Assessment of mammal populations on Bernier and Dorre Island 2006-2013

Tamra F. Chapman, Colleen Sims, Neil D. Thomas and Linda Reinhold

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Contributions and acknowledgments

Jeff Short supplied raw data from Short *et al.* (1989) and Linda Reinhold conducted distance analyses using Distance 6.0 software. Tamra Chapman repeated the analyses using Distance 6.2 software and the results were the same as those obtained by Linda Reinhold. Colleen Sims, Linda Reinhold and Neil Thomas conducted spotlighting and trapping, Tamra Chapman analysed the data and prepared the report and Matt Williams reviewed the statistics. Cover photograph by Colleen Sims.

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CONTENTS

Summary

The threatened mammal populations on Bernier and Dorre Islands have been a source of animals for translocation to captive breeding facilities and as part of reintroduction programs since the early 1970s. Populations of banded hare-wallaby (*Lagostrophus fasciatus*), burrowing bettong (*Bettongia lesueur*), rufous hare-wallaby (*Lagorchestes hirsutus*) and western barred bandicoot (*Perameles bougainville*) were monitored via spotlighting transects between 2006 and 2013. Relative abundance and biology of ash grey mouse (*Pseudomys albocinereus squalorum*), burrowing bettong, Shark Bay mouse (*Pseudomys fieldi*) and western barred bandicoot were monitored via cage and Elliott trapping between 2006 and 2009. The purpose of this report is to analyse and present the demographic and biological information that can be used as part of population management and recovery programs.

Total annual rainfall two years prior to the survey period was a strong driver of estimated population sizes on Bernier and Dorre Islands. Wallaby, bettong and bandicoot populations were highest two years after more than 300 mm total annual rainfall and lowest two years after less than 200 mm total annual rainfall. Variation in monthly rainfall also appeared to affect mammal populations, because below average monthly rainfall between July 2005 and May 2007 led to very low population estimates and relative abundance in 2007 and 2008. Mammal translocation programs aim to capture fauna at peak population size to maximise genetic diversity and minimise impact on local populations. Thus, the ideal time to take animals for translocation would be two years after above average annual rainfall (in excess of 300 mm) at Carnarvon Airport, but after 6-12 months of below average monthly rainfall, when populations would be expected to be on the cusp of a decline.

In comparison with similar surveys undertaken in 1988/89 and 1991, the population estimates in this study were low for banded hare-wallaby, rufous hare-wallaby and western barred bandicoot and high for burrowing bettong. Thus, it appears that the banded hare-wallaby, rufous hare-wallaby and western barred bandicoot populations on these islands may have declined over the last 25 years. Rainfall is predicted to be declining in this region and this may explain the apparent population declines, but a declining trend in total annual rainfall at Carnarvon Airport could not be confirmed in this study. Contrary to the other species, the estimated population sizes for burrowing bettong appeared to increase during the past 25 years, and during this study. It is hypothesised that the bettongs may be more resilient and

adaptable than the other species and may have been advantaged by reduced competition due to the decline in the populations of the other species.

Populations of burrowing bettong, rufous hare-wallaby and western barred bandicoot were larger on Dorre than Bernier Island and thus, based on population size, they should be sourced from Dorre Island. The bandicoots on Bernier Island exhibit papillomatosis and carcinomatosis syndrome and thus, are not suitable for translocation. Shark Bay mouse is only present on Bernier Island and ash grey mouse was only trapped on Dorre Island in 2006 and not thereafter. Thus, Bernier Island would be the preferred source for ash grey and Shark Bay mouse if they are needed for translocation programs. Capture rates for translocation are most likely to be maximised in dune habitats for ash grey mouse, sandplain heath for Shark Bay mouse and Travertine heath for western barred bandicoot. The burrowing bettong was captured in similar relative abundance across all habitats.

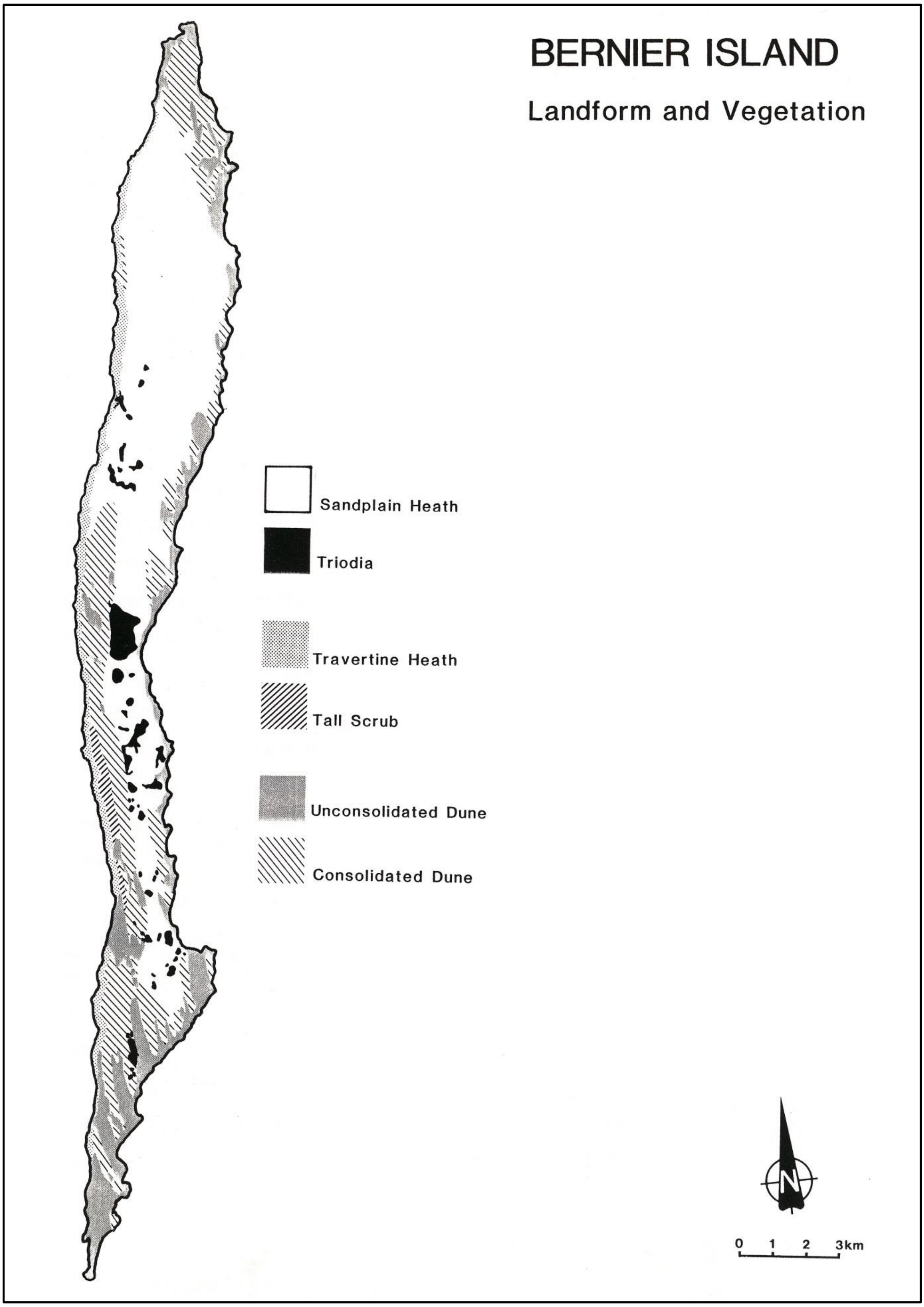
A number of recommendations are made for the future of the mammal monitoring program on Bernier and Dorre Islands, based on the data presented in this report.

1 Introduction

Bernier and Dorre Islands are located in the Shark Bay World Heritage Property, about 50 km west of Carnarvon on the Western Australian mainland (DEC 2012a). Five threatened mammals are extant on these islands: Shark Bay mouse (*Pseudomys fieldi*), banded hare-wallaby (*Lagostrophus fasciatus*), rufous hare-wallaby (*Lagorchestes hirsutus*), Western barred bandicoot (*Perameles bougainville*), and burrowing bettong (*Bettongia lesueur*). The ash grey mouse is not a threatened species, but is of conservation significance because it is recognised as a Bernier Island subspecies (*Pseudomys albocinereus squalorum*) (Jackson and Groves 2015).

Bernier Island is 42 km^2 in area and Dorre Island is 55 km^2 in area and both are Pleistocene coastal limestone underlain by quartz sandstone (Ride *et al.* 1962). The islands have low topography surrounded by cliffs on the west coast, and cliff headlands interspersed with sandy bays on the east coast. The primary landform and vegetation habitats are shown in Figure 1 and described in detail by Short *et al.* (1989).

These islands have been a source of threatened mammals for translocations to captive breeding facilities and reintroduction programs since the early 1970s (Morris *et al.* 2000; DEC 2012b). Their populations were monitored via spotlighting transects and trapping (capture-recapture study) between 2006 and 2013. The purpose of this report is to analyse and present the demographic and biological information to inform translocation as part of recovery programs.


BERNIER ISLAND
Landform and Vegetation
Sandplain Heath
Triodia
Travertine Heath
Tall Scrub
Unconsolidated Dune
Consolidated Dune
N
0 1 2 3km

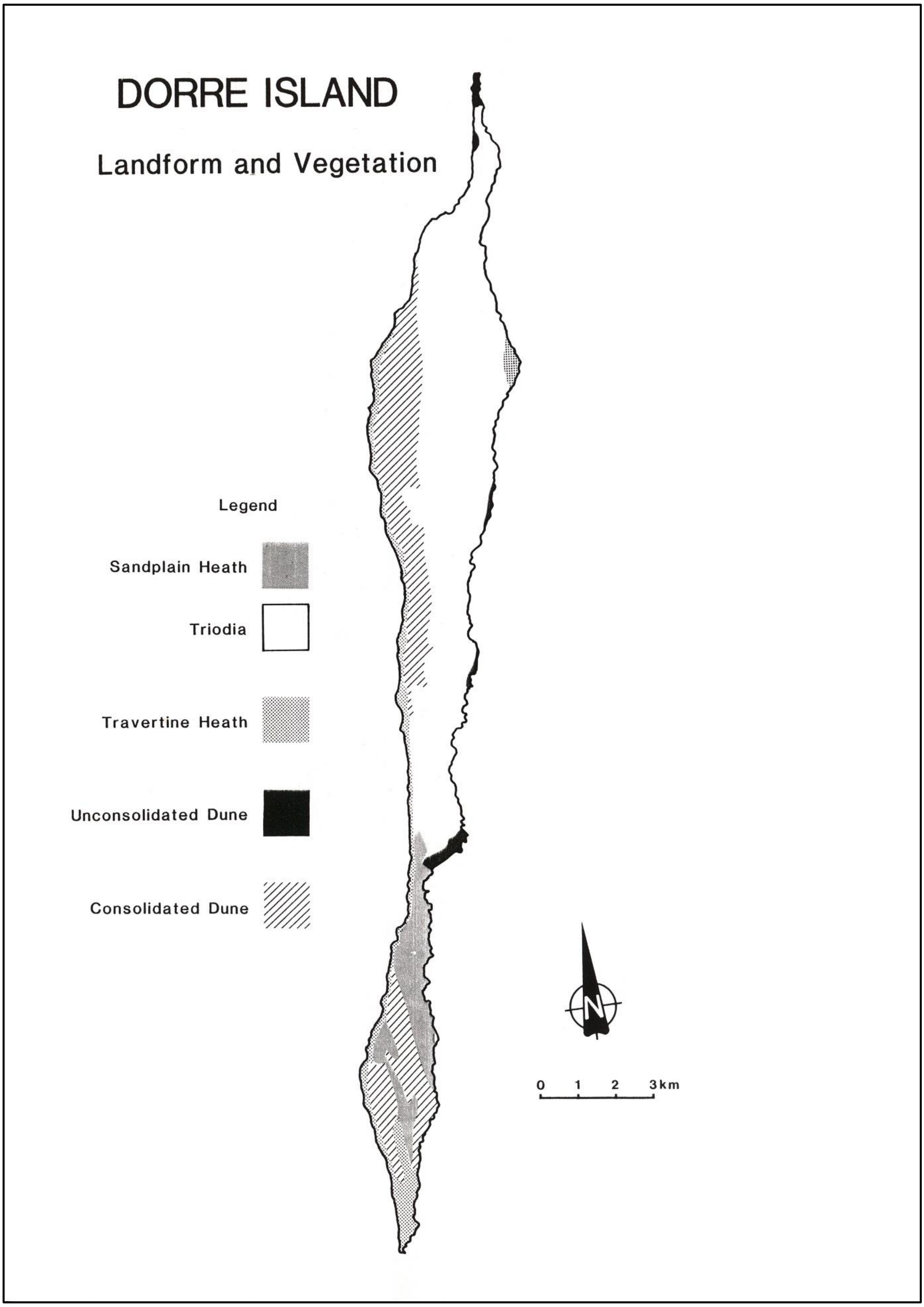


Figure 1 Landform and vegetation of Bernier and Dorre Islands from Short *et.al* (1989).

2 Methods

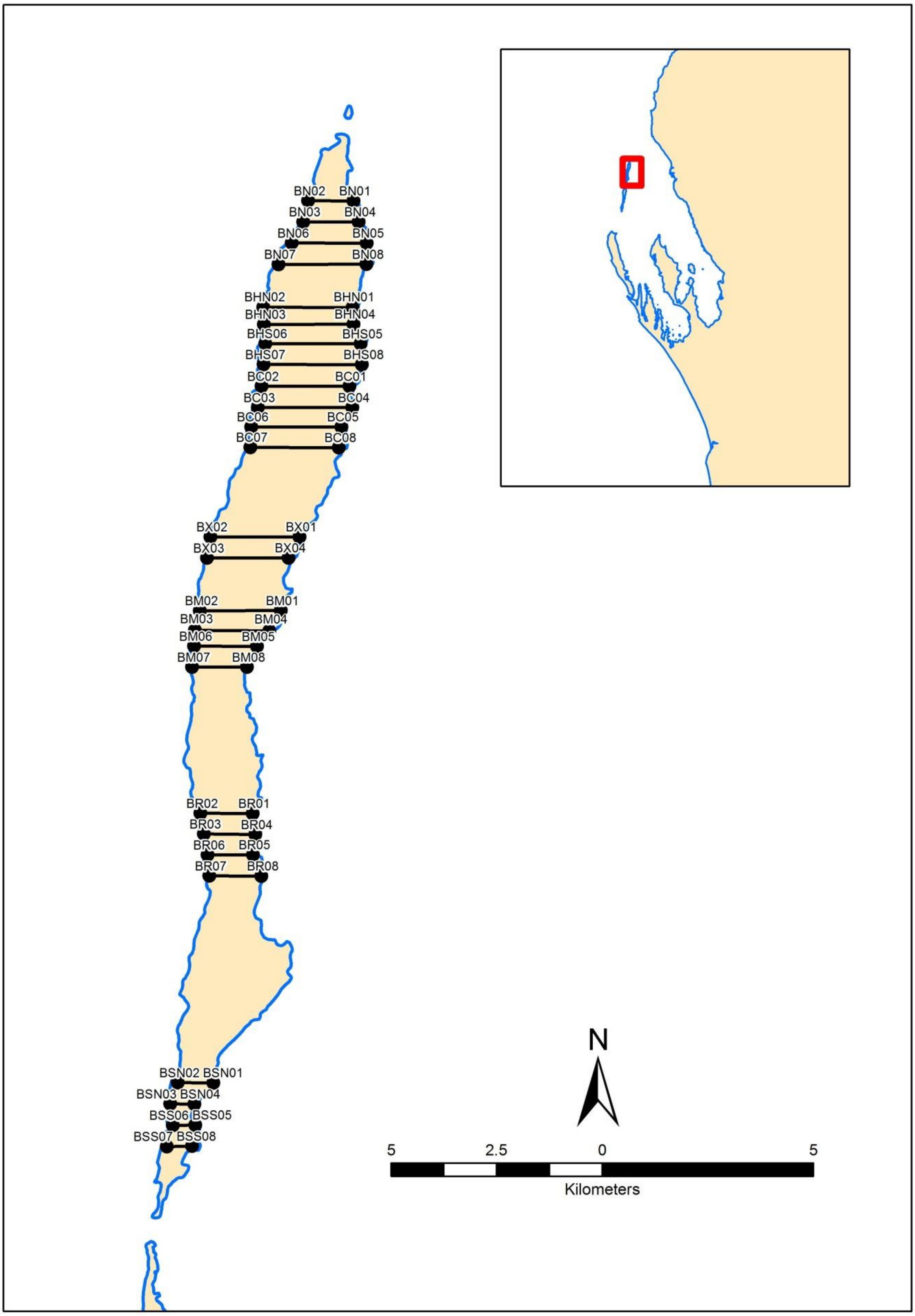
2.1 Spotlighting

The islands were divided into blocks of two or four transect lines, based on Short *et.al* (1989) and / or placed in proximity to safe landing points. Transects were marked with a 1.8 m jarrah stake driven into the ground and marked at the top with reflective tape, with the start or finish of the transect set above high water mark or at a cliff-top. Five blocks of four transects, 500m apart (total of 20 transects) were marked for spotlighting on each island from 2006 to 2010. Transect locations and survey frequencies were then modified to meet distance analysis requirements from 2011 to 2013. The codes for the transects and their lengths are shown in Table 1 and their locations are shown in Figure 2.

The specific transects surveyed and the times of year when they could be surveyed varied subject to weather conditions. Spotlighting surveys were conducted within a week either side of the new moon. Transects were walked by two team members, one spotter and one navigator, at no more than three kilometres per hour. A 30W spotlight was used to search and the positions of the animals, relative to the transect line were recorded with GPS and / or by pacing. Detailed protocols for spotlighting surveys are provided in Appendix 1.

Table 1 Transect codes and lengths.

Island	Block	Code	Length (km)
Bernier Island	Bernier Cleft Rock	BC	8.9
	Bernier Hospital	BHN	4.4
	Bernier Hospital	BHS	5.1
	Bernier Mid	BM	6.8
	Bernier North	BN	6.2
	Bernier Red Cliff	BR	4.9
	Bernier South	BSN	1.7
	Bernier South	BSS	1.3
	Bernier X	BX	4.0
Dorre Island	Dorre Castle	DC	6.6
	Dorre Mid	DM	4.5
	Dorre Quoin	DQ	13.0
	Dorre South	DS	6.5
	DP	DP	5.1
	DWN	DWN	0.9
	DWS	DWS	1.8
	DX	DX	4.7



BN02 BN01
BN03 BN04
BN06 BN05
BN07 BN08
BHN02 BHN01
BHN03 BHN04
BHS06 BHS05
BHS07 BHS08
BC02 BC01
BC03 BC04
BC06 BC05
BC07 BC08
BX02 BX01
BX03 BX04
BM02 BM01
BM03 BM04
BM06 BM05
BM07 BM08
BR02 BR01
BR03 BR04
BR06 BR05
BR07 BR08
BSN02 BSN01
BSN03 BSN04
BSS06 BSS05
BSS07 BSS08
N
5 2.5 0 5
Kilometers

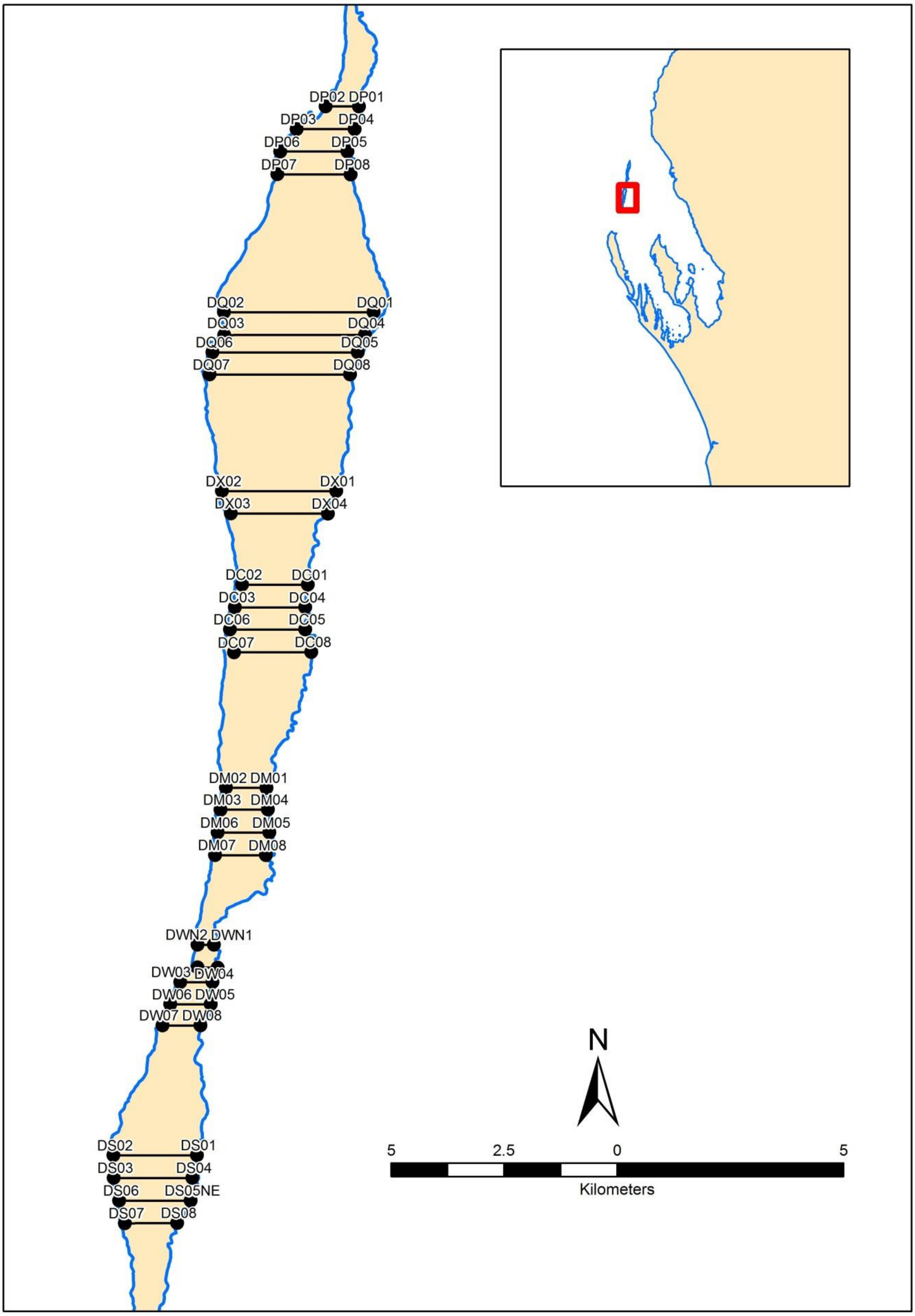


Figure 2 Locations of spotlighting transects on Bernier Island (above) Dorre Island (below).

Table 2 shows the times of year when spotlighting surveys were conducted and the number of times each block was surveyed from 2006 to 2010. Data from the April and September surveys were combined in the analysis for 2007. Table 3 shows the times of year when spotlighting surveys were conducted and the number of times each block was surveyed from 2011 to 2013. The total survey effort each year (kilometers of transect surveyed) is shown in Table 4.

Table 2 Number of times blocks were surveyed 2006-2010 (*BH and BC combined, *n* = 9 transect blocks).

Block	Aug. 2006	Apr. 2007	Sep. 2007	May/Jun./ Jul. 2008	Aug./Sep. 2009	May/Aug. 2010
BH*	1	2	2 (- 2km)	2	2 (- 1km)	1
BC*	1	2	2	1	2	1
BM	1	2	2	2	2 (northern half once)	1
BR	1	2	2	2	2 (southern half once)	1
BS	1	0	2	2	1	1
DQ	1	2	2	2	2	1
DC	1	2	2 (southern half once)	2	2 (- 0.3km)	1
DM	1	2	2	2	2	1
DW	1	2	2	2	2	1
DS	1	0	2	2	2	1

Table 3 Number of times blocks were surveyed 2011-2013 (*n* = 17 transect blocks).

Block	Jun. 2011	Jul./Aug. 2012	Jun./Jul./Aug. 2013
BN	1	0	0
BNN	0	1	1
BHN	1	1	1
BC	1	1	1
BX	1	1	1
BM	1	1	1
BR	1	1	1
BSN	1	1	1
BSS	1	1	1
DP	1	1	1
DQ	1	1	0.5 (south only)
DX	1	1	1
DC	1	1	1
DM	1	1	1
DWN	1	1	1
DWS	1	1	1
DS	1	1	1

Table 4 Total sampling effort per year (km of transect surveyed).

	2006	2007	2008	2009	2010	2011	2012	2013	Total
Bernier Island	32.4	238.4	56.0	54.8	32.5	38.3	36.4	36.4	525.1
Dorre Island	33.9	224.3	67.2	66.9	20.7	43.1	43.1	36.6	535.7
Total	66.2	462.7	123.2	121.7	53.2	81.4	79.5	72.9	

Transect parameters and fauna observations were modeled using Distance 6.2 software (Thomas *et al.* 2010), to account for diminishing probability of detection with increasing distance from the transect line. The design of the analysis was a line transect 40m wide (20m each side of the transect), single observer and single observations of fauna at distances perpendicular to the transect. Conventional distance sampling was used to model the probability of detection as a function of the distance from the transect line via size bias regression and bootstrapped variance (Buckland *et al.* 1993; Buckland *et al.* 2001).

Akaike's Information Criterion was used to select the 'best' fitting models from amongst the following: uniform cosine, uniform simple polynomial, half-normal cosine, hazard rate cosine and hazard rate simple polynomial (see Buckland *et al.* 1993; Buckland *et al.* 2001 for more information). The best fitting models were used to estimate population sizes for the areas surveyed and these were extrapolated to estimate total population sizes for each Island. The data were log transformed to ensure they met the assumptions of the tests and *t*-tests were used to compare population sizes between islands.

The same analyses distance analyses described above were also applied retrospectively to data collected by Short *et al.* (1989), on Bernier Island in July / August 1989 and July / August 1992 and Dorre Island in October 1988 and September 1991. Population size estimates were compared between Short *et al.* (1989) and the present study, but no statistical tests could be undertaken due to low sample sizes.

GRETL econometric software (Baiocchi and Distaso 2003) was used to examine patterns of variability in rainfall, mammal populations and their inter-relationship. Data for annual rainfall at Carnarvon Airport, from the first year of observation (1945) to present, were obtained from the Bureau of Meteorology and a periodogram showing the periodicity of peak rainfall years was produced. A generalised linear model (Poisson distribution, log link) and a log linear regression model was used to test for significant trends in rainfall over the 70 years of observation. Monthly rainfall data were also obtained for Disaster Cove, on the northern tip of Dorre Island, using a tipping bucket gauge for 35 months between 2007 and 2012. Total monthly rainfall was compared between Dorre Island and Carnarvon Airport using a paired *t*-test, after log transforming the data to ensure they met the assumptions of the test.

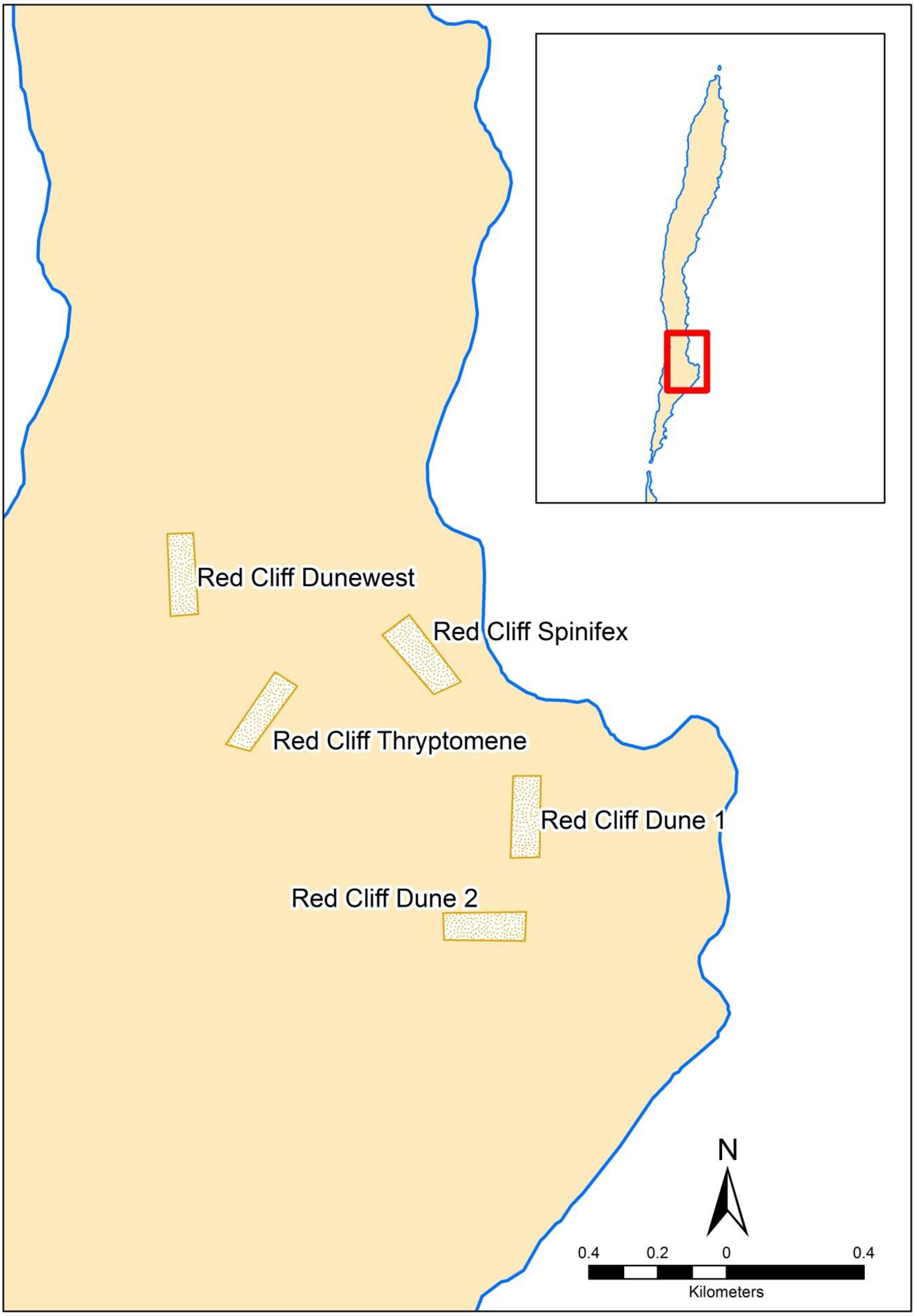
Augmented Dickey–Fuller (ADF) unit root tests were used to determine if the data were stationary. Rainfall data were stationary and thus, required no differencing, but the fauna population estimates were non-stationary. The ADF tests were used to determine autoregressive order (p) and autocorrelation functions (ACF) and partial autocorrelation functions (PACF) were used to determine the differencing order (d) and moving average order (q) respectively. The resulting Auto Regressive Integrated Moving Average (ARIMA) models were estimated for the fauna populations and Augmented Dickey-Fuller regressions were used to select the lags best representing the relationship between rainfall and mammal populations for 3, 2 and 1 years, using the Schwartz Bayesian criterion. Ordinary least squares regression was then used to forecast fauna population sizes as a function of rainfall. For more information on these techniques and algorithms, see Baiocchi and Distaso (2003).

2.2 Capture - Recapture Program

Detailed protocols for trapping are provided in Appendix 1, the trapping grids and their associated habitat types are shown in Table 5 and their locations are shown in Figure 3.

Table 5 Trapping grids and their habitat types.

Island	Grid	Habitat
Bernier	Red Cliff Dune 1	Dune
	Red Cliff Dune 2	Dune
	Red Cliff Dunewest	Dune
	Red Cliff Spinifex	Spinifex
	Red Cliff Thryptomene	Sandplain heath
Dorre	White Beach Dune 1	Dune
	White Beach Dune 2	Dune
	White Beach Scaevola 1	Sandplain heath
	White Beach Spinifex 2	Spinifex
	White Beach Travertine 2	Travertine heath


Red Cliff Dunewest
Red Cliff Spinifex
Red Cliff Thryptomene
Red Cliff Dune 1
Red Cliff Dune 2
N
0.4 0.2 0 0.4
Kilometers

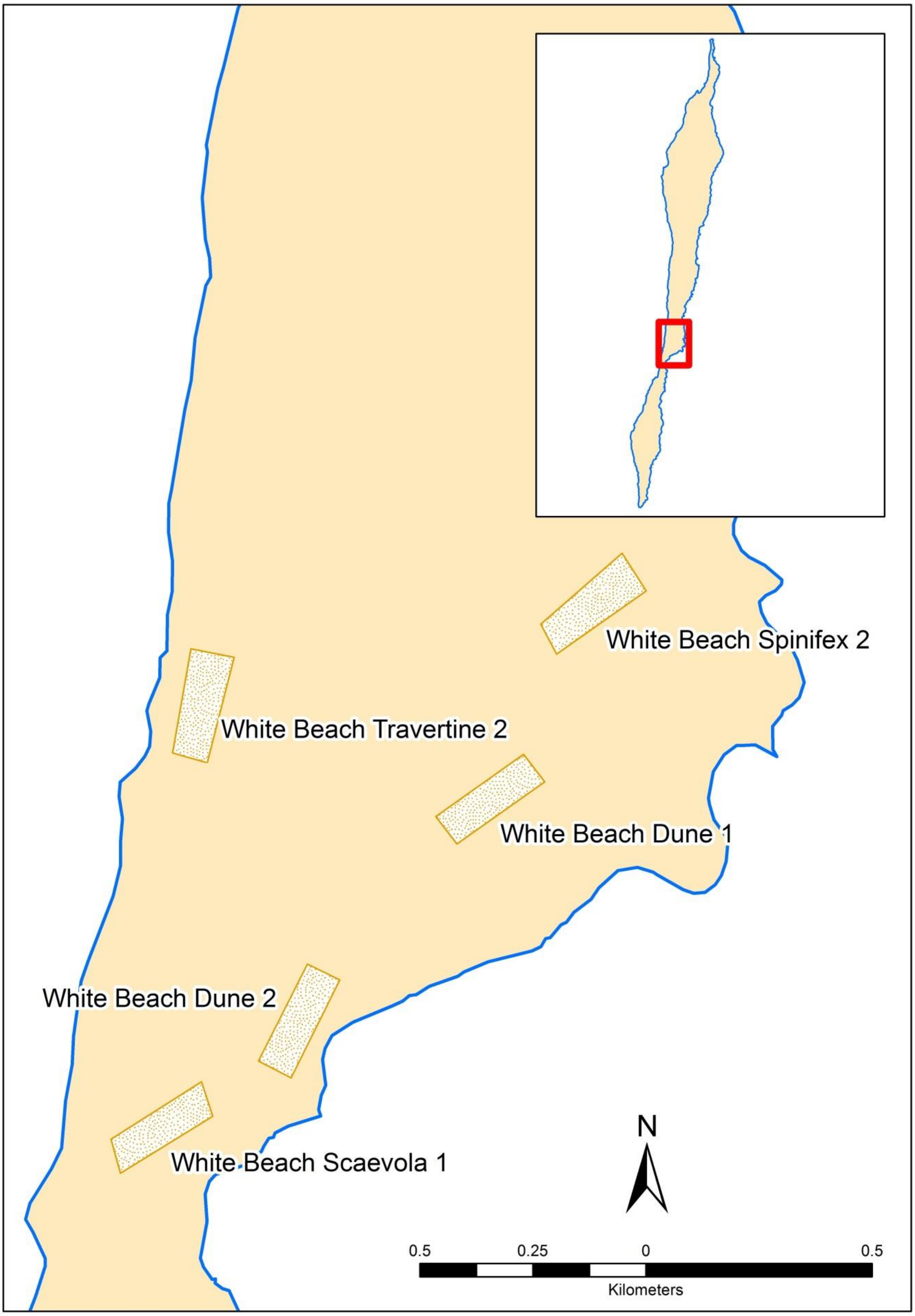


Figure 3 Location of trapping grids for Bernier Island (above) Dorre Island (below).

Trapping grids consisted of 10 cage traps and 21 Elliott traps spaced 40m apart, as shown in Figure 4. All traps were baited with universal bait (oats, peanut butter and sardines in oil). The time of year trapping was undertaken and relative number of trap nights per year is shown in Table 6. Burrowing bettongs occupied a high proportion of cage traps and set off Elliott traps and the number of traps set off empty is shown in Table 6. The dates on which the traps were checked are shown in Appendix 2.

eC	e	e	eC	e	e	eC
e	eC	eC	e	eC	eC	e
eC	e	e	eC	e	e	eC

Figure 4 Layout for cage traps (C) and Elliott traps (e) at each trapping site.

Table 6 Trap nights for Bernier and Dorre Island by trap type 2006-2009.

Island	Year	Month of trapping	Cage trap nights	Proportion of cage trap nights with bettongs (%)	Elliott trap nights	Elliott traps set off empty	Total trap nights
Bernier Island	2006	Aug. / Sep.	156	33	336	Not recorded	492
	2007	Sep.	160	4	336	7	496
	2008	May / Jul.	120	8	252	66	372
	2009	Aug.	120	29	252	Not recorded	372
Dorre Island	2006	Aug.	200	48	420	Not recorded	620
	2007	Sep.	160	38	336	119	496
	2008	May / Jul.	160	41	336	446	496
	2009	Aug.	160	65	336	Not recorded	496

On first capture, each animal was individually marked, by ear-punching for ash grey mouse and Shark Bay mouse, ear-tagging for burrowing bettongs, and microchipping (PIT tagging) for western barred bandicoots. Each animal was weighed, sexed and its head, pes (foot) and tail were measured. For males, the testes were measured and for females, the condition of the pouch was documented and the presence and size of pouch young was recorded.

Trapping data were entered into a Microsoft Access relational database and queries were used to extract data for further analysis. The analyses were restricted to the type of traps in which the species were most commonly captured: Elliott traps only for ash grey mouse and Shark Bay mouse, cage traps only for burrowing bettong and cage traps and Elliott traps for western barred bandicoot.

The number of captures per 100 trap nights was calculated for species by year and island and categorical response analyses (Chi-square tests) were used to determine if the relative abundance of each species varied between year and island using JMP9 software (SAS Institute Inc.). Observations for species were classified by habitat type corresponding to trapping grid and categorical response analyses (Chi-square tests) were used to determine if the relative abundance of each species varied by habitat type using JMP9 software (SAS Institute Inc.).

The minimum number of individuals captured on each island was calculated by sex. Sex ratios were calculated for each species by island and year, but low numbers meant statistical analysis could not be conducted. Two measures of physical condition were used; a qualitative score for burrowing bettongs and western barred bandicoots, as defined in Table 7 and a condition index; cube root of weight in grams divided by long pes in centimetres (after Caughley *et al.* 1988) for all four species trapped. Weight, long pes and condition score were compared between year, island and sex using Wilcoxon tests because the sample sizes were small and the data distributions did not meet the assumptions of parametric tests.

The proportion of females of breeding size (over 880g for burrowing bettongs (Short and Turner 1999) and over 175g for western barred bandicoots (Short *et al.* 1998)) with pouch young was calculated by year and island. Mean crown-rump length and head length of pouch young were then calculated by year and island for burrowing bettong and western barred bandicoot.

Table 7 Categories and definitions used to score condition for burrowing bettong and western barred bandicoot.

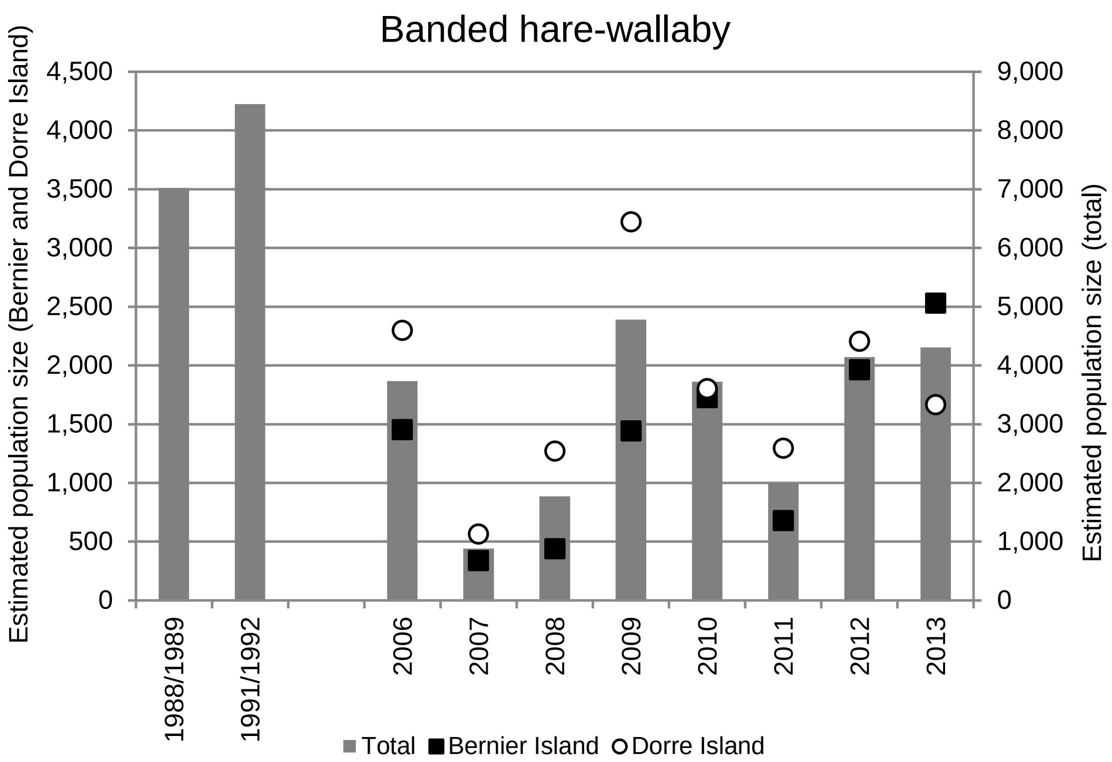
Score	Category	Definition
1	Emaciated	Very little flesh, transverse processes of spine prominent
2	Under weight	Little flesh, able to feel transverse process of spine easily
3	Ideal	Able to (just) feel transverse processes and able to feel a ‘good’ amount of flesh between spinous processes
4	Over weight	Only just able to feel spinous processes, unable to feel transverse processes
5	Obese	Unable to feel spinous processes, can see rolls of fat around neck and on tail

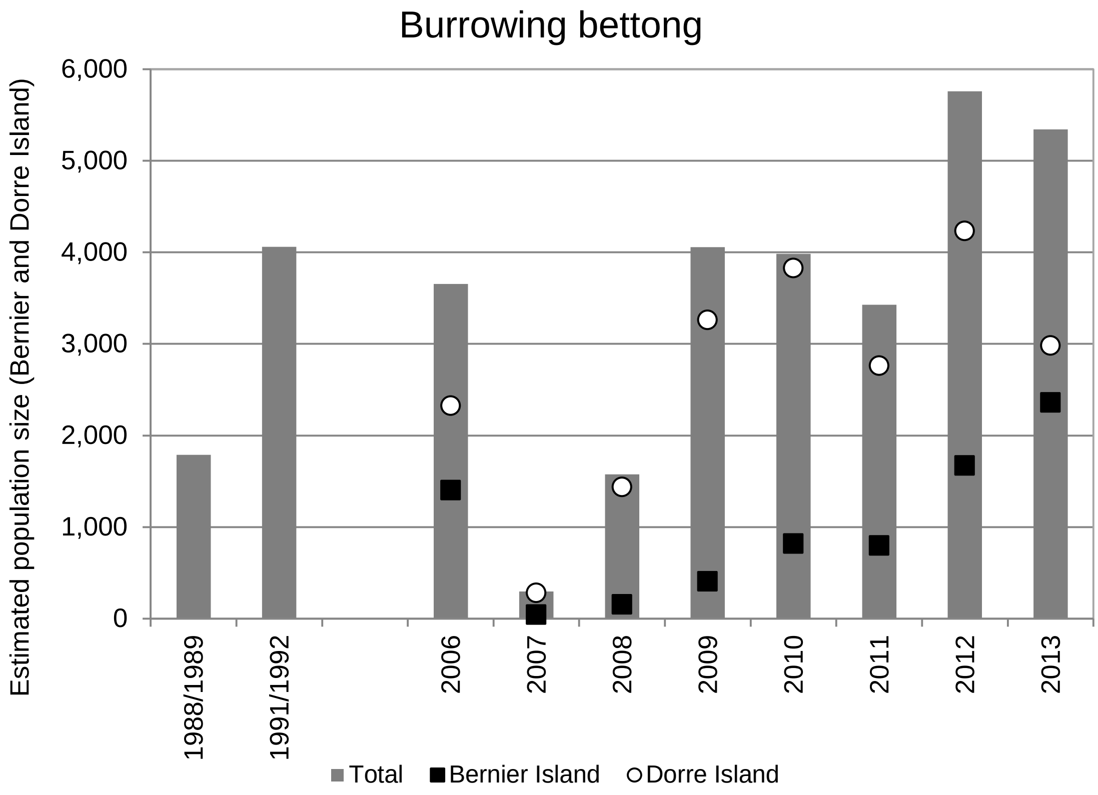
3 Results

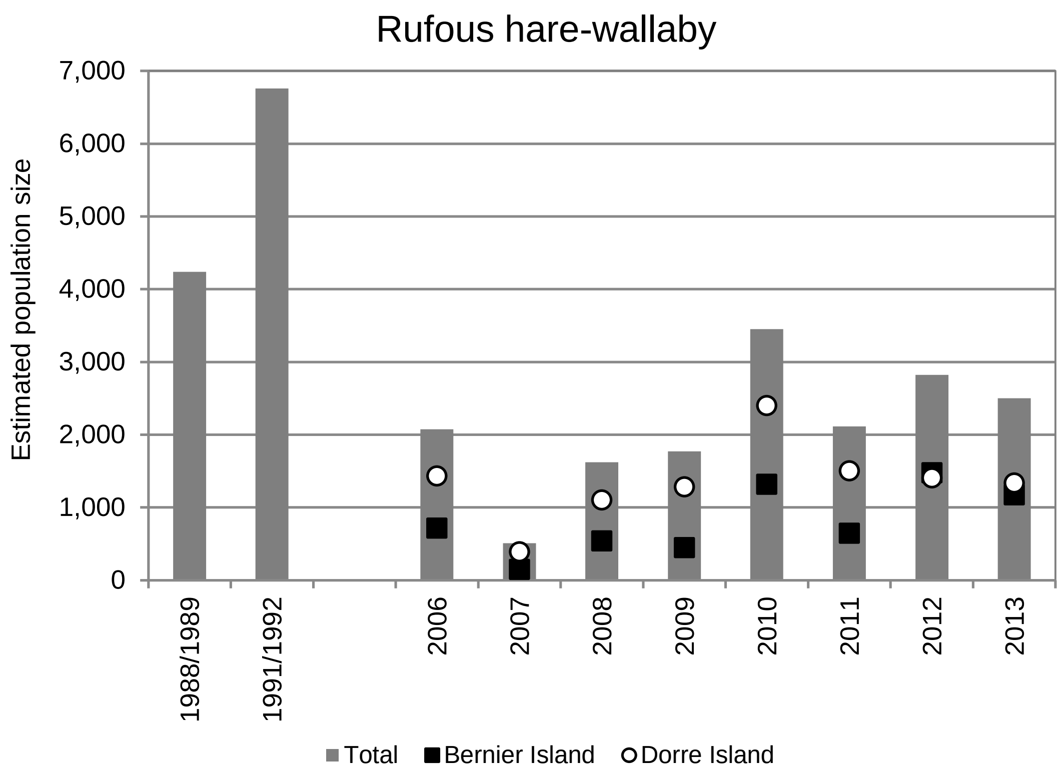
3.1 Distance population estimates

For all four species, estimated population sizes were lowest in 2007 and 2008 and highest in 2010, 2012 and 2013 (Figure 5). In comparison with population sizes estimated by Short *et al.* (1989), the wallaby and bandicoot populations estimated in this study were smaller and burrowing bettong populations in this study were larger (Figure 5).

The burrowing bettong (*t*-ratio = 2.62, d.f. = 14, P 0.0199), rufous hare-wallaby (*t*-ratio = 2.04, d.f. = 14, P = 0.0602) and western barred bandicoot (*t*-ratio = 1.45, d.f. = 14, P 0.0839) populations were larger on Dorre than Bernier Island, but the differences were not significant at P = 0.05 for the latter two species. Population sizes did not differ between islands for banded hare-wallaby.




Burrowing bettong
Estimated population size (Bernier and Dorre Island)
6,000
5,000
4,000
3,000
2,000
1,000
0
1988/1989
1991/1992
2006
2007
2008
2009
2010
2011
2012
2013
Total
Bernier Island
Dorre Island


Rufous hare-wallaby
Estimated population size
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1988/1989
1991/1992
2006
2007
2008
2009
2010
2011
2012
2013
Total
Bernier Island
Dorre Island

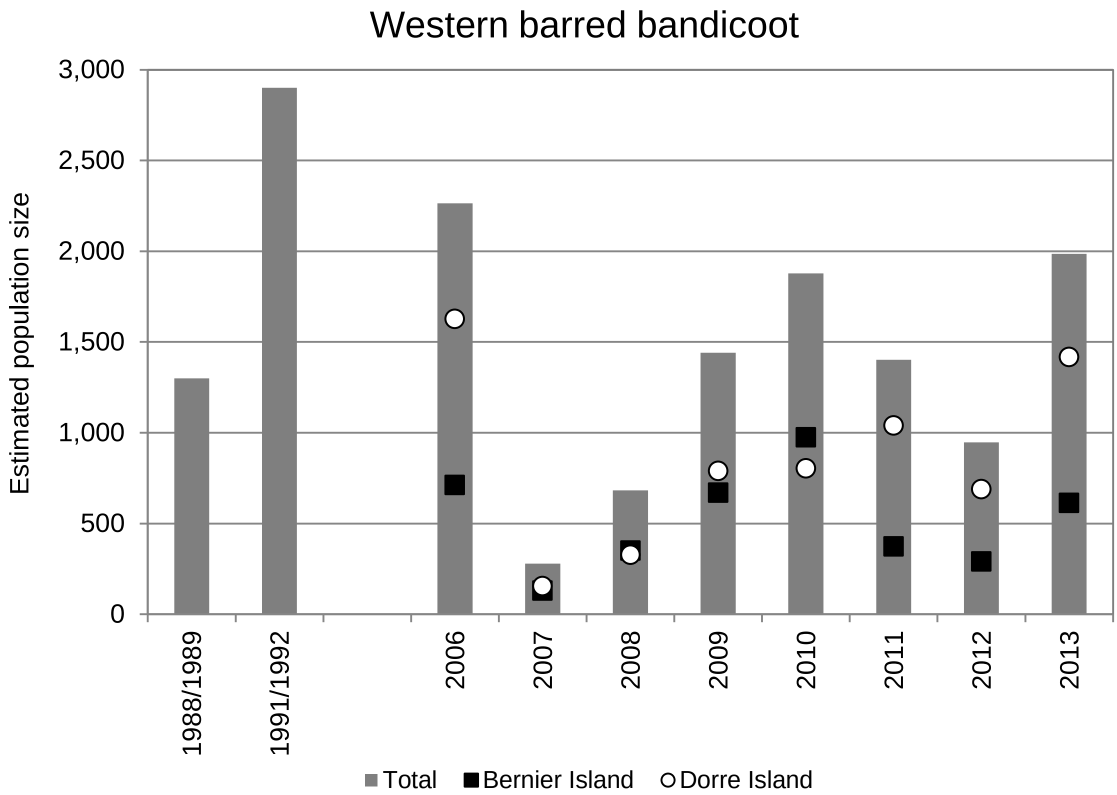
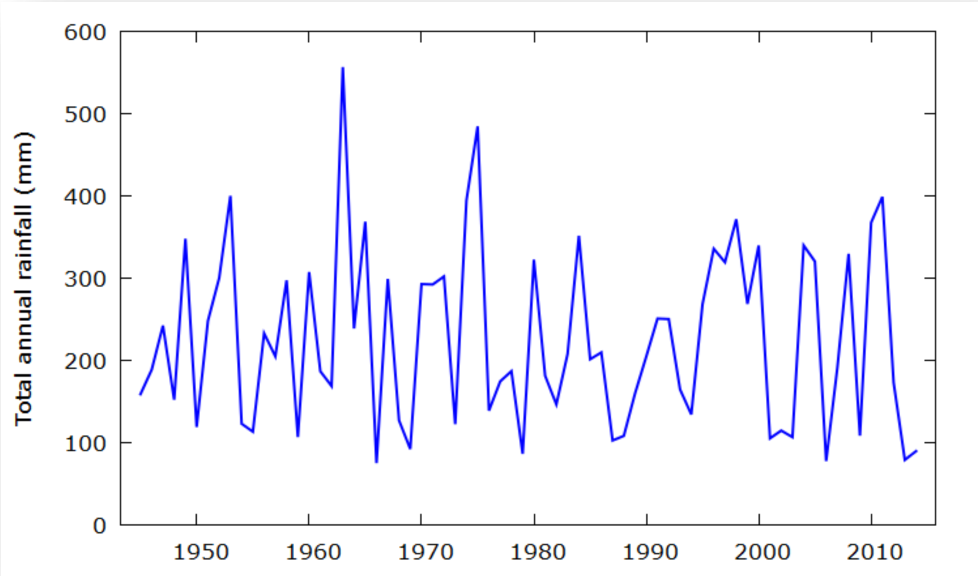


Figure 5 Total estimated population sizes for four species on Bernier and Dorre Island based on distance analyses of spotlighting line transect observations.

3.2 Variation in rainfall

Rainfall at Carnarvon Airport averaged 226 mm annually (n = 70 years) and it was highly variable, peaking at intervals of 11.7 years, 3.7 years and 2.3 years (Figure 6). Generalised linear modelling (poisson distribution, log link) showed that rainfall declined at Carnarvon Airport between 1945 and 2014 ($y = \exp(-0.0009x+7.401)$, G = 6.46, P = 0.01), but log linear regression did not detect any trend ($R^2 = 0.006$, $P > 0.05$).



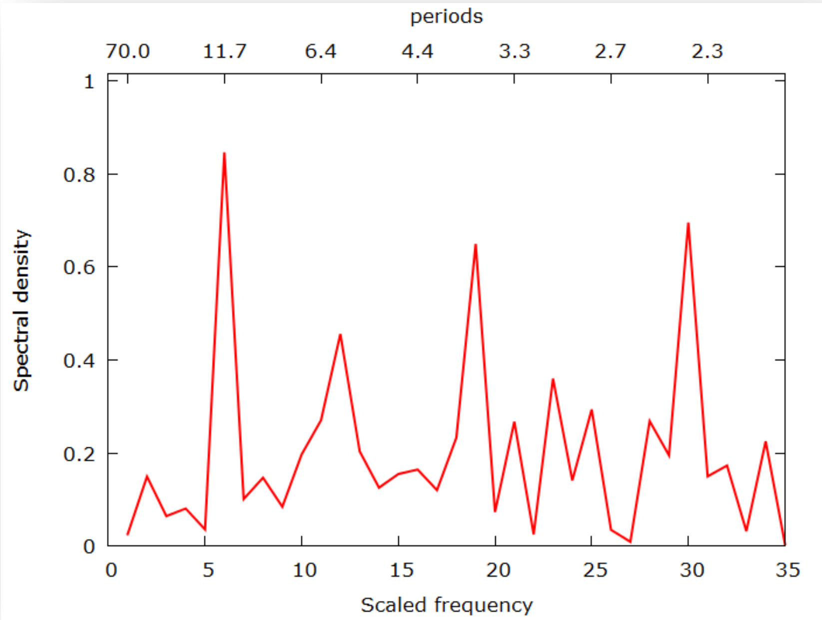


Figure 6 Total annual rainfall for Carnarvon Airport from 1945 to 2014 (above) and the corresponding periodogram (below), showing peak periods in years.

Between 2004 and 2014, rainfall was relatively low in 2006, 2009, 2013 and 2014 and relatively high in 2004, 2005, 2008, 2010 and 2011 (Figure 7). Generalised linear modelling (poisson, log link) showed that rainfall increased between 2004 and 2014 ($y = \exp(0.11202x-222.23)$, G = 16.84, P < 0.0001).

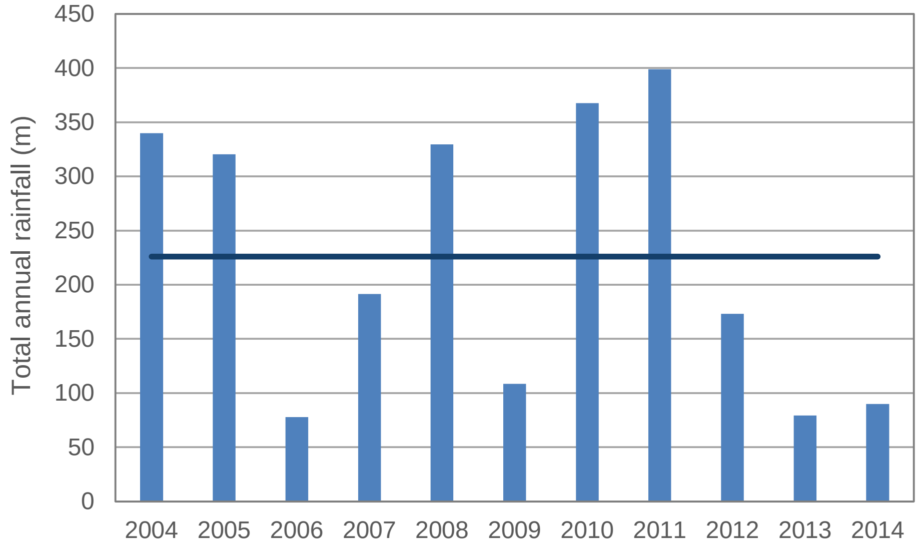


Figure 7 Total annual rainfall for Carnarvon Airport 2004-2014. Line shows long term average annual rainfall (1945-2014).

Monthly rainfall was highly variable between 2004 and 2014 and the monthly average was relatively high in May, June and July and relatively low in September, October and November (Table 8). Total monthly rainfall was relatively high in July 2004, May 2005 and June 2005 and low (< 32 mm) in all months in 2006, 2013 and 2014 (Table 8). For the 35 months that could be compared, rainfall was significantly lower on Dorre Island than at Carnarvon Airport (*t*-Ratio = -3.60, d.f. = 34, P < 0.0005).

Table 8 Total monthly and annual rainfall (mm) for Carnarvon Airport 2004-2014 and Dorre Island (Disaster Cove) 2007-2012. Comparable months are shaded grey.

Location	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Carnarvon Airport	2004	35.6	51.2	0	0	22.2	3.4	215.6	8.4	2.8	0	0.6	0	339.8
	2005	0	0	1.2	7.4	141.2	135.2	6.2	13	7.6	8.6	0	0	320.4
	2006	15.8	1.6	23.6	3	13	6	1.2	3	3.8	6.8	0	0	77.8
	2007	1	0	0	23.2	0.6	81.8	81.4	1	1.4	1	0	0	191.4
	2008	0.6	60.6	94.2	75.6	0.4	52	29.4	2.2	1.4	2.2	10.6	0.4	329.6
	2009	0.6	32.4	2.2	0.2	3.2	33.8	13.6	11.2	4.4	6.8	0.2	0	108.6
	2010	5	0	0	1.8	15	40.6	6.2	36.2	4.6	0	3.2	255	367.6
	2011	62.4	88.6	22	44.4	21.2	62.8	61.8	20	3.6	6	6	0.2	399
	2012	21	15.2	56.2	6.6	0.6	32.2	10.4	6.8	4.6	0	5	14.6	173.2
	2013	25.8	0.2	2.2	0	11	29	0.6	0.2	7	2.8	0	0.4	79.2
	2014	9	0	0.4	7.8	23.6	14	2.4	0.2	31.4	1	0	0	89.8
	Mean	10.8	19.8	21.9	18.1	28.3	42.1	48.6	14.7	6.6	4.0	2.9	17.6	235.4
Dorre Island	2007				8.2	0	1.2	3.6	0	0	0	0	0	
	2008	0	8.6	15.2	21.8	0	1.4	2.4	0	0	0	0	0	49.4
	2009	0	0	0.8	6.8	2.6	1.6	0.4						
	2010	1	0	0	0	0	0	0.2	0.6	0	0	0.2	100	102.0
	2011	48	67.2	0	39.6	14	81	32.6	17	0.4	17.2	0.8	3.4	321.2
	2012	22.2	1.6	26.2	0	3	57.2	11.8						

3.3 Influence of rainfall on mammal populations

Lag testing showed that total annual rainfall two years prior to the spotlighting surveys had the strongest influence on mammal population sizes for all four species (Table 9) and Figure 8 compares rainfall, transposed forward two years, with mammal populations estimated from spotlighting transect surveys. Based on rainfall, mammal populations were forecast to be low between 2014 and 2016 (Table 9, Figure 9).

Table 9 Differencing applied, lag period best representing the relationship between rainfall and mammal populations ($P < 0.05$) and forecasts for population sizes based on ordinary least squares regression model, shown with R^2 and P values. ARIMA = Auto Regressive Integrated Moving Average model shows p,d,q, where p = autoregressive order, d = differencing order, q = moving average order.

Species	Island	ARIMA Differencing model (p,d,q)	Lag with rainfall (years)	Forecast population (± 95% confidence interval)			Strength of the model	
				2014	2015	2016	R^2	P
Banded hare-wallaby	Bernier	1,0,0	2	841	383	436	0.88	0.0002
	Dorre	1,2,2	2	995	455	516	0.74	0.0029
	Total	0,2,2	2	1,869	855	969	0.83	0.0006
Burrowing bettong	Bernier	1,0,0	2	639	292	331	0.78	0.0017
	Dorre	1,0,0	2	1,519	694	787	0.77	0.0018
	Total	1,0,0	2	2,095	958	1,086	0.81	0.0009
Rufous hare-wallaby	Bernier	1,0,0	2	495	226	257	0.82	0.0008
	Dorre	1,2,0	2	755	345	391	0.76	0.0021
	Total	1,0,0	2	1,214	555	629	0.81	0.0009
Western barred bandicoot	Bernier	0,2,2	2	295	135	153	0.74	0.0028
	Dorre	1,0,0	2	506	232	263	0.76	0.0022
	Total	1,0,0	2	795	363	412	0.79	0.0014

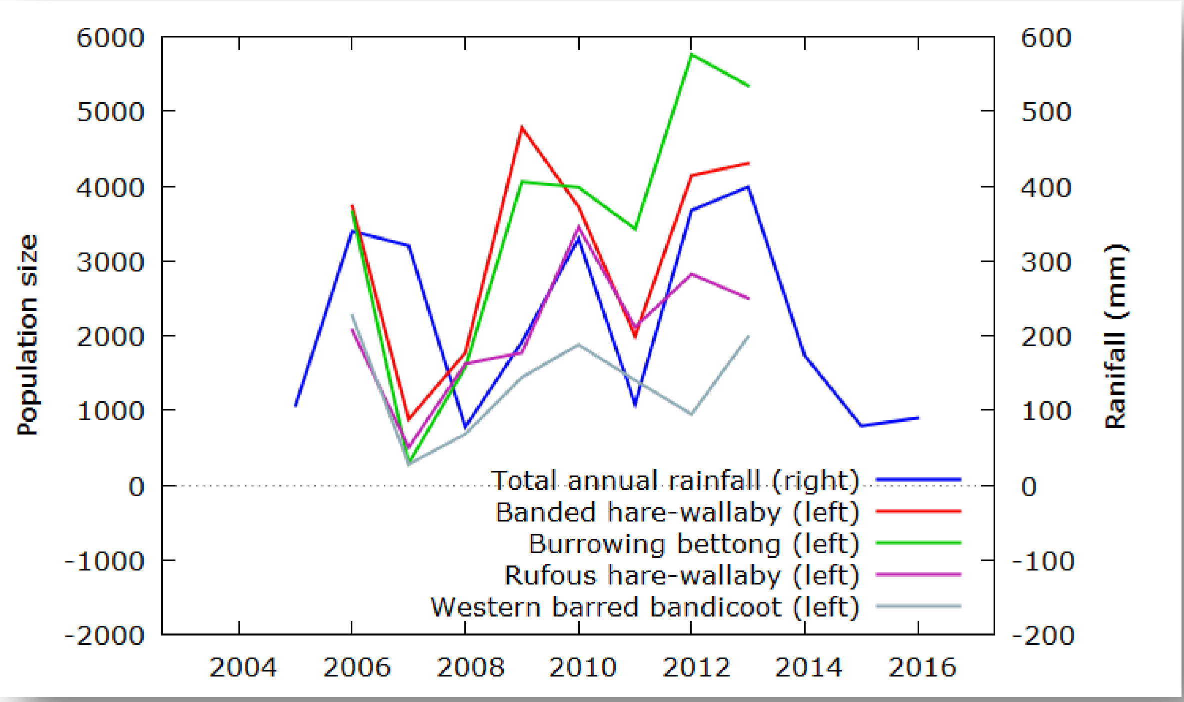
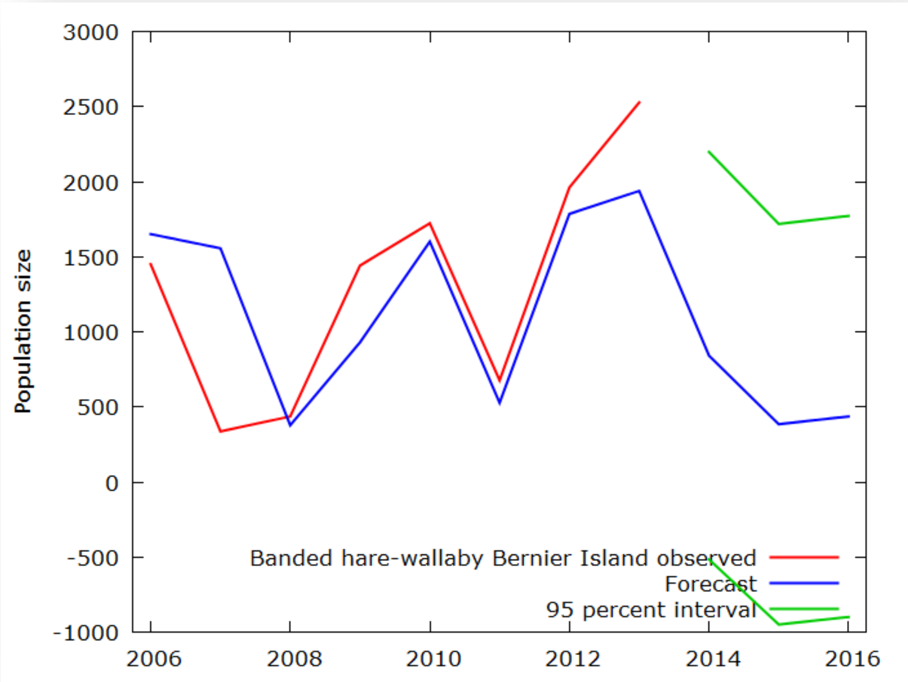
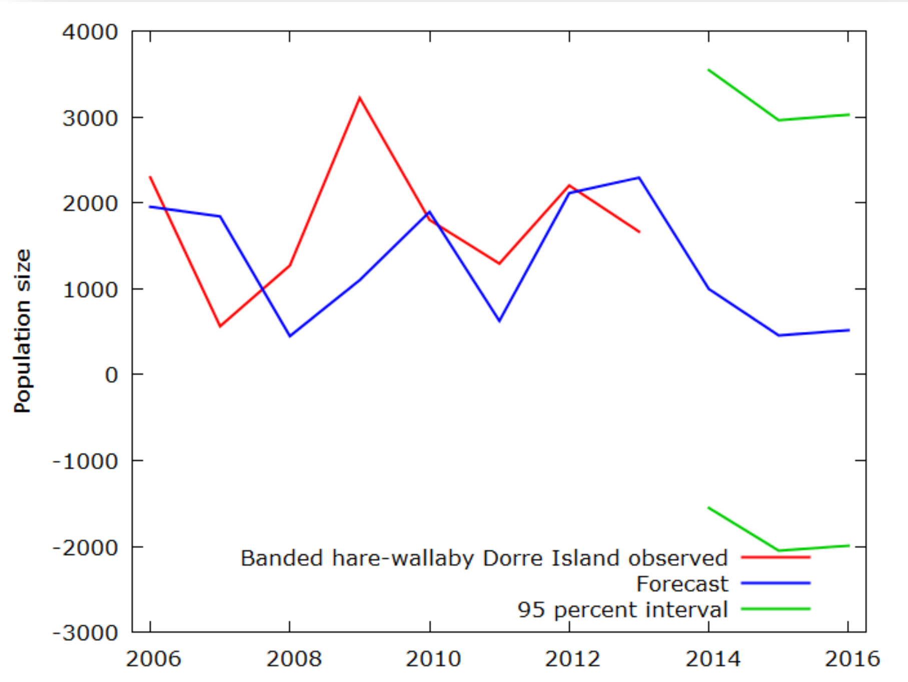
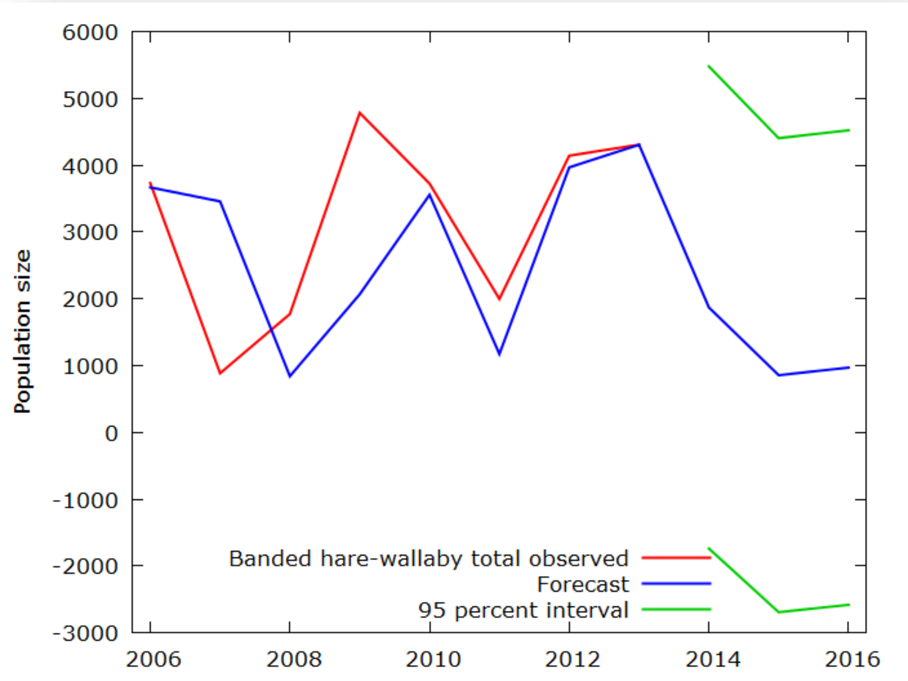
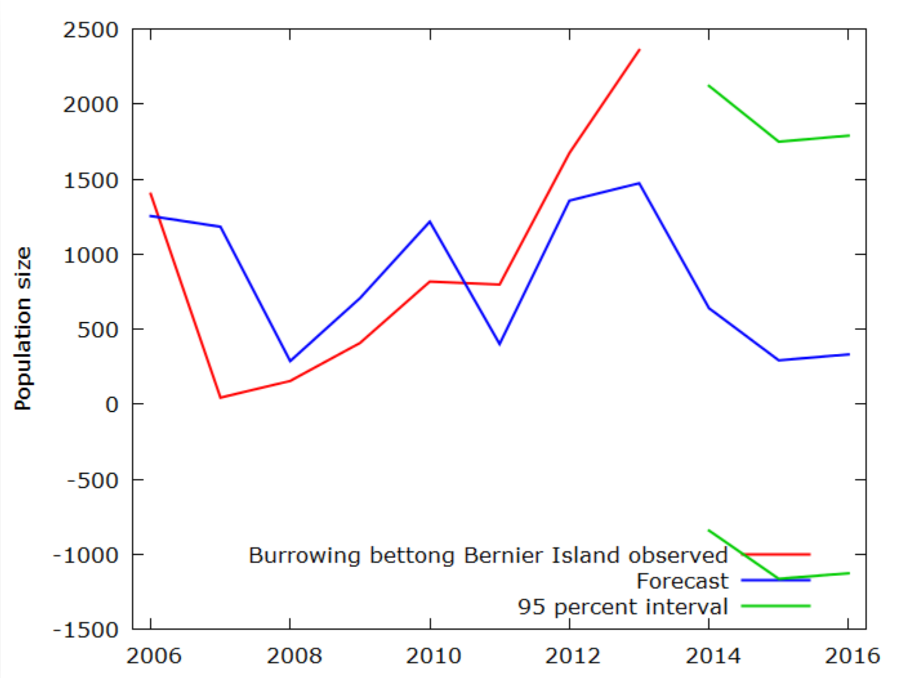


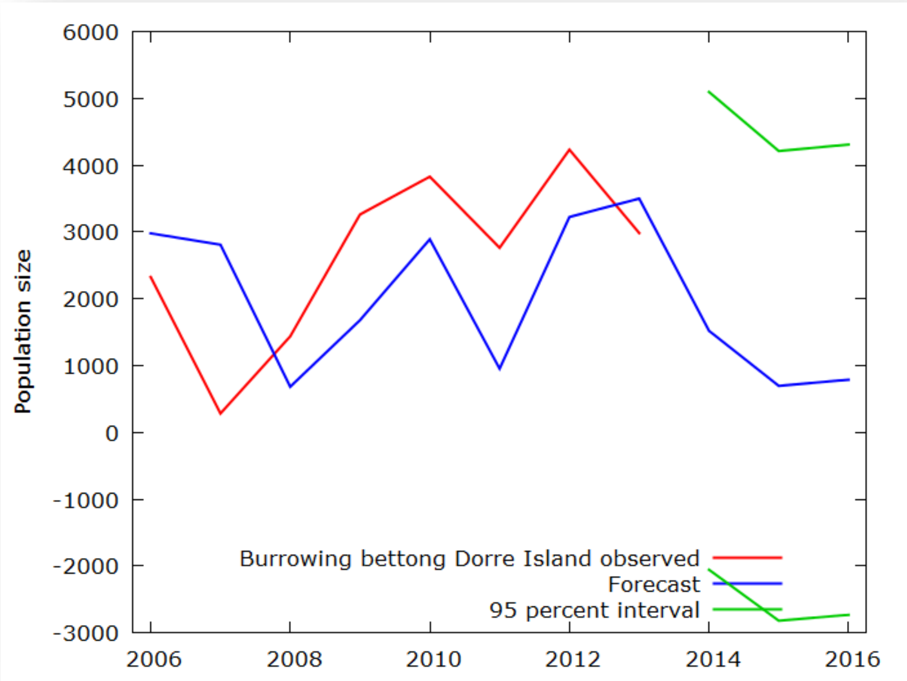
Figure 8 Relationship between total annual rainfall at Carnarvon Airport, transposed forward 2 years, and total estimated mammal population sizes for Bernier and Dorre Islands combined.

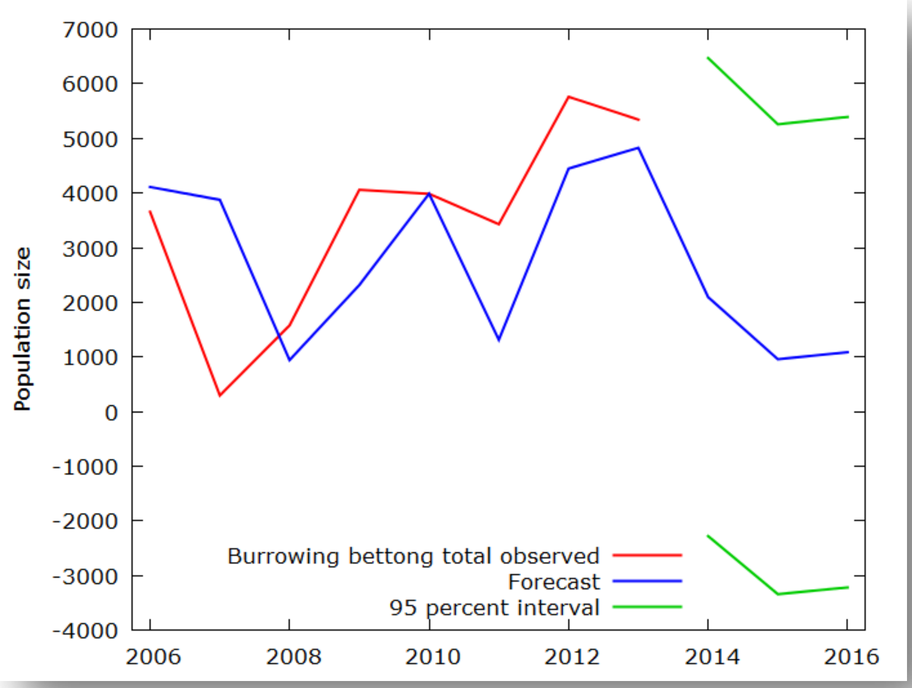


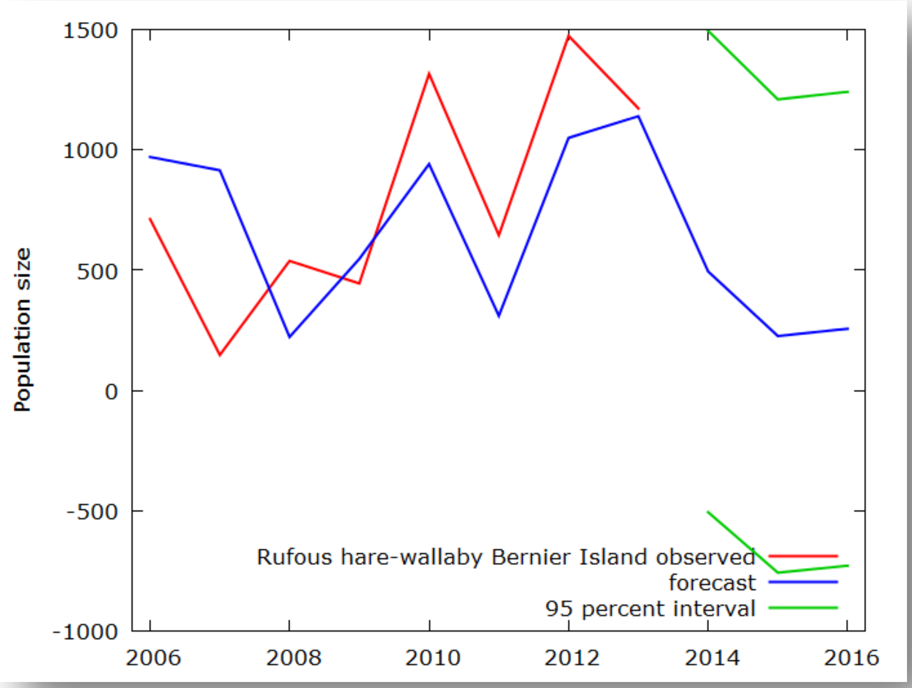

Population size
4000
3000
2000
1000
0
-1000
-2000
-3000
2006
2008
2010
2012
2014
2016
Banded hare-wallaby Dorre Island observed
Forecast
95 percent interval

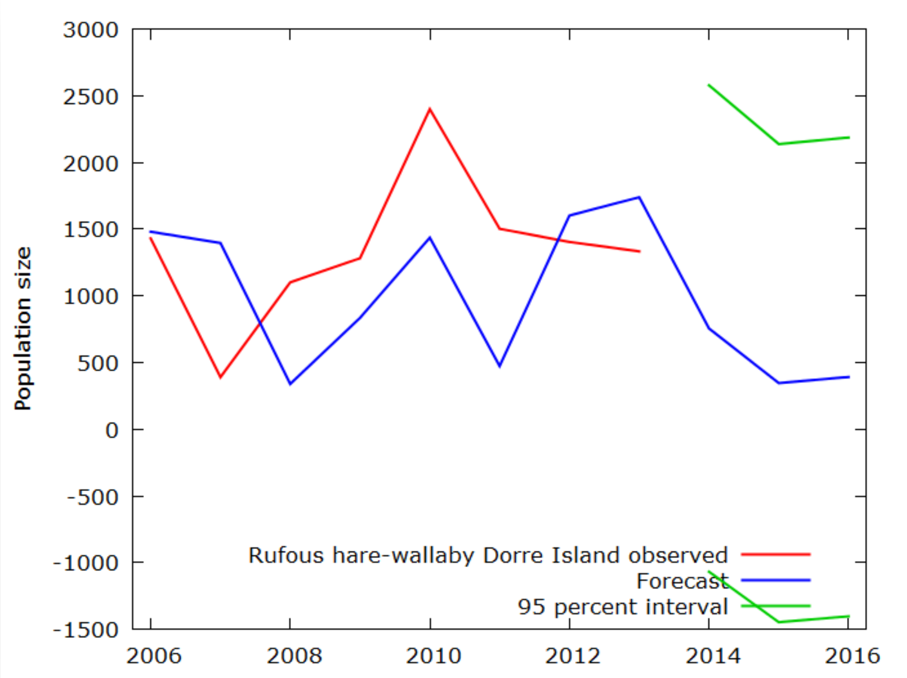

Population size
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
2006
2008
2010
2012
2014
2016
Banded hare-wallaby total observed
Forecast
95 percent interval

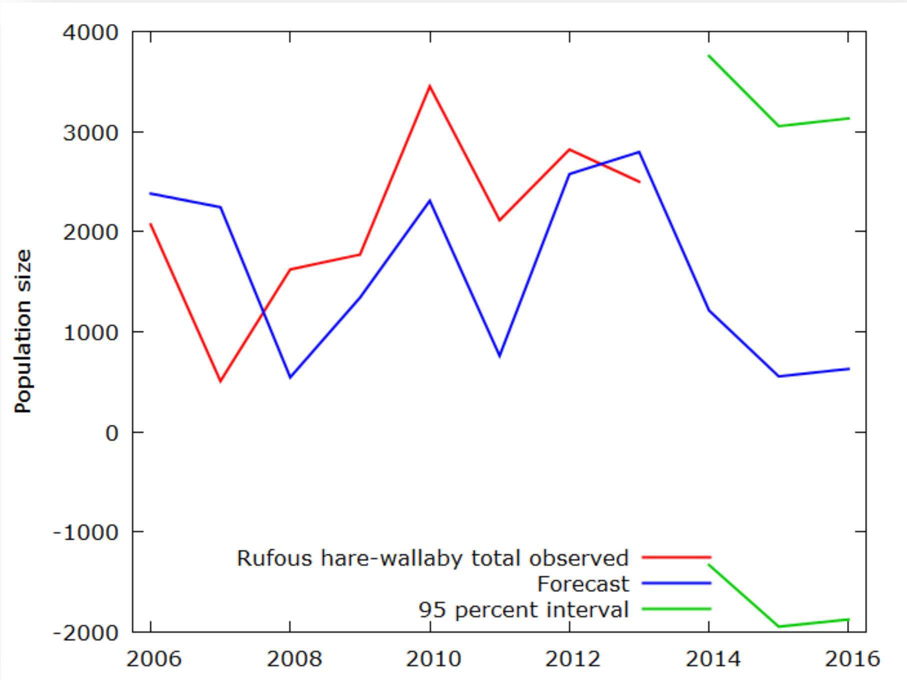

2500
2000
1500
1000
500
0
-500
-1000
-1500
Population size
2006
2008
2010
2012
2014
2016
Burrowing bettong Bernier Island observed
Forecast
95 percent interval

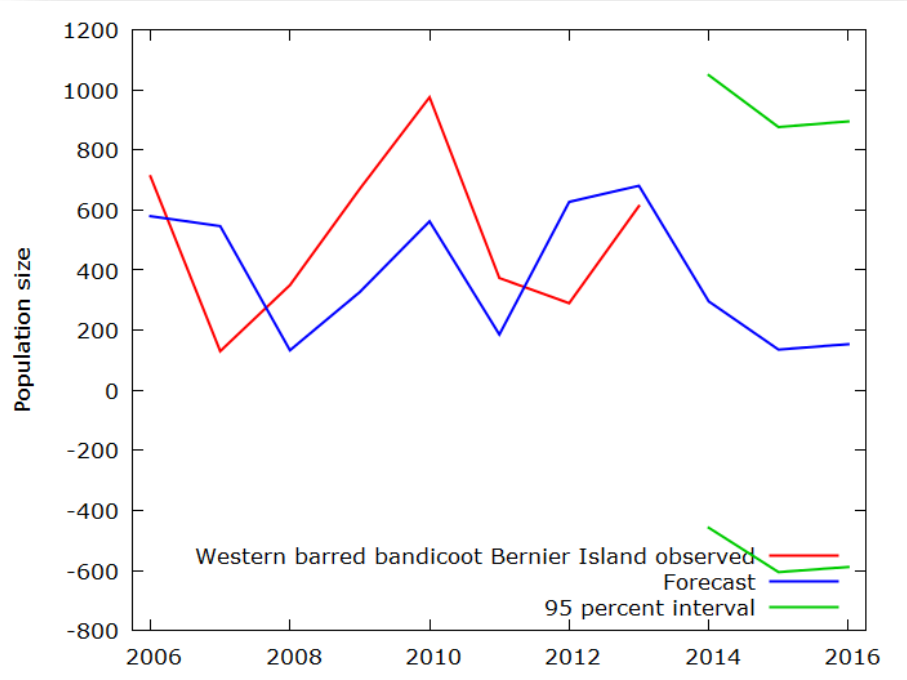

6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
Population size
2006
2008
2010
2012
2014
2016
Burrowing bettong Dorre Island observed
Forecast
95 percent interval

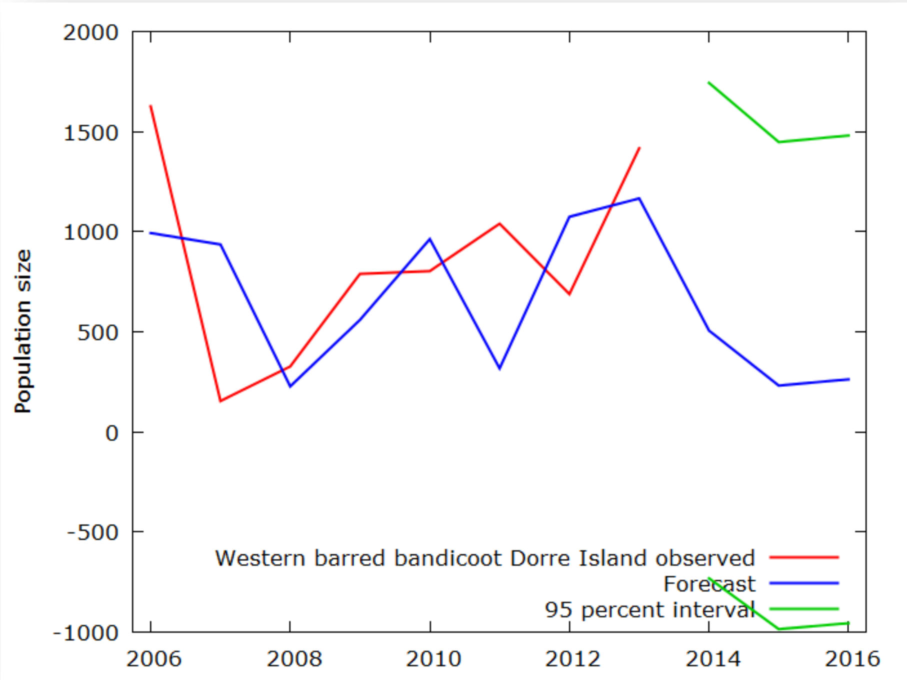

7000
6000
5000
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
Population size
Burrowing bettong total observed
Forecast
95 percent interval
2006
2008
2010
2012
2014
2016


1500
1000
500
0
-500
-1000
Population size
Rufous hare-wallaby Bernier Island observed
forecast
95 percent interval
2006
2008
2010
2012
2014
2016


Population size
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
2006
2008
2010
2012
2014
2016
Rufous hare-wallaby Dorre Island observed
Forecast
95 percent interval


Population size
4000
3000
2000
1000
0
-1000
-2000
2006
2008
2010
2012
2014
2016
Rufous hare-wallaby total observed
Forecast
95 percent interval


1200
1000
800
600
400
200
0
-200
-400
-600
-800
Population size
2006
2008
2010
2012
2014
2016
Western barred bandicoot Bernier Island observed
Forecast
95 percent interval


2000
1500
1000
500
0
-500
-1000
Population size
2006
2008
2010
2012
2014
2016
Western barred bandicoot Dorre Island observed
Forecast
95 percent interval

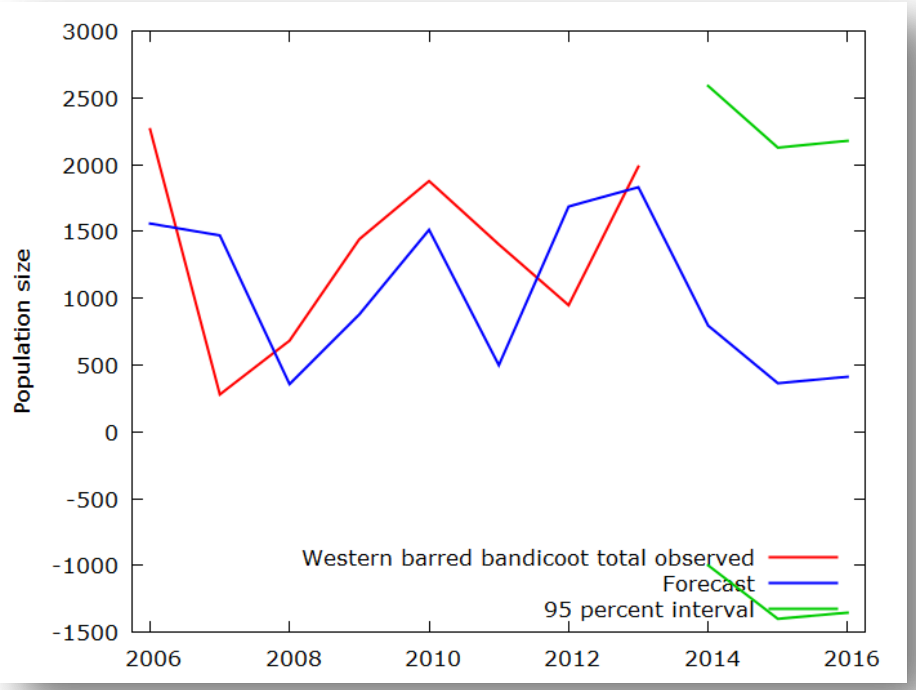


Figure 9 Population sizes observed, based on distance analysis, and forecast, using ordinary least square regression with rainfall incorporating a two year time lag, for Bernier Island, Dorre Island and both islands combined (total).

3.4 Relative abundance of mammal populations

Relative abundance was lower in 2007 than other years (X^2 = 8.57, P = 0.0356) for all species combined, and the burrowing bettong was more abundant on Dorre Island than Bernier Island (X^2 = 14.07, P = 0.0028), but no patterns could be detected for the other species (P > 0.05) (Figure 10). The relative abundance of all species was very low on Bernier Island in 2007, and while most increased in abundance in 2008 and 2009, the relative abundance of western barred bandicoot fell between 2008 and 2009 (Figure 10). Ash grey mouse was only captured on Dorre Island in 2006 and not in other years (Figure 10).

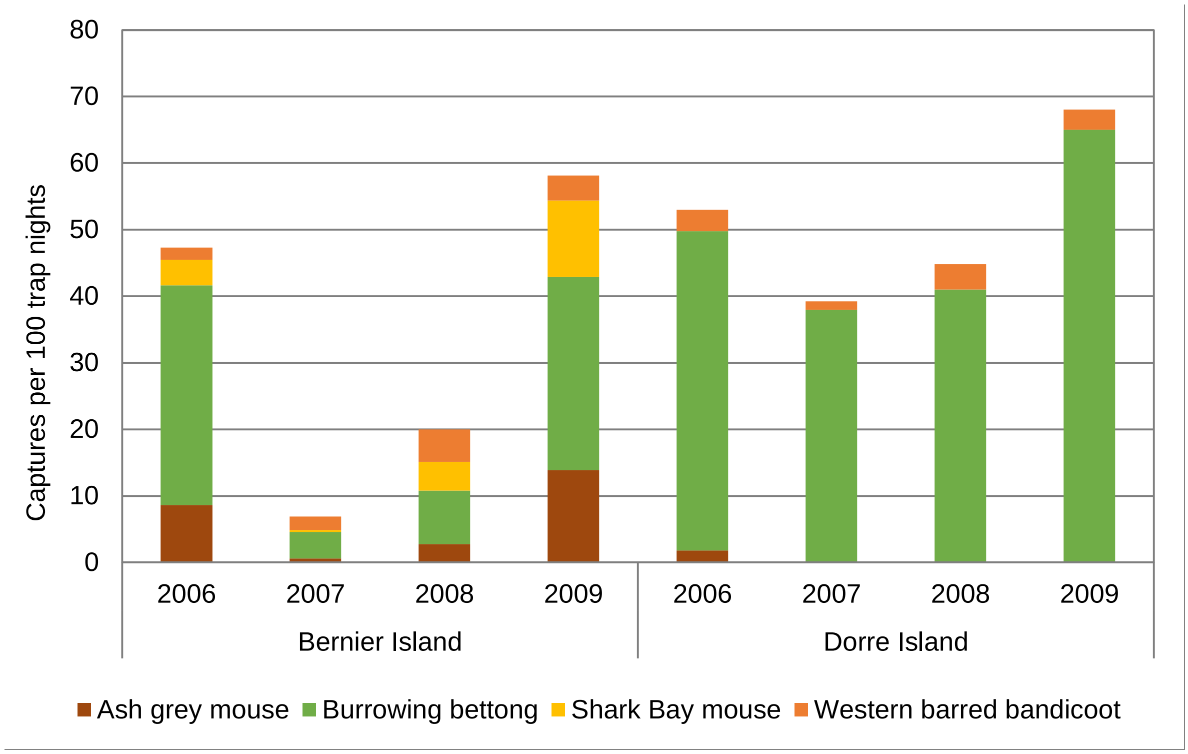
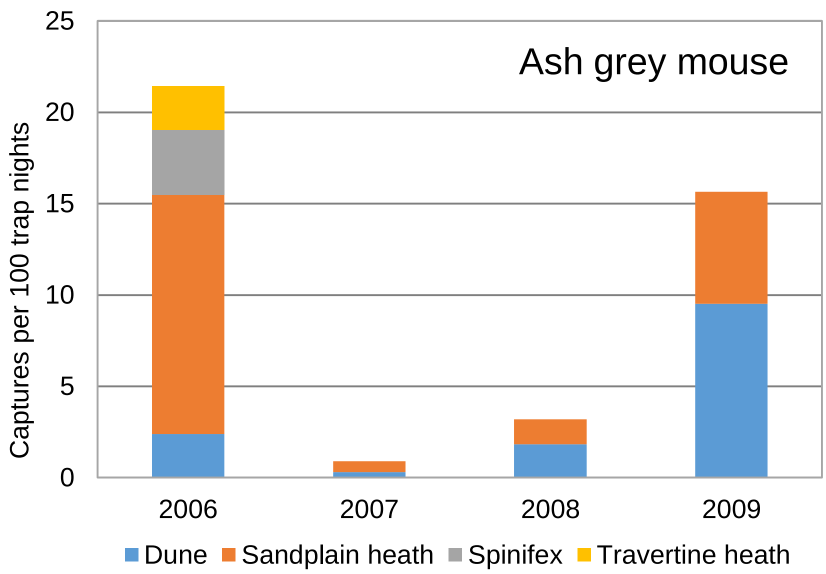
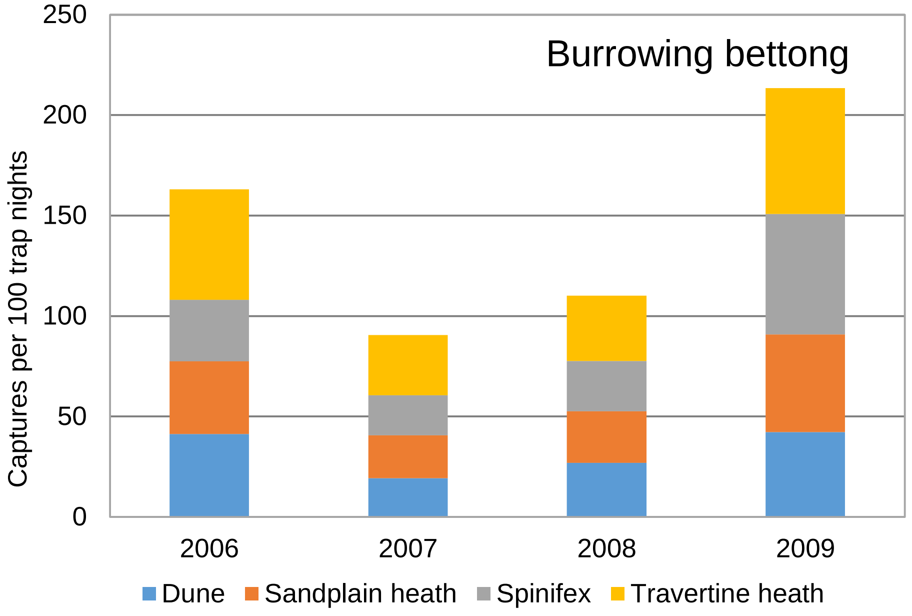
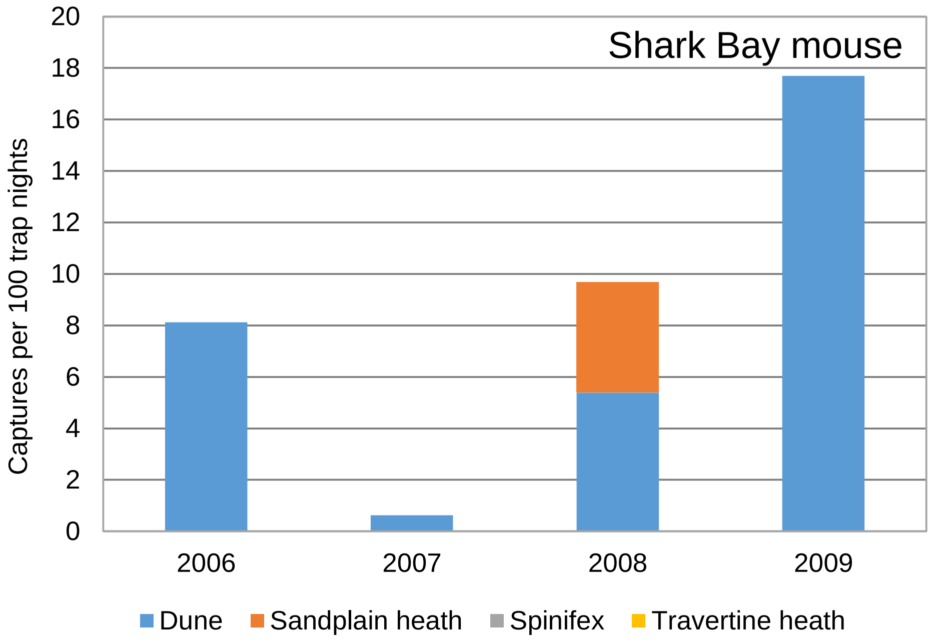


Figure 10 Relative abundance of mammals trapped on Bernier Island and Dorre Island 2006-2009.

Figure 11 compares the relative abundance of species for habitat types each year and Table 10 shows the results of categorical tests for differences in relative abundance between habitat types across all years. Ash grey mouse was most commonly captured in dune habitats, Shark Bay in sandplain heath and western barred bandicoot in Travertine Heath. The burrowing bettong was captured in similar relative abundance across all habitats.




Burrowing bettong
Captures per 100 trap nights
0
50
100
150
200
250
2006
2007
2008
2009
Dune
Sandplain heath
Spinifex
Travertine heath


Shark Bay mouse
Captures per 100 trap nights
0
2
4
6
8
10
12
14
16
18
20
2006
2007
2008
2009
Dune
Sandplain heath
Spinifex
Travertine heath

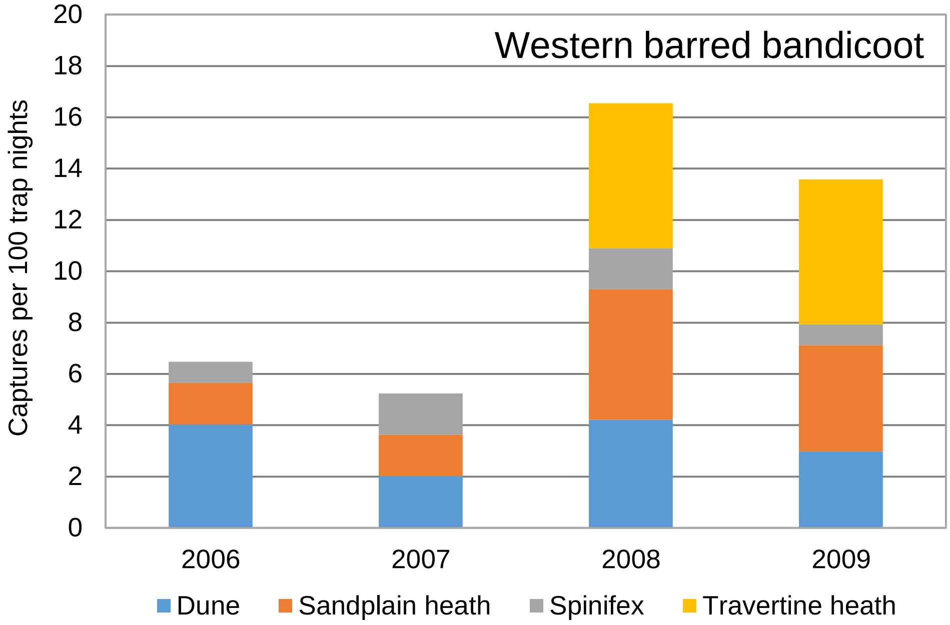


Figure 11 Relative abundance of mammals trapped by habitat type 2006-2009.

Table 10 Results of categorical analyses for frequency of captures across habitat types for each species across all years (*n* = number of captures).

Species	*n*	Results	Dune	Sandplain heath	Spinifex	Travertine heath
Ash grey mouse	79	X^2	10.6	6.1	4.9	3.3
		P	0.014	0.109	0.180	0.354
Burrowing bettong	411	X^2	2.12	0.14	4.02	0.11
		P	0.548	0.987	0.260	0.990
Shark Bay mouse	54	X^2	1.23	8.97	0	0
		P	0.746	0.030	-	-
Western barred bandicoot	107	X^2	4.3	1.6	1.4	13.7
		P	0.231	0.665	0.703	0.003

3.5 Biology

Table 11 shows the minimum number of individual animals recorded for each sex for the four mammal species captured during the trapping program. Table 12 shows the sex ratios for each species on each island each year, based on captures for new individuals and recaptures between years, but excluding re-traps within years. The sex ratios were variable between years and islands, but any patterns were difficult to distinguish due to low sample sizes.

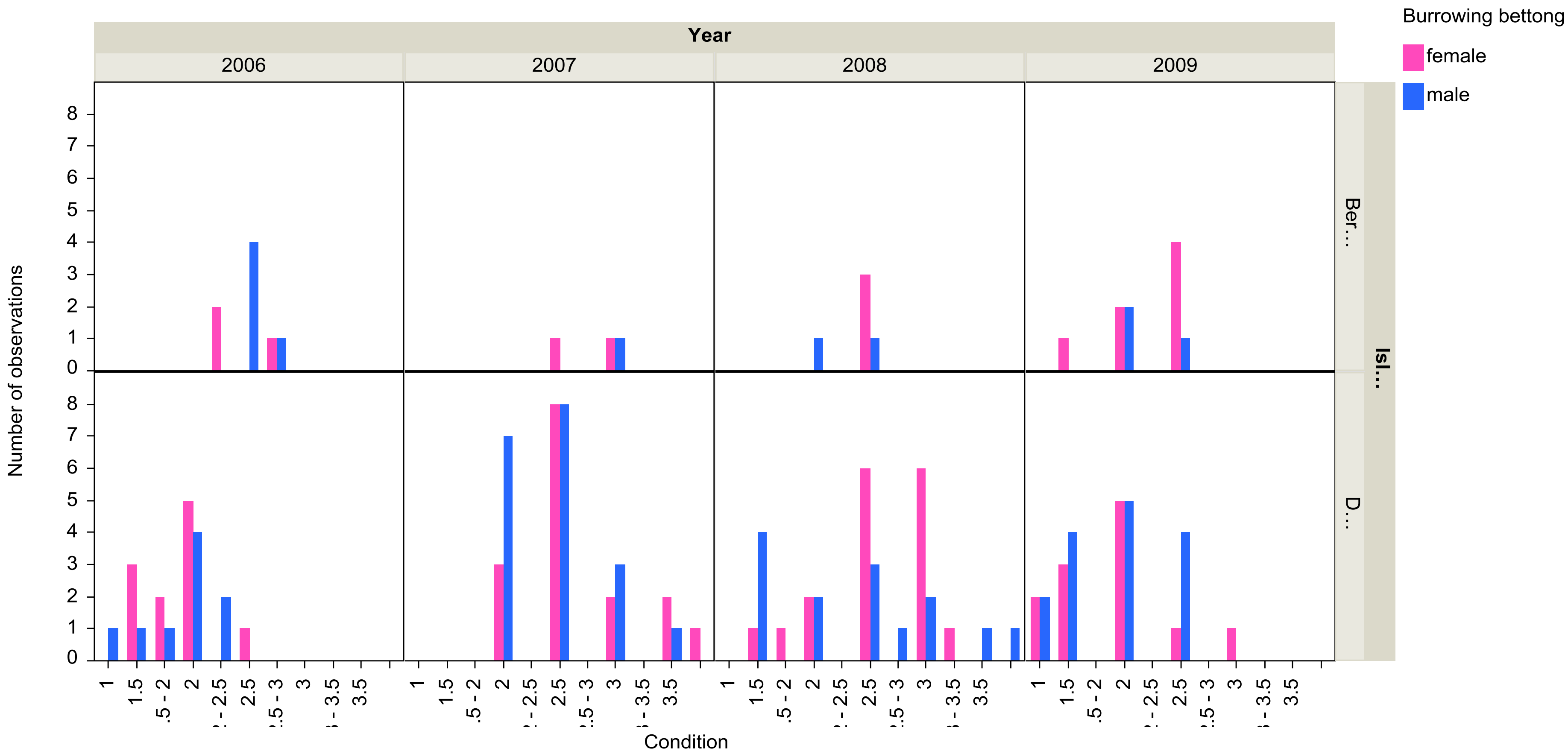
Figure 12 shows the frequency of observations for condition score for burrowing bettong and western barred bandicoot and Table 13 shows mean weight, long pes and condition index for all four species. The data were insufficient for statistical testing for ash grey mouse and Shark Bay mouse. However, for burrowing bettong, weight was significantly greater in 2007 than other years (n = 224, X^2= 20.4, d.f. = 3, P < 0.0001), long pes was significantly greater on Bernier Island than Dorre Island (X^2 = 9.5 n = 219, d.f. = 1, P = 0.0020) and condition index was significantly greater for females than males (X^2 = 6.4, n = 214, d.f. = 1, P = 0.0115). For western barred bandicoot, long pes was significantly greater for males than females (X^2 = 3.9, n = 73, d.f. = 1, P = 0.0469) and condition index was significantly greater for females than males (X^2 = 8.0, n = 71, d.f. = 1, P = 0.0048).

Table 11 Minimum number of individuals of each species trapped on Bernier and Dorre Island 2006-2009.

Island	Species	Female	Male	Total
Bernier Island	Ash grey mouse	22	15	37
	Burrowing bettong	15	10	25
	Shark Bay mouse	16	18	34
	Western barred bandicoot	14	16	30
Dorre Island	Ash grey mouse	1	2	3
	Burrowing bettong	53	45	98
	Western barred bandicoot	13	19	32

Table 12 Ratio of males to females for each species for Bernier and Dorre Island 2006-2009.

Year	Species	Bernier Island			Dorre Island		
		Female	Male	M:F	Female	Male	M:F
2006	Ash grey mouse	11	10	0.9	2	3	1.5
	Burrowing bettong	10	18	1.8	24	23	1.0
	Shark Bay mouse	3	5	1.7			
	Western barred bandicoot	6	2	0.3	3	7	2.3
2007	Ash grey mouse	2					
	Burrowing bettong	2	1	0.5	19	22	1.2
	Shark Bay mouse		1				
	Western barred bandicoot	3	3	1.0	4	2	0.5
2008	Ash grey mouse	4	3	0.8			
	Burrowing bettong	4	2	0.5	19	16	0.8
	Shark Bay mouse	4	6	1.5			
	Western barred bandicoot	2	10	5.0	7	8	1.1
2009	Ash grey mouse	22	8	0.4			
	Burrowing bettong	14	9	0.6	29	27	0.9
	Shark Bay mouse	10	12	1.2			
	Western barred bandicoot	4	6	1.5	4	4	1.0


Year
2006
2007
2008
2009
Burrowing bettong
female
male
Ber...
D...
Isl...
Number of observations
Condition

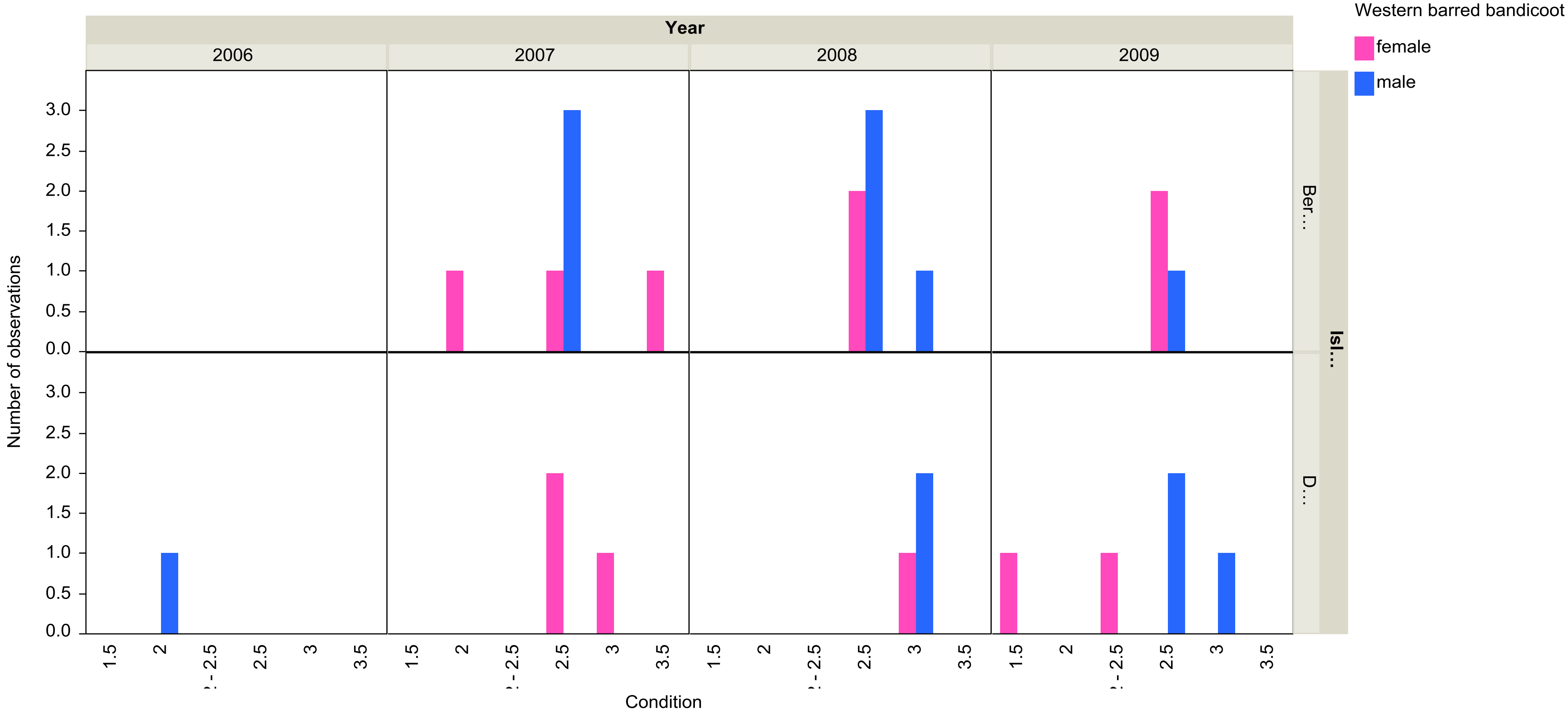


Figure 12 Frequency of observations for condition score, defined in Table 7, for burrowing bettong (above) and western barred bandicoot (below) trapped on Bernier and Dorre Island 2006-2009.

Table 13 Mean weight, long pes (foot) measurement and condition index (cube root of weight in grams divided by long pes in centimetres) by sex for mammals trapped on Bernier and Dorre Island 2006-2009.

Sex	Species	Year	Island	Weight (g)			Long pes (mm)			Condition index		
				Mean	**s.e.**	***n***	**Mean**	**s.e.**	***n***	**Mean**	**s.e.**	***n***
Female	Ash grey mouse	2006	Bernier	18.7	0.83	10	20.2	0.27	6	1.33	0.03	6
			Dorre	20.0		1	20.9		1	1.30		1
		2007	Bernier	19.5	0.50	2	21.5		1	1.24		1
		2008	Bernier	20.7	3.18	3						
		2009	Bernier	19.6	0.56	20	15.4	0.12	20	1.75	0.02	20
	Burrowing bettong	2006	Bernier	1,174.4	40.03	9	100.1	0.96	9	1.05	0.02	9
			Dorre	1,118.3	44.26	23	97.0	0.75	22	1.07	0.01	22
		2007	Bernier	1,252.5	52.50	2	98.2	0.90	2	1.10	0.03	2
			Dorre	1,281.8	33.29	19	98.3	0.57	17	1.11	0.01	17
		2008	Bernier	1,087.5	260.52	4	94.8	2.95	4	1.05	0.09	4
			Dorre	1,135.9	29.95	17	98.6	0.77	19	1.06	0.01	17
		2009	Bernier	1,275.4	52.24	13	102.0	0.97	10	1.06	0.02	10
			Dorre	1,165.6	30.68	27	100.1	0.55	28	1.05	0.01	27
	Shark Bay mouse	2006	Bernier	42.3	0.33	3	25.6	0.40	3	1.36	0.03	3
		2008	Bernier	36.5	2.40	4						
		2009	Bernier	44.3	2.99	7	20.4	0.25	7	1.73	0.04	7
	Western barred bandicoot	2006	Bernier	205.2	9.02	6	48.5	0.36	6	1.21	0.02	6
			Dorre	229.0	11.37	3	48.5	0.41	3	1.26	0.03	3
		2007	Bernier	205.0	0.00	2	47.2	0.09	3	1.25	0.00	2
			Dorre	215.0	35.30	4	49.2	0.63	4	1.20	0.06	4
		2008	Bernier	155.0	77.00	2	45.0	4.00	2	1.15	0.11	2
			Dorre	187.5	34.78	6	47.4	1.15	7	1.18	0.06	6
		2009	Bernier	210.0	4.56	4	47.5	0.35	4	1.25	0.02	4
			Dorre	173.8	36.76	4	47.5	1.89	4	1.14	0.06	4

Sex	Species	Year	Island	Weight (g)			Long pes (mm)			Condition index		
				Mean	**s.e.**	***n***	**Mean**	**s.e.**	***n***	**Mean**	**s.e.**	***n***
Male	Ash grey mouse	2006	Bernier	17.8	0.49	9	19.5	0.17	5	1.34	0.01	5
			Dorre	16.0	2.00	2	20.5	0.15	2	1.23	0.06	2
		2008	Bernier	12.0	0.58	3						
		2009	Bernier	15.5	0.43	6	15.7	0.26	6	1.59	0.03	6
	Burrowing bettong	2006	Bernier	1,099.3	32.94	14	99.8	0.59	14	1.03	0.01	14
			Dorre	1,103.0	45.21	22	97.6	0.57	23	1.05	0.02	22
		2007	Bernier	1,370.0		1	104.3		1	1.06		1
			Dorre	1,193.8	50.46	20	99.4	0.63	20	1.07	0.01	19
		2008	Bernier	1,065.0	325.00	2	108.0		1	1.03		1
			Dorre	1,142.5	43.32	16	100.3	0.72	15	1.04	0.02	15
		2009	Bernier	1,231.3	57.37	8	101.7	1.56	8	1.05	0.02	8
			Dorre	1,037.8	66.84	27	99.1	0.80	26	1.01	0.02	26
	Shark Bay mouse	2006	Bernier	49.0	2.19	5	26.5	0.42	5	1.38	0.02	5
		2007	Bernier	35.0		1	25.6		1	1.28		1
		2008	Bernier	34.8	6.86	4						
		2009	Bernier	45.4	1.17	7	20.7	0.10	7	1.72	0.02	7
	Western barred bandicoot	2006	Bernier	191.5	22.50	2	49.9	0.00	2	1.15	0.05	2
			Dorre	198.3	7.14	7	49.0	0.33	6	1.18	0.01	6
		2007	Bernier	166.7	51.02	3	46.9	3.03	3	1.13	0.08	3
			Dorre	190.0	10.00	2	48.4	1.45	2	1.19	0.01	2
		2008	Bernier	171.3	16.58	10	47.0	1.13	10	1.16	0.03	10
			Dorre	207.1	6.80	7	48.9	0.46	7	1.21	0.01	7
		2009	Bernier	204.2	7.46	6	48.9	0.49	6	1.20	0.01	6
			Dorre	215.5	7.82	4	51.1	1.02	4	1.17	0.02	4

The proportion of females captured with pouched young is shown in Table 14 and the measures for pouched young are summarised in Table 15. The number of observations was insufficient to detect patterns for western barred bandicoot and the proportions were highly variable for burrowing bettong between years. No pouch young were recorded for Bernier Island in 2006 (Table 14).

Table 14 Status of the pouch for female burrowing bettongs over 880g and western barred bandicoots over 175g trapped on Bernier and Dorre Island 2006-2009.

Species	Year	Island	Total females	Pouch			Proportion of females with pouch young
				Empty	Virginal	Young present	
Burrowing bettong	2006	Bernier	9	3			0%
		Dorre	20	2	5	2	10%
	2007	Bernier	2		1	1	50%
		Dorre	19	4		11	58%
	2008	Bernier	3			2	67%
		Dorre	17			15	88%
	2009	Bernier	13		1	8	62%
		Dorre	25	1	3	8	32%
Western barred bandicoot	2006	Bernier	6				0%
		Dorre	3			1	33%
	2007	Bernier	2			2	100%
		Dorre	3			2	67%
	2008	Bernier	1				0%
		Dorre	4			4	100%
	2009	Bernier	4			3	75%
		Dorre	3	1			0%

Table 15 Size of pouch young for female burrowing bettongs over 880g and western barred bandicoots over 175g.

Species	Year	Island	Crown-rump length (mm)			Head length (mm)		
			Mean	s.e.	*n*	Mean	s.e.	*n*
Burrowing bettong	2006	Bernier						
		Dorre	26.0	14.0	2			
	2007	Bernier				8.0		1
		Dorre	33.3	1.7	3	14.2	1.9	6
	2008	Bernier				7.0		1
		Dorre	20.9	5.2	7	9.4	2.5	5
	2009	Bernier	25.8	3.5	3			
		Dorre	20.8	6.5	6			

Species	Year	Island	Crown-rump length (mm)			Head length (mm)		
			Mean	**s.e.**	***n***	**Mean**	**s.e.**	***n***
Western barred bandicoot	2006	Bernier						
	2006	Dorre	18.0		1			
	2007	Bernier	10.0		1	7.0		1
	2007	Dorre				14.0		2
	2008	Bernier						
	2008	Dorre	18.3	4.4	3	25.0		1
	2009	Bernier	20.0		1	13.0	6	2
	2009	Dorre						

4 Discussion

4.1 Influence of rainfall on mammal populations

The analyses presented in this report demonstrated that mammal populations on Bernier and Dorre Island fluctuated widely between years and that the fluctuations were a function of rainfall. Short *et al.* (1997) suggested that rainfall in the 22 months prior to the survey period may influence mammal populations on these islands and this was confirmed in the present study, because time series analysis established that total annual rainfall two years prior to surveying was a strong predictor for total estimated populations of banded hare-wallaby, burrowing bettong, rufous hare-wallaby and western barred bandicoot.

Short *et al.* (1997) suggested that populations would be high following above average rainfall and low following below average rainfall. This was the case in the present study, because average annual rainfall was 226 mm, the mammal populations were highest two years after more than 300 mm total annual rainfall and lowest two years after less than 200 mm total annual rainfall.

There was one exception to this rainfall model however, because rainfall was relatively high in 2005, but two years later, in 2007, the mammal populations were the lowest recorded in this study. This was despite the combination of spotlighting surveys in April and September 2007, resulting in the largest survey effort of any year in the study. Total monthly rainfall was 141.2 mm in May 2005 and 135.2 mm in June 2005, which was 3-4 times the average rainfall for these months of 34.4 and 46.8 mm (n = 71) respectively. However, monthly rainfall was very low during the remainder of 2005, 2006 and during the first three months of 2007 (refer to Table 8). Field officers reported low leaf cover on plants and dead vegetation, as well as the presence of macropod carcasses during the April 2007 field trip. Thus, it appears that despite high winter rainfall in 2005, very low rainfall in 2006 and early 2007 led to very low population estimates in 2007 and 2008.

4.2 Long-term population assessment

In comparison with similar surveys undertaken in 1988/89 and 1991/1992 (Short *et al.* 1989; Short and Turner 1992; Short *et al.* 1997), the population estimates in this study were low for banded hare-wallaby, rufous hare-wallaby and western barred bandicoot and high for burrowing bettong. This comparison should be interpreted with caution because the earlier study was undertaken for only two years and there may be differences in the methods used and environmental conditions during the two studies. These may include factors like local rainfall, wind strength, temperature range, moon phase, transects surveyed, survey effort (length of transect surveyed) and observers. However, since the 1988/89 surveys were undertaken after below average rainfall and the 1991/1992 surveys were undertaken after average to above average rainfall (Short *et al.* 1989; Short and Turner 1992; Short *et al.* 1997), the two surveys in the previous study could be considered representative of population sizes at that time. If so, and assuming all other factors to be equal, using the mean population estimates for the two studies, it would appear that the wallaby populations have declined by around 60%, western barred bandicoot by about 35% and the burrowing bettong population increased by about 20% over the past 25 years.

Total annual rainfall is thought to be decreasing in this region (Holper 2011; Watterson *et al.* 2015) and given the strong link between rainfall and the mammal populations, this may be one reason for the lower wallaby and bandicoot populations recorded in this study compared with the earlier study. It was not clear from this study if long-term rainfall is declining at Carnarvon Airport, because only 70 years of records have been collected and while generalised linear modelling detected a declining trend, log linear regression did not. However, the forecasted populations continued to follow this declining trend. If annual rainfall is declining and climate extremes become more frequent and severe (as predicted (Holper 2011)), and they coincide with other stochastic events such as fire and disease, then the wallaby and bandicoot populations on these islands are likely to decline due to lower baseline populations from which to recover and lower peaks in maximum populations after years of high rainfall.

The burrowing bettong population was also strongly linked to rainfall in this study, yet its population apparently increased over the past 25 years and during the course of this study. This raises the question; why did the bettong population increase during the same period when populations of the other species declined? The burrowing bettong was the most commonly trapped mammal in this study and it is known to occupy a high proportion of cage trap nights and set-off Elliott traps (making the traps unavailable to other animals). This is likely to result in underestimation of the relative abundance estimates for other species. If it did become more habituated to traps over time, then the proportion of cage trap nights occupied by bettongs would also be expected to increase between 2006 and 2009. However, there was no solid evidence of this in this study and in addition, trap dominance would not account for the apparent increase in the bettong population over time during spotlighting surveys.

The bettong was the most abundant species observed in this study and the rate of increase in its total population size and relative abundance after the very low estimates in 2007 was higher than for the other species. This rapid recovery from the population 'crash' in 2007 suggests that the bettong is more resilient and adaptable than the other species. For example, while the other species were restricted to particular habitats, particularly in years of low relative abundance, the bettong was widely distributed across all habitats in all years, both in this and the previous study (Short and Turner 1993). The bettong may also have other ecological, behavioural, breeding and biological characteristics that make it less vulnerable to change than the other species, although limited data inhibits comparisons (McKenzie *et al.* 2007). Prior to its decline on the mainland, the burrowing bettong had a broader distribution than any other of the 'critical weight range' mammal species (Strahan 2000). These characteristics suggest that the bettong is adapted to a wide range of habitats, is resilient and that it can rapidly adapt to change. While this hypothesis was not directly tested in the present study, during 2007, when populations were the lowest recorded, the weight of the bettongs was significantly higher than other years. This suggests that the remaining bettongs may have been able to take advantage of the reduced competition and that they increased their body weight by feeding on the carcasses of other deceased mammals in that year (authors' obs.).

4.3 Planning for translocation

Mammal translocation programs aim to capture fauna at peak population size to maximise genetic diversity and minimise the impact on local populations. Thus, the ideal time to take animals for translocation would be two years after above average annual rainfall (in excess of 300 mm) at Carnarvon Airport, but after 6-12 months of below average monthly rainfall, when populations would be expected to be on the cusp of a rapid decline. However, suitability for taking animals for translocation would have to be verified on the ground late in the preceding year and / or early during the year planned for take.

At Carnarvon airport, years of the highest annual rainfall occurred at intervals of 11.7 years and other high rainfall events occurred at 3.7 and 2.3 year intervals. In this study, populations were forecast to be low in 2014, 2015 and 2016 due to low rainfall between 2012 and 2014. In addition, to the end of November 2015, 207.8 mm of rainfall had been recorded at Carnarvon airport and therefore, it is likely that 2017 will be a year of moderate to low mammal population sizes on the islands and unsuitable for taking animals for translocation by these criteria. In this study, monthly rainfall was significantly lower on Dorre Island than at Carnarvon airport. Thus, more accurate assessments of the most appropriate year and time of year to take animals would be improved by monitoring monthly rainfall on the Islands, rather than using rainfall data collected at Carnarvon Airport.

Populations of burrowing bettong, rufous hare-wallaby and western barred bandicoot were larger on Dorre than Bernier Island and thus, based on population size, they should be sourced from Dorre Island. The bandicoots on Bernier Island exhibit papillomatosis and carcinomatosis syndrome (Woolford *et al.* 2007; Woolford *et al.* 2008) and thus should preferably be sourced from Dorre Island as a healthier source population. Shark Bay mouse is only present on Bernier Island and ash grey mouse was only trapped on Dorre Island in 2006 and not thereafter, so Bernier Island would be the preferred source for the mouse species if they are needed for translocation programs. Further investigation is recommended to establish if ash grey mouse is extant on Dorre Island. This species showed a preference for dune habitats and the trapping effort was higher for dune habitats on Bernier than Dorre Island. It may also be that cover of dune habitat is higher on Bernier than Dorre Island in proximity to the trapping grids, accounting for the greater relative abundance on that island.

Capture rates for translocation are most likely to me maximised in dune habitats for ash grey mouse, sandplain heath for Shark Bay mouse and Travertine heath for western barred bandicoot. The burrowing bettong was captured in similar relative abundance across all habitats. The habitats occupied by the wallabies could not be established in this study because they were not captured in traps and the spotlighting transects were not stratified by habitat type. However, Short and Turner (1992) showed that they favoured sandplain heath and consolidated dune habitats.

5 Recommendations

- Broad scale analysis of the influence of rainfall showed annual rainfall was a predictor of mammal populations two years later. However, seasonal cycles were also evident and it is recommended that these are analysed to refine the model.
- Some rainfall data were collected for Dorre Island using tipping bucket rain gauges. These data should be analysed to investigate the effects of local rainfall on fauna populations.
- Rainfall differed significantly between Carnarvon and Dorre Island and it is therefore recommended that rain gauges be installed, maintained and monitored on Bernier and Dorre Island to monitor the effects of local rainfall on mammal populations.
- Some photo-point images of vegetation were taken for Bernier and Dorre Island and these should be analysed to determine the relative spatial and temporal changes in vegetation cover / quality.
- Ash grey mouse was recorded in low numbers during trapping on Dorre Island in 2006 but was not captured between 2007 and 2009. Further investigation is recommended to establish if this species is extant on Dorre Island.
- Some of the changes is mammal populations may have been due to factors like local rainfall, wind strength and temperature, moon phase, transects surveyed, survey effort (length of transect surveyed), observers, temporal and spatial variation in habitat type and condition. Where possible, the effects of these factors should be analysed.
- Analysis of habitat ‘preferences’ could be conducted by stratifying spotlight observation areas by habitat. The efficacy of this should be investigated and implemented if it is found to be feasible.
- The population sizes and relative abundance of fauna on the two islands may be a function of the relative land area of the islands and the relative cover of the ‘preferred’ habitats of each species. At present there are no accurate habitat maps in spatial format (GIS layers) in the Department of Parks and Wildlife corporate dataset. Accurate habitat maps should be prepared and the population sizes and relative abundance should be analysed relative to the cover of each habitat type on each island. It should be acknowledged, however, that habitat cover and quality may

change over time as a result of fire and variation in rainfall. If so, regular monitoring would be required to determine the relationship between vegetation cover and productivity on mammal population sizes.

- The small mammals, Ash Grey mouse and Shark Bay mouse, are not detected via spotlighting and thus trapping is the only means to monitor their relative abundance. However, the four larger mammals, which are likely to be the main species considered for translocation, can be monitored by spotlighting alone. Thus, while spotlighting and trapping data are complimentary, if resources are a severe constraint then spotlighting should be undertaken each year as a minimum. However, this would exclude biological information like weight, body condition and breeding status.
- Understanding of the drivers of small mammal populations and population forecasting is dependent on long-term, continuous datasets. Due to the high variability in population sizes, a minimum of 12 years of continuous monitoring is needed to meet the objectives of a population monitoring and forecasting program. Time series analyses and population forecasting, in particular, is hampered by missing values and thus it is essential that there are no gaps in years of monitoring.

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Appendix 1 Bernier and Dorre Islands – mammal monitoring protocols

Spotlighting

To be conducted a week either side of the May/June new moon.

Six nights on each island, three teams of two (one spotting, one navigating/pacing).

Dorre Island has 33.7 km of transects, but only 27.2 km available in rough weather.

Bernier Island has 32.4 km of transects, but only 29.6 km available in rough weather.

Each transect line is walked twice during a trip. The total transect length walked for both islands for the Autumn/Winter 2008 trip was 124km. This may vary, as nights are sometimes missed due to rough weather.

The transects are marked out by 6ft jarrah stakes which have reflective tape at the top. This is supplemented by reflective tape on bushes. The spacing between the markers is generally a few hundred metres, on high points, but is variable depending on terrain and vegetation.

Weather variables including temperature, humidity, wind speed and wind direction are taken at an end post on the east side of the island at the commencement of each night's work.

Each team of two has the spotter in front using a 30W globe in a 'LightForceSL170 Striker'. The team walks at a pace of up to 3km/hr, which can vary due to terrain and vegetation. Although initially we tried to maintain a constant speed of 3km/hr, we found that we were missing a number of animals (ie. heard them hopping away as we passed them), and reasoned that for the limited trip length we had for gathering data, it was important to see more animals to increase the data per effort. Therefore, the upper speed of 3km/hr should not be exceeded. Always walk at a speed which ensures you don't miss sighting animals as you walk past them. The spotter uses the spotlight beam to search for animals on the line (ie. directly in the path of transit) and out to the side, and to check the course by shining at the reflective markers. The beginning and end of each transect line is at the high tide mark, so that the beach is not excluded. The first marker post may be some distance from the sea; in some cases you will be able to walk down to the sea, but often not. You cannot pretend to cover this distance by shining your light down from the top of the cliff because even if you saw an animal down there, it would be a safety issue to climb down to it to pace it out. You should not be that close to the cliff edge anyway. This means that this particular habitat is excluded from the ends of many transects.

The line is defined as the most direct route from each transect post (or piece of reflective tape on a bush) and the next, all of these sections joining up from end post to end post. Each transect line has an average northing designated to it. You can use this northing to help keep on track and you should use the easting at the animal to determine perpendicular, but as the line as defined as the posts in the ground is always going to be the same relative to the actual grounds, this is what you should use primarily to stay on track, as these same posts can be followed from year to year. It is also okay to navigate by GPS. It is okay to have left the line while walking along, therefore the line may not be necessarily where you are walking, but should always be the GPS reference point. However, keep in mind that it is an assumption of distance sampling that you see all the animals that are on the line!

The sweep of the spotlight should be slow enough that the observer is able to see without straining their eyes, and have enough delay at each site to focus and look for animals. The observer should have a feel for the speed they need to sweep at to see any animals which might be there, while maximising the area covered. The spotlight has to be shone directly ahead often enough that any animals on the line will be seen. This is a critical assumption of distance sampling. The observer may leave the centreline temporarily, provided he or she records detection distances from the transect line, not from his or her current position. However, the centreline should not be left to such an extent that an animal on it may be missed. The light can shine out to a distance of about 30m, which will also pick up eyeshine beyond. Further out, it is too difficult to identify the species. Data from sightings at great distance is also likely to be truncated. Both people should be looking in the beam of the spotlight, but the navigator is observing opportunistically between keeping the course. If an animal is only seen because it is heard first, then the sighting is still included, otherwise animals close to the line will be underestimated.

The navigator walks behind, also looking in the beam of the spotlight. When an animal is spotted, the navigator takes a waypoint on the line where the spotter is, then goes to where the animal was when it was first sighted. The pacer/navigator takes a GPS waypoint at the animal sighting point. The distance will be calculated later by subtracting the northing of where the animal was from the northing the spotter was on at the time of sighting. It can alternatively be determined using a laser range finder.

There is a tendency for people to overestimate the number of animals which are on the line (ie. at 0 m perpendicular to it) by seeing the path of the line in front of them as more liberal than it really is. Therefore, animals "on the line" can tend to be overrepresented, when the animal could really be a couple of metres off it. In reality, it is difficult to pinpoint that 1 m-wide line between posts which may be hundreds of metres apart. Although it is a fundamental assumption of the methodology that you see all of the animals on the line, you should be objective enough that you don't pre-allocate sightings to this category before measuring the distances. If you think that an animal looks like it is on the line, make sure you verify it with your GPS northing.

Species of animal and time sighted is also recorded. The species searched for are: banded hare-wallabies, rufous hare-wallabies, boodies and western barred bandicoots. Ash grey and Shark Bay mice are also recorded in the same manner when seen, but are not targeted specifically.

The habitat type in which the animal was seen can also be recorded. Vegetation structure will fall into one of the following broad habitat types:

UD - Unconsolidated dune (blow-outs / shifting dune)
CD - Consolidated dune (sand with semi-open vegetation, incl. beach and coastal spinifex)
T - Travertine (limestone capping)
S - Spinifex (hummock grass)
O - Open bushes (low vegetation with scattered bushes)
J - Dense scrub (virtually impenetrable vegetation with a closed "canopy")

It is unlikely that many animals will be active on unconsolidated dunes, or be visible in dense scrub.

Spotlighting definitions

Detection function. This is the curve of the line that fits the detectability histogram (ie. frequency of sightings at increasing distances from the line), and should have a 'shoulder' near the line, ie. detection remains nearly certain at small distances from the line.

Detection probability. The probability that if an animal is there, it will be seen. This probability should equal 1 on the line, and gradually decrease out to distance.

End post. The first or last post of a transect, navigable to by GPS, but does not necessarily define the end of a transect, which is at the high water mark or top of cliff.

Line. The 1 m-wide path walked from one transect post or reflective tape on bush to the next, which join up across the island from edge to edge to form the transect. Each line is defined by an average constant northing, but in case of error inherent in GPSs (which may be a few metres) it is more accurate and consistent between years to follow the posts which are in the ground and therefore remain in the same place relative to the actual ground.

Pacer (Navigator). Person who walks behind, paces to animal and records data (may also help keep course via GPS/compass). Waypoints are recorded on this person's GPS.

Perpendicular distance. The distance (to the nearest metre) from the GPS line directly north or south to where an animal was first seen, as both paced in the field and calculated later with GIS.

Site. One of five places on each island where there is a block of four spotlighting transects. The 10 sites on the islands are listed below:

DS – Dorre South (fine weather only)
DW – Dorre Whitebeach
DM – Dorre Mid
DC – Dorre Castle
DQ – Dorre Quoin

BS – Bernier South (fine weather only)
BR – Bernier RedCliff
BM – Bernier Mid
BC – Bernier Cleftrock
BH – Bernier Hospital

Spotter. Person who walks in front and holds the spotlight. Not only does this person have the primary responsibility for sighting animals, but for keeping on course by walking in a direct line from one reflective marker to the next.

Transect. One of four lines per block/site, numbered 1 to 4 from north to south. The transect is to be described on the datasheet as the start post to end post, which are numbered 1 to 8 in a continuous manner starting with the most north-easterly. For example, if you were walking the second-most northerly transect of the Dorre Mid site, you would write it on the datasheet as "DM03 – DM04".
The numbering system for the start and end posts of the transect is represented below for the Dorre Mid site:

DM02 -- DM01

DM03 -- DM04

DM06 -- DM05

DM07 -- DM08

Trapping

Four nights on each island, two teams of two (one handling, one recording).

There are four permanent grid sites on each island. The sites are all accessible from the same beach landing (White Beach on Dorre Island and Red Cliff Bay on Bernier Island). Appendix – maps.
Each site on Dorre Island is located in a different vegetation type (Travertine(2), Scaviola(1), Dune(1) and Spinifex(2)). These match four of the original eight grid sites established by CALM in the 1990s. Bernier Island has one Thryptomene site and three dune sites. One Spinifex site was trialled here in 2006, but had relatively low captures. The disproportionate number of dune sites is to try and maximise the captures of Shark Bay mice and western barred bandicoots. Each site has 21 Elliott traps and 10 cage traps (requiring a total of 84 Elliott and 40 cage traps per island session). They are set out in three lines of seven Elliott traps, with collapsible cage traps set out in the following configuration:

eC	e	e	eC	e	e	eC
e	eC	eC	e	eC	eC	e
eC	e	e	eC	e	e	eC

The lines, and the traps within a line, are at a spacing of 40 metres. On grids DU1 and SC1 the lines are lettered A to C from east to west, and traps numbered 1 to 7 from north to south. On grids SP2 and TR2 the configuration is opposite to this. All Bernier Island grids follow the first configuration, except for DU2 which runs perpendicular east-west to DU1. All traps are baited with quick (or rolled) oats, smooth (or crunchy) Sanitarium peanut butter and sardines (in oil).

Shark Bay and ash grey mice are caught in Elliott traps.
Western barred bandicoots are caught in both cage and Elliott traps.
Boodies are caught in cage traps, but also set off Elliott traps.
Mice are ear clipped, boodies are ear notched and western barred bandicoots are PIT tagged.

Setting of traps

Cage traps are to be wrapped in a Hessian bag, with the edges underneath, so that they cannot blow off. As some of the disposable Hessians are not big enough to cover the back of the trap, it is preferable to put the back of the trap against a bush or other blockage. Hessians are impractical for Elliott traps on Bernier and Dorre, so it is important to put these under shade from the morning sun. Coopex is provided to discourage ants. Please take care to set the traps properly, otherwise the trap success results are meaningless! (With numbers of individuals too low for mark-recapture analysis, trap success rate is the only comparative measure of numbers across years.) This means making sure the bait is behind the treadle, the treadle is set light enough that it will be set off by the target species, and the door will swing freely shut. Traps are baited with a peanut butter/oat/sardine mix.

Hygiene

Boots are to be disinfected with VirkonS before arrival to, and between, the islands. All clothes worn on the islands must be clean, and either a separate set for each island or washed between the islands.

All traps are those specifically designated for Bernier and Dorre Islands only. Between each trip and each island, traps are to be scrubbed clean of any biological material, then soaked in VirkonS for a minimum of 10 minutes before being rinsed with fresh water and sun dried. The dilution for all VirkonS treatments, whether porous materials or equipment, is 1:100. In between trips, traps are to be stored in the islands sea container in sealed plastic bags, and not used at any other locations.

New Hessian bags are to be purchased for covering the cage traps for each trip, and not reused between islands. Used bags are to be discarded. Additionally, if a warty bandicoot is caught in a trap, that trap is to have its Hessian bag replaced, and be sprayed with F10SC before being reset. The trap can be identified with flagging tape to be singled out for extra disinfecting after the trip.

There is a specific set of animal handling bags for Bernier and Dorre Islands and these are to be autoclaved or washed in VirkonS between islands.

Upon catching a western barred bandicoot in a trap, the animal handler is to don a lab coat (specific for each island and washed in bleach after the trip). Hands are to be disinfected between bandicoots using F10SC hand gel. PIT tag implanters, calipers and any other measuring equipment coming into contact with the animal are to be sprayed with F10SC Veterinary Disinfectant at a dilution of 1:125, and allowed to dry. There can be a 30 minute contact time treatment with the disinfectant daily upon return to the boat. Unless your PIT tag scanner is waterproof, do not let it come into contact with the animals, otherwise it will also have to be disinfected.
The designated green bandicoot-handling bags are to be autoclaved or washed in VirkonS between each animal.

Other equipment used on the islands such as backpacks, trap boxes and straps, catching nets, plastic barrels etc. can also be disinfected using VirkonS, then rinsed.

For full veterinary protocols, refer to Lucy Woolford's "Protocol for working with *Perameles bougainville* on Bernier and Dore Islands", July 2007.

Appendix 2 Dates trapping was conducted for each grid

Year	Island	Grid	Date
2006	Bernier	Bernier Red Cliff Dune 1	29/08/2006
			30/08/2006
			31/08/2006
			1/09/2006
		Bernier Red Cliff Dune 2	29/08/2006
			30/08/2006
			31/08/2006
			1/09/2006
		Bernier Red Cliff Spinifex	29/08/2006
			30/08/2006
			31/08/2006
			1/09/2006
		Bernier Red Cliff Thryptomene	29/08/2006
			30/08/2006
			31/08/2006
			1/09/2006
	Dorre	Dorre White Beach Dune 1	23/08/2006
			24/08/2006
			25/08/2006
			26/08/2006
		Dorre White Beach Dune 2	23/08/2006
			24/08/2006
			25/08/2006
			26/08/2006
		Dorre White Beach Scaevola 1	23/08/2006
			24/08/2006
			25/08/2006
			26/08/2006
		Dorre White Beach Travertine 1	23/08/2006
			24/08/2006
			25/08/2006
			26/08/2006
2007	Bernier	Bernier Red Cliff Dune 1	13/09/2007
			14/09/2007
			15/09/2007
			16/09/2007
		Bernier Red Cliff Dune 2	13/09/2007
			14/09/2007
			15/09/2007
			16/09/2007
		Bernier Red Cliff Dunewest	13/09/2007
			14/09/2007
			15/09/2007
			16/09/2007
		Bernier Red Cliff Thryptomene	13/09/2007

Year	Island	Grid	Date
			14/09/2007
			15/09/2007
			16/09/2007
	Dorre	Dorre White Beach Dune 1	6/09/2007
			7/09/2007
			8/09/2007
			9/09/2007
		Dorre White Beach Scaevola 1	6/09/2007
			7/09/2007
			8/09/2007
			9/09/2007
		Dorre White Beach Spinifex 2	6/09/2007
			7/09/2007
			8/09/2007
			9/09/2007
		Dorre White Beach Travertine 2	6/09/2007
			7/09/2007
			8/09/2007
			9/09/2007
2008	Bernier	Bernier Red Cliff Dune 1	3/07/2008
			4/07/2008
			5/07/2008
		Bernier Red Cliff Dune 2	3/07/2008
			4/07/2008
			5/07/2008
		Bernier Red Cliff Dunewest	3/07/2008
			4/07/2008
			5/07/2008
		Bernier Red Cliff Thryptomene	3/07/2008
			4/07/2008
			5/07/2008
	Dorre	Dorre White Beach Dune 1	28/05/2008
			29/05/2008
			30/05/2008
			31/05/2008
		Dorre White Beach Scaevola 1	28/05/2008
			29/05/2008
			30/05/2008
			31/05/2008
		Dorre White Beach Spinifex 2	28/05/2008
			29/05/2008
			30/05/2008
			31/05/2008
		Dorre White Beach Travertine 2	28/05/2008
			29/05/2008
			30/05/2008
			31/05/2008
2009	Bernier	Bernier Red Cliff Dune 1	22/08/2009
			23/08/2009

Year	Island	Grid	Date
			24/08/2009
		Bernier Red Cliff Dune 2	22/08/2009
			23/08/2009
			24/08/2009
		Bernier Red Cliff Dunewest	22/08/2009
			23/08/2009
			24/08/2009
		Bernier Red Cliff Thryptomene	22/08/2009
			23/08/2009
			24/08/2009
	Dorre	Dorre White Beach Dune 1	14/08/2009
			15/08/2009
			16/08/2009
			17/08/2009
		Dorre White Beach Scaevola 1	14/08/2009
			15/08/2009
			16/08/2009
			17/08/2009
		Dorre White Beach Spinifex 2	14/08/2009
			15/08/2009
			16/08/2009
			17/08/2009
		Dorre White Beach Travertine 2	14/08/2009
			15/08/2009
			16/08/2009
			17/08/2009