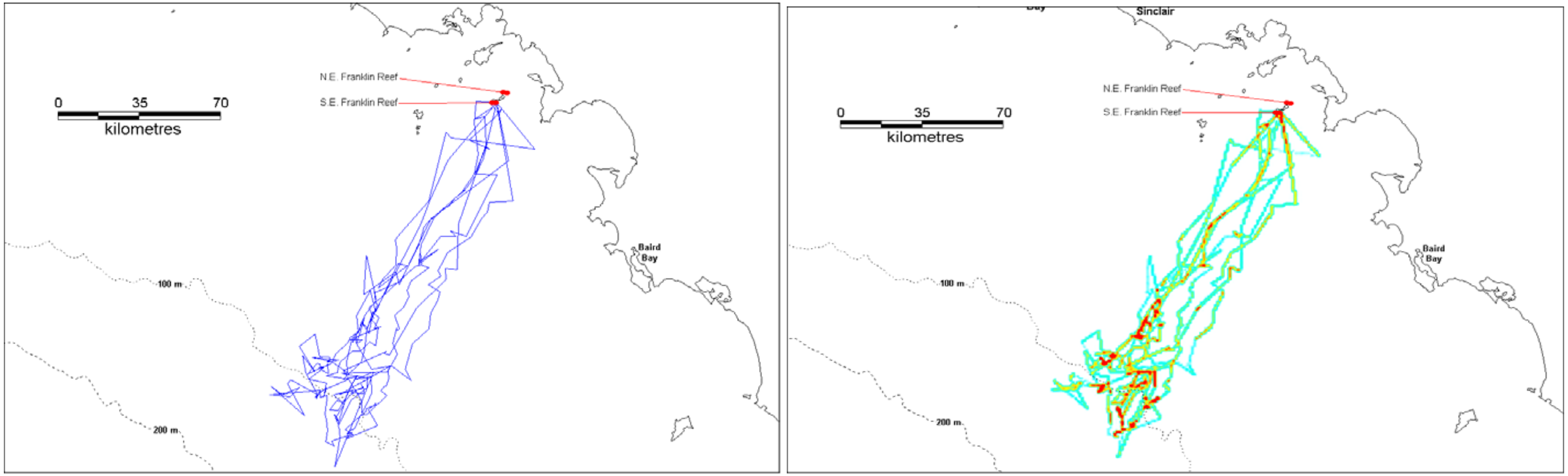
Adult female 451 from SE Franklin Is. Tracks of 37 foraging trips (left) and time spent in 1 x 1 km areas (right).



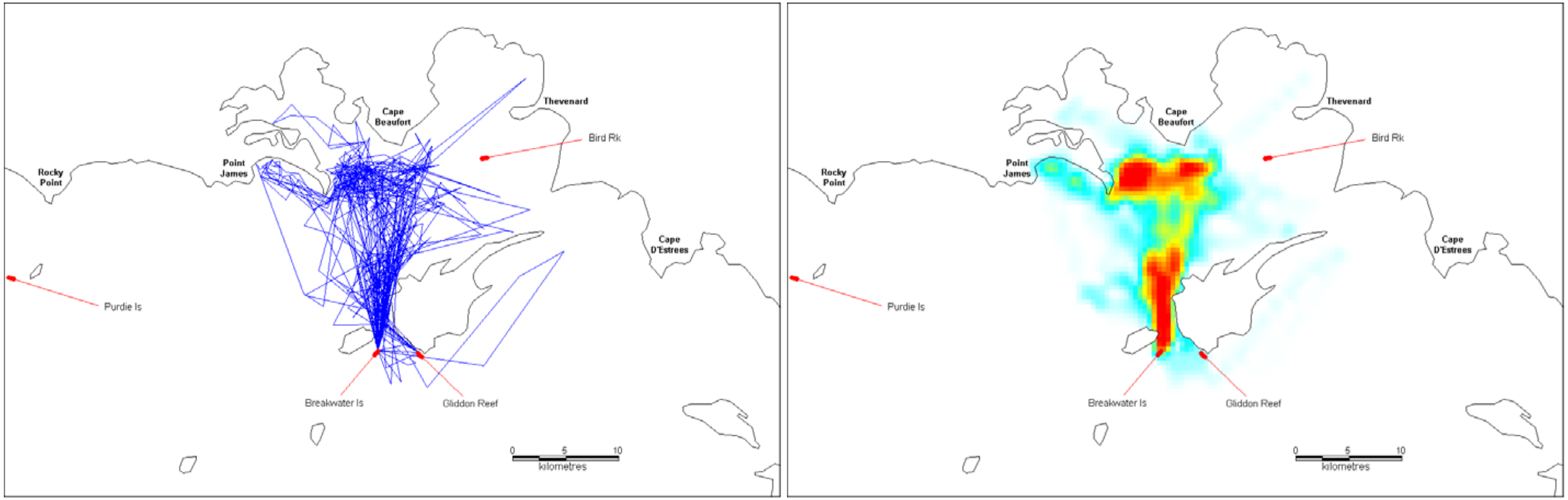
Adult female 651 from SE Franklin Is. Tracks of 132 foraging trips (left) and time spent in 1 x 1 km areas (right).



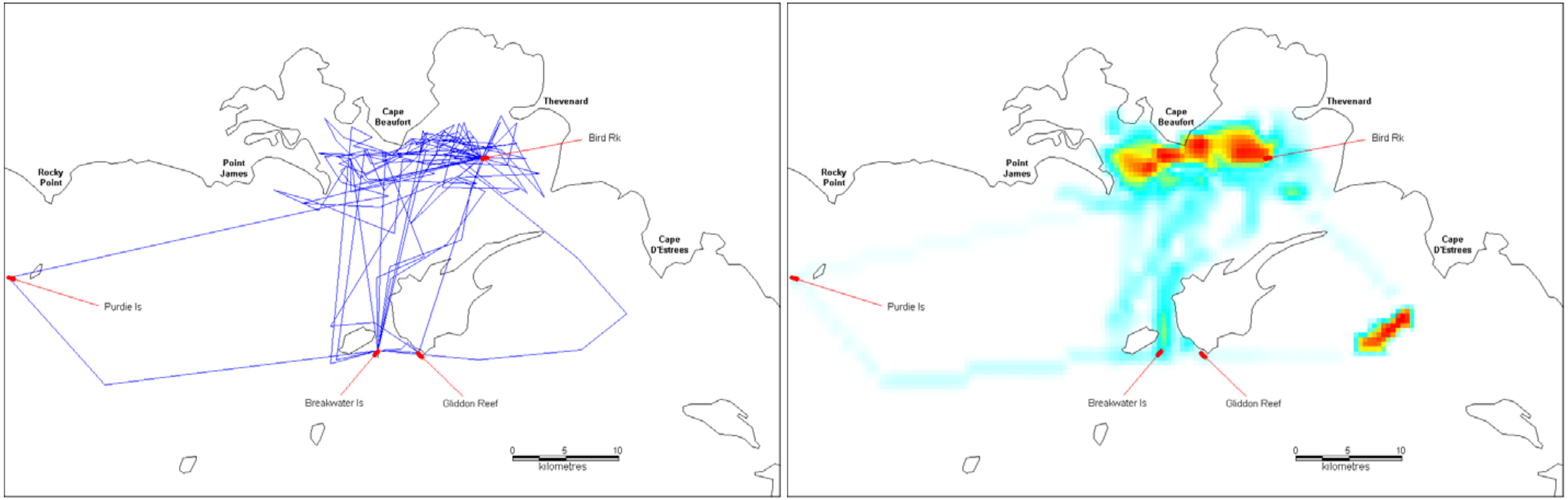
Adult male 152 from SE Franklin Is. Tracks of 2 foraging trips (left) and time spent in 1 x 1 km areas (right).



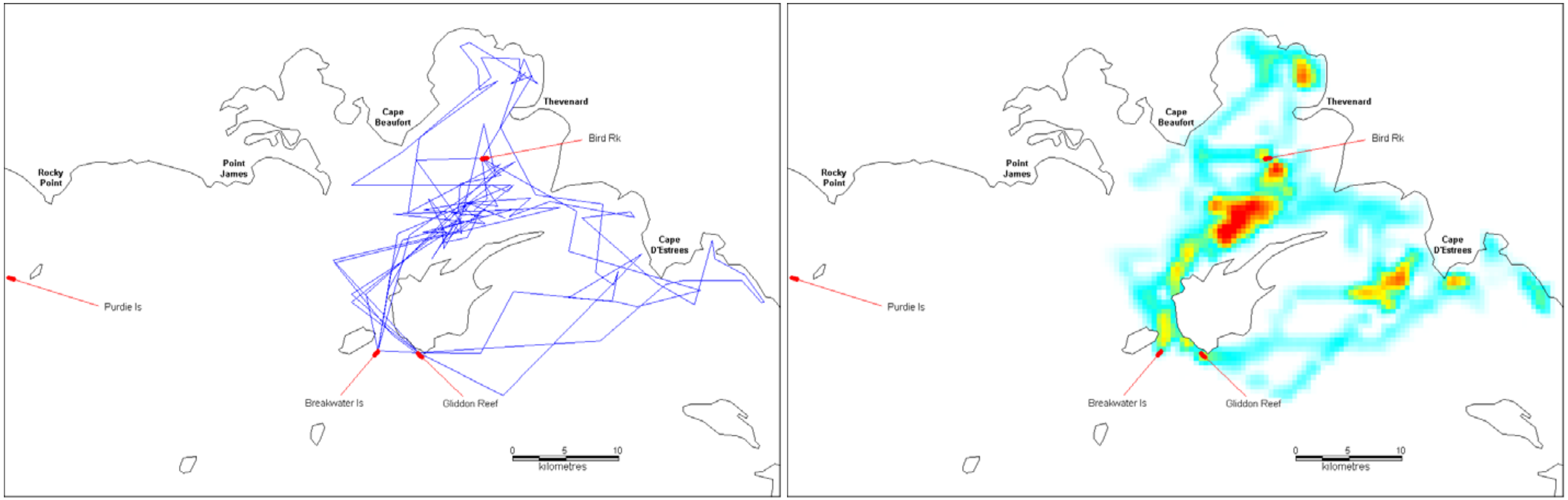
Adult male 252 from SE Franklin Is. Tracks of 4 foraging trips (left) and time spent in 1 x 1 km areas (right).



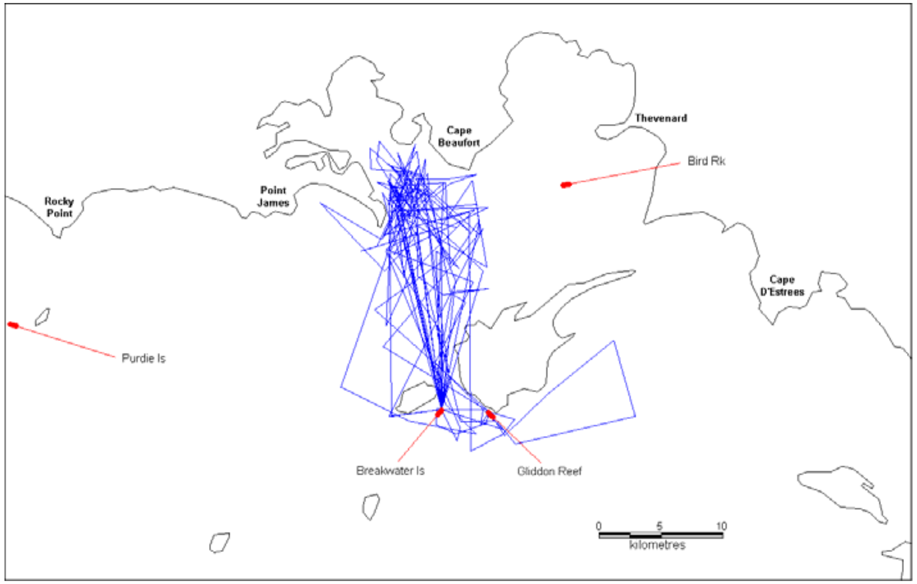
Adult female 181 from Breakwater Is. Tracks of 35 foraging trips (left) and time spent in 1 x 1 km areas (right).

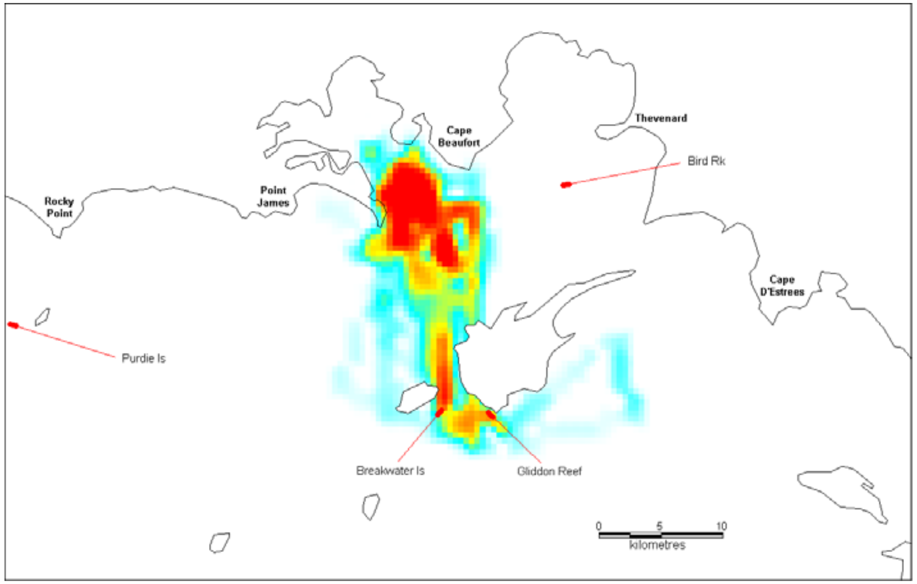


Adult female 281 from Breakwater Is. Tracks of 22 foraging trips (left) and time spent in 1 x 1 km areas (right).

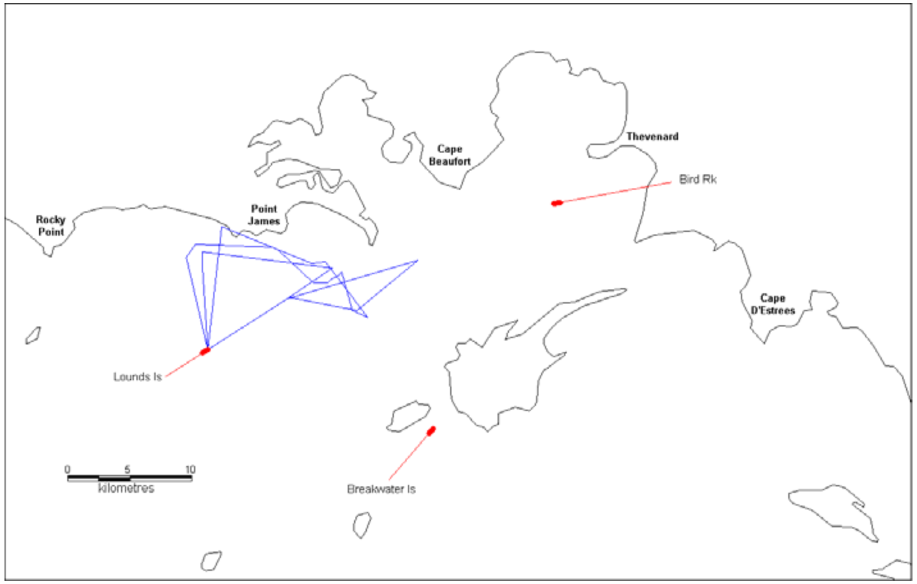


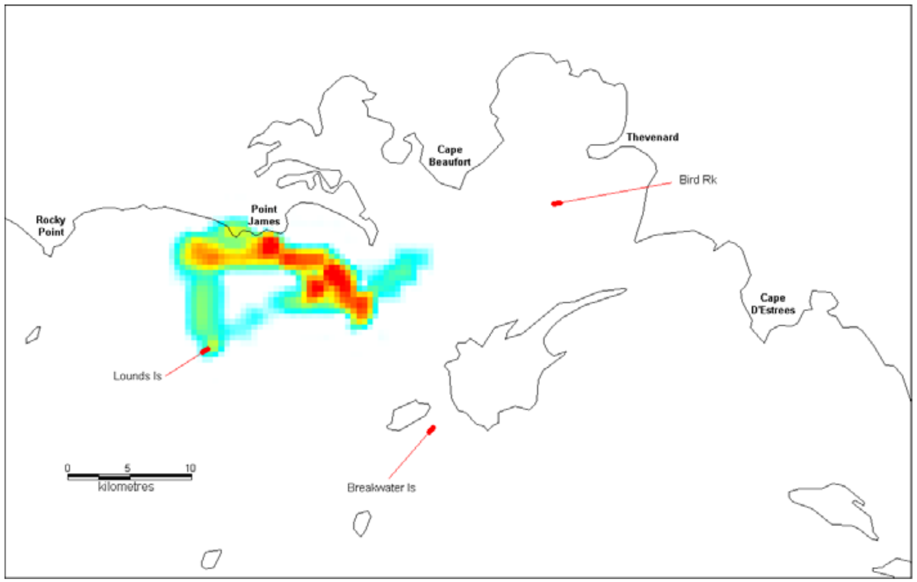
Adult female 381 from Breakwater Is. Tracks of 9 foraging trips (left) and time spent in 1 x 1 km areas (right).



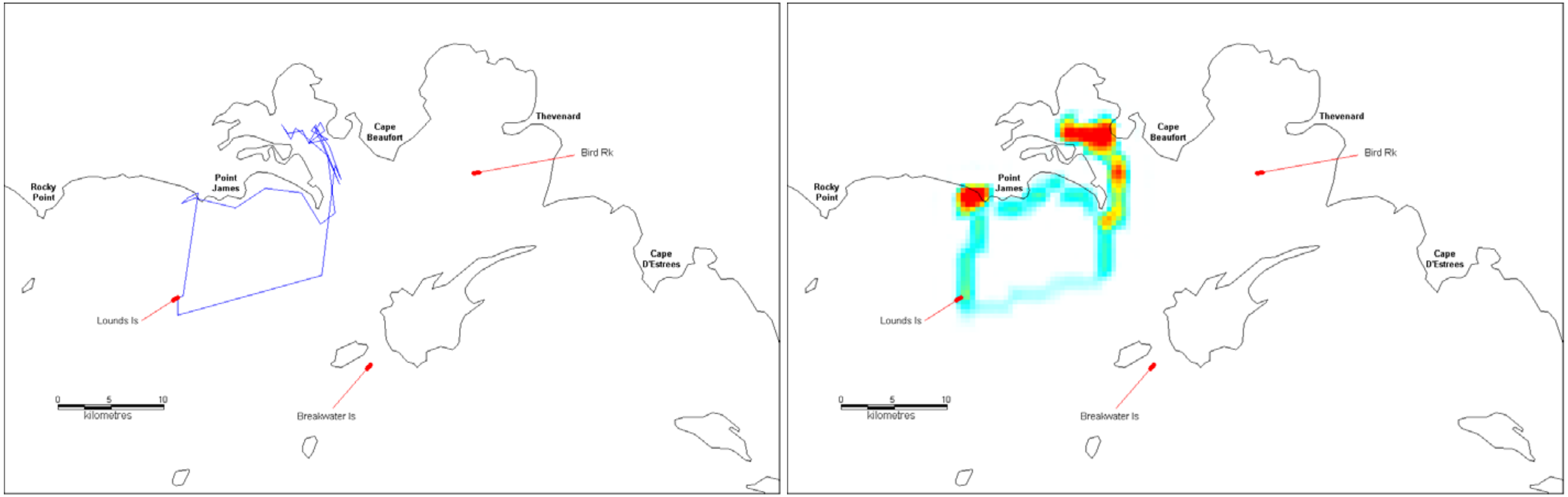


Adult female 481 from Breakwater Is. Tracks of 17 foraging trips (left) and time spent in 1 x 1 km areas (right).

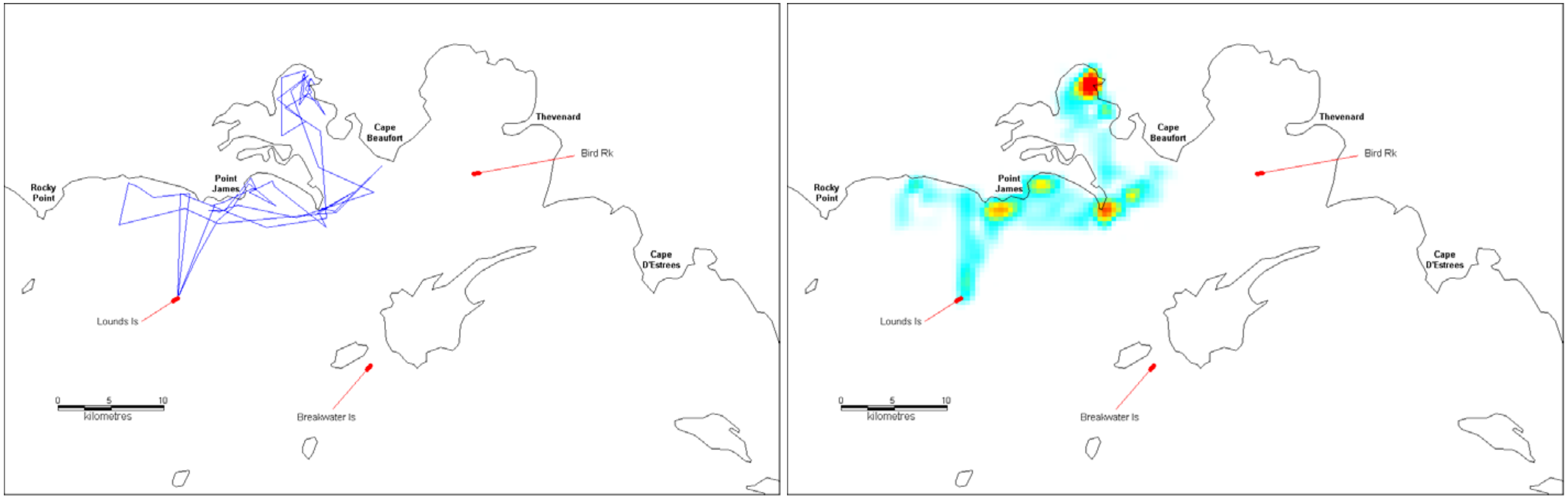




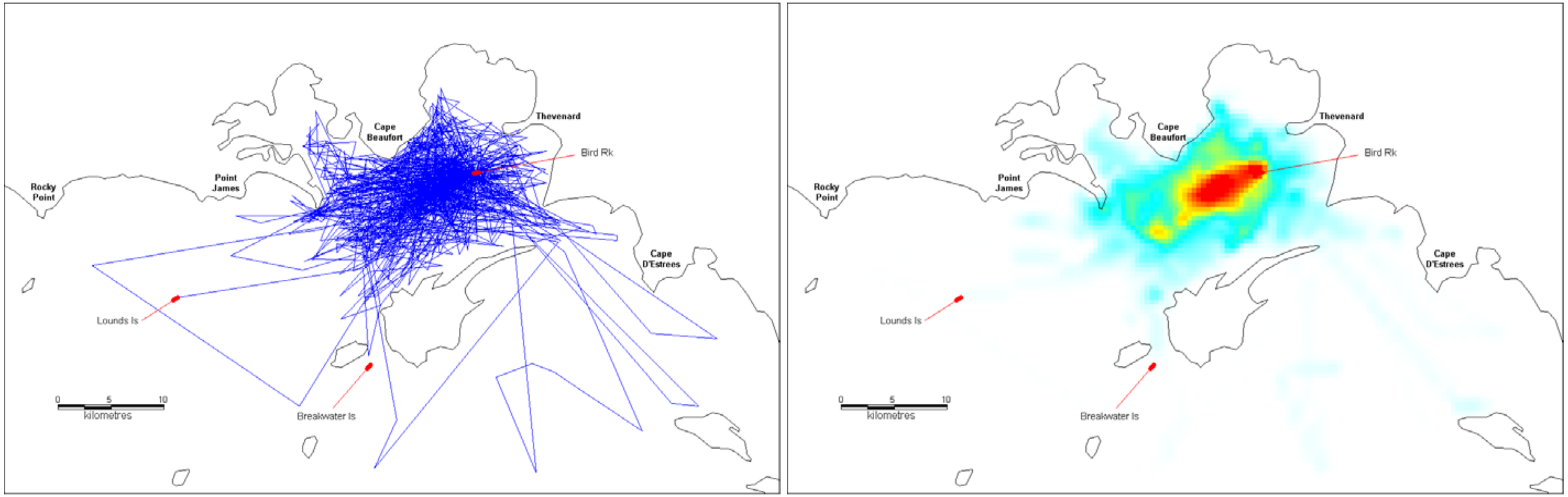
Adult female 161 from Lounds Is. Tracks of 2 foraging trips (left) and time spent in 1 x 1 km areas (right).



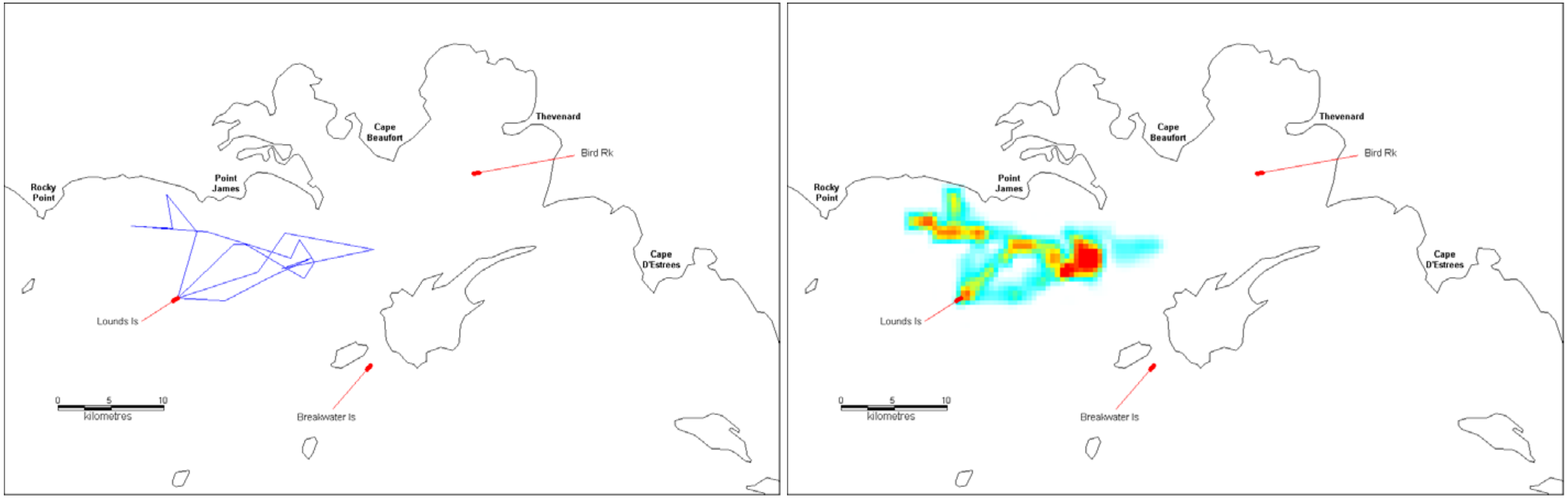
Adult female 261 from Lounds Is. Track of 1 foraging trip (left) and time spent in 1 x 1 km areas (right).



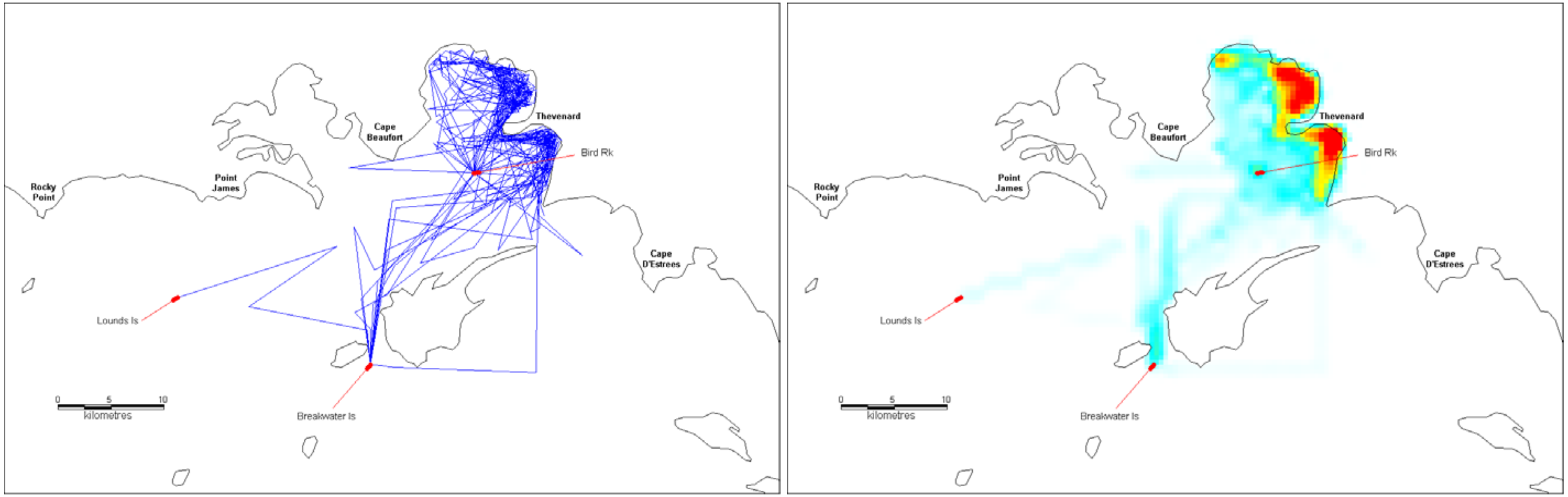
Adult female 361 from Lounds Is. Tracks of 2 foraging trips (left) and time spent in 1 x 1 km areas (right).



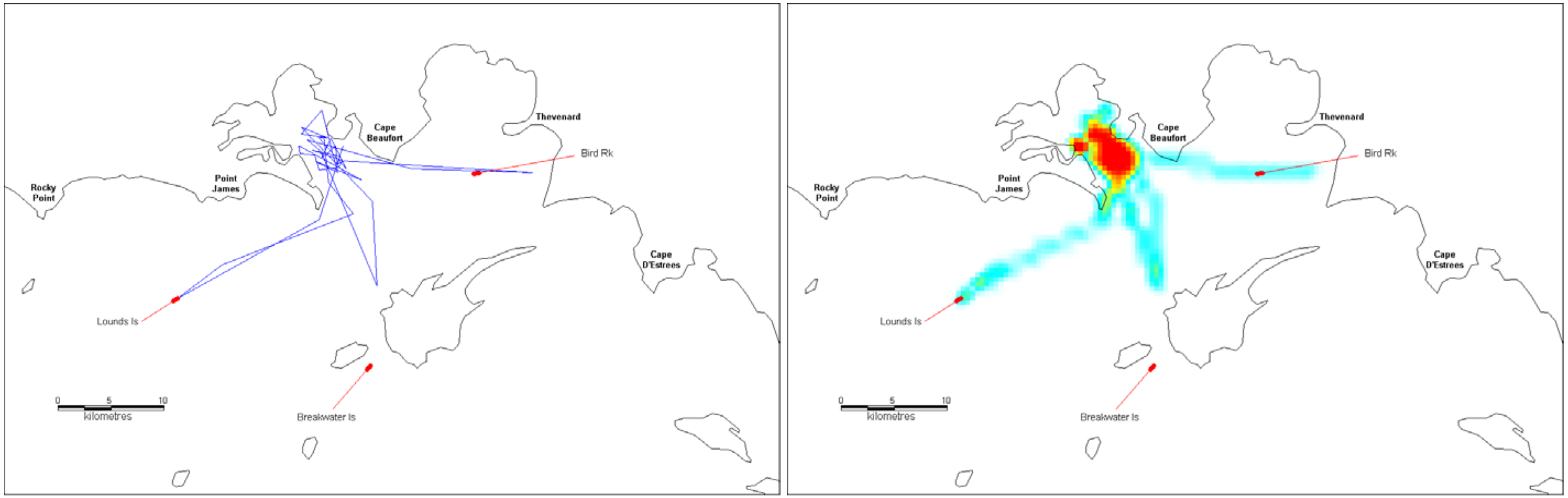
Adult female 461 from Lounds Is. Tracks of 114 foraging trips (left) and time spent in 1 x 1 km areas (right).



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