THE FLUCTUATING ABUNDANCE OF ENDANGERED MAMMALS ON BERNIER AND DORRE ISLANDS, WESTERN AUSTRALIA - CONSERVATION IMPLICATIONS

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Bernier and Dorre Islands in Shark Bay, Western Australia, provide refuge to populations of five species of threatened mammals that are extinct on the mainland other than as reintroduced or captive populations. This paper provides estimates of changes in population size of four species over three years from 1988-9 to 1991-2. The period from November 1986 to March 1989 was one of below average rainfall intensifying to severe drought on the islands; the period from mid 1989 to 1992 was one of average to above-average rainfall. Three of the four species (*L. hirsutus*, *B. lesueur* and *P. bougainville*) showed substantial and significant increases and one species (*L. fasciatus*) showed a small but non-significant increase in abundance. Combined estimates of minimum population size for both islands in 1991-2 vary from *c.* 4,000 *P. bougainville* to *c.* 10,000 *L. fasciatus*. If these densities are regarded as typical of average rainfall years then the drought in the late 1980s reduced populations of *P. bougainville* by up to 75%, *B. lesueur* by 65%, and *L. hirsutus* by up to 60%. Combined estimates for the four species give densities for the community of medium-sized mammals which vary between 160 km^{-2} in drought and 260 km^{-2} in years of average to above average rainfall.

Key words: threatened mammals, drought, island, extinction, line transect

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FIVE species of endangered mammals occur on Bernier and Dorre Islands: the banded and rufous hare-wallabies *Lagostrophus fasciatus* and *Lagorchestes hirsutus*, the burrowing bettong *Bettongia lesueur*, the western barred bandicoot *Perameles bougainville*, and the Shark Bay mouse *Pseudomys fieldi*. All have suffered range contractions of > 99% in the two hundred years since European settlement. Secure populations now only occur on between one (*P. fieldi*) and three (*B. lesueur*) off-shore islands. All are classified as rare (Thornback and Jenkins 1982) and endangered (ANZECC 1991). Recently, there have been attempts to re-establish populations in the Tanami Desert (*L. hirsutus*), on Heirisson Prong on the southern shores of mainland Shark Bay (*B. lesueur*, *P. fieldi* and *P. bougainville*), in the Gibson Desert (*B. lesueur*), and on Doole Island in Exmouth Gulf (*P. fieldi*) as part of planned recoveries for these species (Christensen and Burrows 1994, Gibson, Johnson, Langford, Cole, Clarke, and Willowra Community 1994, Short, Turner, Parker, and Twiss 1994, Morris, Speldewinde, and Orell 1995; Short 1995, Richards and Short 1997).

Surveys of Dorre Island in 1988 and Bernier Island in 1989 established broad patterns of distribution and absolute estimates of population size for *L. fasciatus*, *L. hirsutus*, *P. bougainville* and *B. lesueur* (Short, Turner, and Majors 1989, Short and Turner 1992, 1993). They indicated combined minimum populations for the two islands of *c.* 7 700 *L. fasciatus*, 4,300 *L. hirsutus*, 2,200 *P. bougainville*, and 1 600 *B. lesueur*. Population size of mammals on these islands are likely to fluctuate greatly due to high variability of rainfall (Short and Turner 1992). The 1988 and 1989 surveys were conducted during the third worst drought in the 89 year rainfall record of the area, so population sizes may well have been at a low level. A major die-off of wallabies in a drought year on the islands was reported by Shortridge (1909).

We repeated these surveys in 1991 and 1992 after a 2-3 year period of average to above-average rainfall. This paper reports the changes in abundance of mammal species between surveys, and by comparing years of above and below average rainfall, gives an estimate of the types of fluctuations in population numbers likely to occur due to variation in weather.

MATERIALS AND METHODS

Study area

Bernier and Dorre Islands lie 60 km off the coast of Western Australia and form the outer margin of Shark Bay. They are uninhabited islands of 44 and 53 km^2 respectively. Both are nature reserves and have been free of exotic mammals since the elimination of goats from Bernier Island in 1984. Sandplain and sand dune habitats are covered with a vegetation of heath (with dominant species of *Scaevola crassifolia, Thryptomene baeckeacea,* or *Melaleuca cardiophylla*), grassland of *Triodia plurinervata*, or low scrub (often dominated by *Pileanthus limacis*, *Diplolaena dampieri*, *Pimelia microcephala*, *Acacia rostellifera*, or *A. coriacea*). Their history, climate, landform, and vegetation have been described in detail in Ride, Mees, Douglas, Royce, and Tyndale-Biscoe (1962) and Short and Turner (1992).

The islands have a rainfall of *c.* 250 mm that falls mainly in winter (Table 1). An average of 70% of rain falls in the months May-August. Fig. 1 shows variation of monthly rainfall for the period 1986-1992 from the long-term average monthly rainfall at Denham (120 km south south-east of Dorre Island). Rainfall was well below average from May 1987 to March 1989 during the period of the first surveys. Rainfall in the period leading up to the second surveys was average to above average. The timing of the four surveys relative to variations from mean rainfall are indicated by arrows at the top of Fig. 1.

Survey methods and analysis

Mammals were surveyed by spotlighting 28 east-west lines across each island from coast to coast (see Fig. 2 of Short and Turner 1992). Survey lines were in groups of four lines, each 0.5 km apart. Groups were distributed at random. Method of survey and survey lines are described in Short and Turner (1992, 1993). Dorre Island was surveyed in October 1988 and resurveyed in September 1991; Bernier Island was surveyed in July/August 1989 and resurveyed in July/August 1992. Surveys for each island were three years apart, and all were conducted at new moon. Data were converted to animals per km, transformed (log (x + 1)), and analysed by three-way analysis of variance.

Data from each island were partitioned into two strata based on high and low density areas of *L. fasciatus* reported by Short and Turner (1992) in an attempt to reduce variance of estimates of abundance. Bernier Island was split at a point 11 km south of the northern tip into areas of 28.7 and 15.3 km^2; Dorre Island at a point 22 km south of the northern tip into areas of 42.3 and 10.7 km^2. The northern stratum on Bernier Island was characterised by areas of dense shrubland, particularly in the far north; the southern stratum by sandplains with low heath of *Thryptomene micrantha* and the grass *Eulalia fulva* and unconsolidated dunes with a sparse cover of *Spinifex longifolius*. The predominant habitat in the northern stratum on Dorre Island was sandplain with *Triodia plurinervata*; the predominant habitats in the south were heath of *Scaevola crassifolia* and extensive areas of travertine that were sparsely vegetated with clumps of shrubs such as *Ficus platypoda*, *Diplolaena dampiera* and *Acacia coriacea*.

Absolute estimates were derived using data on angle of sighting, radial distance to observed animals and average cluster size. Data were analysed using the program DISTANCE (Buckland, Anderson, Burnham, and Laake 1993; Laake, Buckland, Anderson, and Burnham 1994). Data were analysed in ungrouped format. Histograms of detection probability versus perpendicular distance from line of travel using a variety of cut points were examined to ensure data were consistent with assumption of maximum sightability close to line of travel. The 5% of sightings furthest from line were omitted from analysis. Models were chosen on basis of minimum Akaike's Information Criterion and close conformity of y-intercepts of modelled line and histogram.

RESULTS

Table 2 provides estimates of relative and absolute population size on Bernier and Dorre Islands. Relative indices were number of animals sighted per kilometre of spotlight survey; absolute population sizes were estimated by analysis of line transect data.

L. fasciatus were the most abundant of the medium-sized mammals with a minimum population size of *c.* 10 000. The estimate of numbers for *P. bougainville*, in particular, is likely to be a substantial underestimate because of the violation of the primary assumption of line transect methodology - that all animals on the line of survey are sighted by

Month	J	F	M	A	M	J	J	A	S	O	N	D
Rainfall	8	15	13	15	38	57	40	23	8	7	3	1

Table 1. Mean monthly rainfall (mm) at Denham for the period 1893-1996. Denham is approximately 120 km south south-east of Dorre Island. Average annual rainfall on Bernier Island for seven years of records was 252 mm (Short and Turner 1992).

Species	No. of sightings	No. per km	Model	ESW (m)	No. per km^2	Minimum population	% CV
Lagostrophus fasciatus	144	1.45	Fourier	7.2	100.0	9 700	13.8
Lagorchestes hirsutus	111	1.12	Fourier	7.4	68.5	6 700	20.3
Bettongia lesueur	107	1.08	Haz/poly	10.9	44.1	4 300	19.5
Perameles bougainville	45	0.45	Haz/poly	4.5	45.5	4 400	31.4

Table 2. Relative and absolute abundance of hare-wallabies, bettongs, and bandicoots on Bernier and Dorre Islands in 1991-2. Sighting rate (no. per km) are raw values from spotlight surveys. Densities (no. per km^2) were estimated by analysis of line transect data. Data from both islands are pooled. The lengths of lines surveyed on Bernier and Dorre Islands were 48.3 and 51.1 km respectively. ESW - effective strip width; Haz/poly - hazard rate key function with polynomial adjustment (Buckland et al 1993).

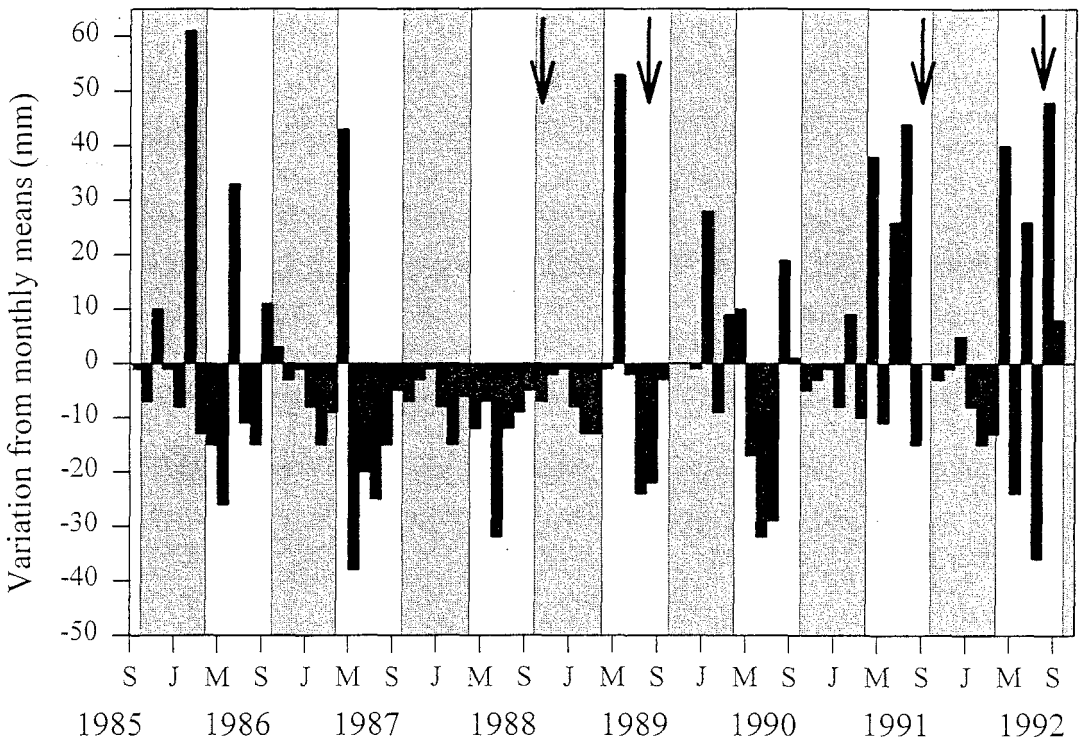

Fig. 1. Variation in rainfall (mm) from long-term monthly average rainfall at Denham, 120 km south south-east of Dorre Island showing the extended period from November 1986 to May 1989 when rainfall was below average. Arrows at the top of figure indicate the time of the four surveys discussed in this paper. Stippled and clear bars indicate summer (Oct - March) and winter (April - Sept) respectively.

the observer. Bandicoots are very cryptic, even in the relatively open habitat of Bernier and Dorre Islands.

If the abundance of endangered mammals on Bernier and Dorre Islands in 1991 and 1992 is regarded as typical of 'average' rainfall years then the 1988 and 1989 surveys measured the extent of decline resulting from drought. All populations on both islands were at lower numbers in 1988 and 1989 (Table 3), and the results differed significantly between years for *P. bougainville*, *B. lesueur* and *L. hirsutus* (Table 4). The greatest difference between surveys (Table 3) was that for *P. bougainville* on Bernier Island: the relative index of abundance for 1989 (in drought) being just 25% of that recorded for 1992 (a year where rainfall was slightly above average). The comparable result for Dorre Island was 58%. The index of bettong density on both islands in 1988 and 1989 was *c.* 35% of that in 1991 and 1992. The decline of *L. hirsutus* varied between islands. The index of abundance of *L. hirsutus* in 1988 was 40% of that three years later on Dorre Island; and 75% on Bernier Island.

'Year' was the only main effect to have a significant impact on indices of density for *P. bougainville*, *B. lesueur* and *L. hirsutus* (Table 4). Island, position on island, and all interactions were not significant.

L. fasciatus showed least change between surveys. The density index on Bernier in 1989 was 60% of that three years later; that on Dorre in 1988 was 92% of that in 1991. In contrast to the results for the other three species, *L. fasciatus* showed no significant change in abundance between surveys. 'Position on island' had a significant effect in influencing density indices but was not consistent between islands (Table 3). *L. fasciatus* were at maximum abundance in the north of Bernier Island in dense scrub of *Abutilon exonemum*, *Scaevola crassifolia*, *Heterodendron oleifolium*, *Acacia coriacea*, and *A. ligulata* and in the south of Dorre Island where dense clumps of *Ficus platypoda*, *Diplolaena dampieri*, *Heterodendron oleifolium*, *A. coriacea*, and *Sarcostemma australe* grow on and amongst extensive surface rock.

There were no significant difference in numbers of *L. hirsutus* between Bernier and Dorre Islands in either survey, despite there being considerably more habitat of *Triodia* grasslands on the latter island (Table 4).

Survey lines	**Transect length (km)**	**Species**							
		L. fasciatus		*L. hirsutus*		*B. lesueur*		*P. bougainville*	
Dorre Island		1988	1991	1988	1991	1988	1991	1988	1991
1.5 - 3.0	2.7	0.37	0.37	0.00	2.59	0.37	0.74	0.00	0.00
6.5 - 8.0	13.8	1.25	0.95	0.59	0.66	0.37	0.37	0.22	0.37
9.5 - 11.0	11.9	0.43	0.58	0.27	0.42	0.00	1.25	0.08	0.50
14.5 - 16.0	7.5	0.53	0.13	0.27	1.59	0.27	0.93	0.53	0.40
19.5 - 21.0	4.7	0.43	0.43	0.43	1.92	0.85	2.34	0.21	0.85
22.5 - 24.0	4.0	1.22	1.71	0.98	0.73	0.73	0.49	0.24	0.00
26.5 - 28.0	6.6	2.22	1.93	0.15	0.30	0.30	1.63	0.30	0.30
Weighted Mean		0.86	0.94	0.37	0.92	0.37	1.04	0.25	0.43
Bernier Island		1989	1992	1989	1992	1989	1992	1989	1992
3.0 - 4.5	8.2	3.05	4.15	0.24	0.12	0.61	1.46	0.00	0.61
6.0 - 7.5	9.5	1.57	3.25	0.00	1.36	0.31	0.21	0.00	0.63
9.0 - 10.5	8.9	0.76	3.63	1.36	1.06	0.30	1.51	0.30	0.00
12.0 - 13.5	6.4	2.05	1.10	0.32	1.89	0.47	2.21	0.00	1.10
17.0 - 18.5	4.9	0.41	0.61	2.04	1.84	0.41	0.82	0.00	0.41
19.0 - 20.5	7.3	0.00	0.14	3.13	2.99	0.41	1.22	0.54	0.41
23.0 - 24.5	3.2	0.00	0.00	1.29	0.32	0.00	0.00	0.00	0.00
Weighted Mean		1.26	2.07	0.99	1.32	0.39	1.12	0.12	0.48

Table 3. Density indices (number sighted per kilometre) of *L. fasciatus*, *L. hirsutus*, *B. lesueur* and *P. bougainville* for surveys conducted on Bernier and Dorre Islands in 1988-9 and 1991-2. Data comes from seven groups of four east-west survey lines across each island. Survey lines are identified by their distance south of the northern tip of each island.

Source of Variation	*L. fasciatus*	*L. hirsutus*	*B. lesueur*	*P. bougainville*
Island (A)	3.5	2.7	0.1	0.0
Position on island (B)	5.9***	3.7	0.9	0.7
Year (C)	1.2	7.2**	20.2***	4.7*
AB	19.8***	1.8	1.6	0.8
BC	2.0	1.7	1.5	0.7
AC	2.4	2.1	0.4	1.9
ABC	0.8	1.5	0.9	2.7

Table 4. Results of analysis of variance of sighting rate of *L. fasciatus*, *L. hirsutus*, *B. lesueur*, and *P. bougainville*. Sightings (animals km^{-1}) were transformed to x' = log(x+1). Values are F ratios. Significance values are indicated by * ($P < 0.05$), ** ($P < 0.01$), and *** ($P < 0.001$).

	Bernier - north	Bernier - south	Dorre - north	Dorre - south
Lagostrophus fasciatus	231.8 (6660)	35.3 (540)	40.6 (1710)	112.6 (1190)
Lagorchestes hirsutus	48.0 (1380)	112.2 (1710)	69.5 (2940)	23.2 (240)
Bettongia lesueur	41.2 (1180)	58.1 (890)	43.4 (1830)	37.1 (390)
Perameles bougainville	41.5 (1190)	55.8 (1850)	52.3 (2210)	12.7 (130)

Table 5. The pattern of abundance of medium-sized mammals within and between Bernier and Dorre Islands in 1991-2. Data are estimates of density of animals per km^2 and total number of animals (bracketed) in two strata on each island. Strata are based on survey results of Short and Turner (1992) and described in text.

The bulk of the *L. fasciatus* population (> 6,000) were concentrated in the northern half of Bernier Island (Table 5). There was a strong inverse relationship in distribution and abundance between the two hare-wallaby species. *B. lesueur* were relatively evenly spread across all strata. *P. bougainville* appeared to be at low densities in the southern stratum of Dorre.

Table 2 suggests a combined density for the community of medium-sized mammals of about 260 per km^2 (25 100 in 97 km^2) after a run of good seasons. This compares to a combined density of about 160 per km^2 recorded during drought in 1988-9 (Short et al 1989). Both values are estimates from the latter part of the annual breeding season.

DISCUSSION

A comparison of 1988 and 1989 with the 1991 and 1992 survey results indicate that populations of at least three species of endangered mammal on Bernier and Dorre Islands can fluctuate greatly in response to variations in rainfall from year to year. *B. lesueur*, *P. bougainville*, and *L. hirsutus* increased substantially in numbers in response to several years of average to above-average rainfall following years of below-average rainfall and drought in 1986-89. Monthly rainfall was below average for each of the 22 months prior to May 1989. The cumulative impact of this drought is presumed to have caused the low densities of animals.

Our estimates from Dorre of the likely level to which mammal species may decline in drought may be underestimates because the maximum impact of that drought was probably in the summer of 1988-89 and early autumn 1989, that is after our 1988 survey. Robertson (1986) recorded the death of > 14,000 red and grey kangaroos (*Macropus rufus* and *M. fuliginosus*) in the 442 km^2 Kinchega National Park in a drought which lasted for more than 12 months. Most deaths occurred within a three month period over the height of summer 1982-3.

Shortridge (1909: p 818) commented on the deaths of both species of hare-wallabies on Bernier Island during his visit in June 1906 "during a very dry season". Animals "were thin and apparently in a very unhealthy condition while numbers were lying about dead". Rainfall was below average for 12 months prior to his survey compared to the 22 month period prior to May 1989. However, the cumulative rainfall deficit from average monthly rainfall was 153 mm in 1905-6 (for the 12 months prior to June 1906) compared to 115 mm for the 12 months prior to the October 1988 survey and 108 mm for the 12 months prior to the breaking of the drought in May 1989. Hence the drought that caused the die-off of hare-wallabies in 1906, while of considerably shorter duration than that in 1986-9, was more intense. The presence of sheep on the island at that

time (Shortridge 1909) may well have exacerbated its effect.

The apparent resilience of *L. fasciatus* in the 1986-9 drought may be due to two factors. The apparent greater tendency of *L. fasciatus* to feed by browsing compared to *L. hirsutus* (Short and Turner 1992; Lundie-Jenkins, Phillips, and Jarman 1993) may give them an advantage in a protracted drought, as shrubs probably form a more reliable food supply during dry times. In addition, the scarcity of dense thickets of vegetation in many parts of the islands may limit the numbers of this species. Groups of *L. fasciatus* shelter under dense thickets and run from one end to another or from thicket to thicket in response to disturbance. Thus dense thickets may be an important resource. The relative abundance of such thickets is probably a function of recent fire history (areas of extensive shrub development are in areas with no recent history of burning).

The densities of *L. hirsutus* were not greater on Dorre Island than on Bernier Island in either survey despite the extensive areas of *Triodia plurinervata* grassland present on Dorre but not on Bernier. This result suggests a habitat preference based more on structure (relatively open habitat with low dense shrubs or hummocks for shelter) than on a particular vegetation type such as *Triodia* grassland. This is consistent with John Gilbert's description of the species' habitat in south-western Australia ("low thick scrub about two feet high" adjacent to open country: Gould (1844, 1863) and Lundie-Jenkins' (1993) description of its habitat requirements in *Triodia* (a mosaic of different regenerative stages created by fire). This suggests that choice of sites for further reintroductions of the mainland subspecies need not be confined to *Triodia* habitat as has occurred to date (Gibson et al 1994). This may allow a wider choice of sites within the constraint that there is close interspersion of open feeding areas and dense shelter to avoid predation.

Bernier and Dorre Islands conserve an unusually rich suite of species which include three macropods of similar size, including two species of hare-wallabies. Serventy (1951) and Main (1961) have speculated on the possibility of competitive exclusion between macropod species on islands off the Western Australian coast leading to the extinction of one of a pair of species. Main (1961) noted that Bernier and Dorre Islands were the smallest islands off the Western Australian coast on which more than one species of macropod had survived. The coexistence of the two species of hare-wallaby on Bernier and Dorre Islands may be due partly to their differing habitat preferences and diet (Short and Turner 1992). However this study indicates another reason which may promote coexistence. The dynamics of the two species of hare-wallaby are decoupled. Highs and lows of abundance do not necessarily occur in synchrony.

L. fasciatus had a former range predominantly within the winter rainfall areas of Australia, while *L. hirsutus* had a former range that included predominantly summer rainfall areas. Rainfall on Bernier and Dorre Islands is strongly winter dominant but receives occasional heavy rainfall from summer cyclones. A good to average winter rainfall year (> 150 mm falling from April to September) occurs on Bernier and Dorre in 65% of years. By contrast, a year of good summer rain (> 72 mm falling from October to March) occurs in only one year in five (20.4% of years). Similarly, drought may result from shortfalls of rainfall that vary in intensity by season. For example, the drought of 1986-89 combined significant shortfalls of winter rainfall (68% of long-term average winter rainfall in 1987; 58% in 1988) with even more intense shortfalls of summer rainfall (30% of long-term average summer rainfall in 1986-7; 15% in 1987-8). These substantial shortfalls of summer rainfall may have had greatest impact on *L. hirsutus* - the species whose former range coincides with areas of predominantly summer rainfall.

This suggests an environment on average more favourable to species attuned to winter rainfall, but with frequent if unpredictable winter droughts and heavy summer rainfall that may favour species attuned to summer rainfall. This variable mix of seasonal rainfall may serve to ameliorate competition between similar species and increase the probability of their long-term coexistence.

The community of four species of medium-sized mammals on Bernier and Dorre Islands had approximate total densities ranging between 160 and 260 per km^2 (1.6-2.6 per ha), numbers varying between drought years and years of average to above-average rainfall. This compares to estimates of the density of rabbits (*Oryctolagus cuniculus*) from 27 sites on the Australian mainland (post-myxomatosis but in the presence of predators) which range from 2-97 per hectare with an average of three per hectare (Wood, Leigh, and Foran 1987). Rabbits are now the most abundant medium-sized mammalian herbivore in many arid and semi-arid ecosystems where hare-wallabies, bettongs and bandicoots would formerly have occurred. Rabbit densities on the mainland adjacent to Bernier and Dorre Island (and in similar habitats to that occurring on the islands) were estimated at 300 - 400 per km^2 (3-4 per ha) in February 1991 (Short and Turner unpubl. data) using counts of active

entrances (Parer 1982, Parer and Wood 1986). At this time, rabbits were near the lowest density recorded in 6 years of observation (Short, Risbey, Turner and Carnamah 1997), rabbit numbers rising to five and ten times this density in the presence of predator control. The high densities of rabbits in such ecosystems begs the question of whether the former niches of the native species have been usurped. This question is of considerable importance if reconstruction of the former communities is considered.

Conservation implications

Major mortality of kangaroos in the arid zone associated with drought has been documented by Caughley, Grigg and Smith (1985), Robertson (1986), and Caughley, Shepherd and Short (1987). Declines of > 40% of total population were measured in a moderate drought in the sheep pastoral zone of eastern Australia. This compares to declines which may have been as high as 75% on Bernier and Dorre Islands. Major peaks and troughs in herbivore numbers may be intrinsic to such systems which combine a highly variable climate with the absence of regulation of herbivore numbers by predators. Such a system operating on the last population or populations of a species, where populations are comparatively small, and where there is no chance of natural recolonisation following local extinction, provides at least some cause for concern for managers charged with custodial care.

Is such variation part of the normal cut and thrust of life in the arid zone or cause for concern and action? One view is that extremes of environmental variation "are often the final insult that drives a small, but otherwise healthy, population extinct" (Lacy and Clark 1990). Several theoretical studies have suggested that increasing the variance in a population's rate of increase relative to its rate of increase leads to a decrease in probability of persistence of the population (Belovsky 1987; Goodman 1987; Lande 1993; Caughley 1994). *P. bougainville*, *B. lesueur*, and *L. hirsutus* on Bernier and Dorre Islands would appear to have a high variance in rate of increase, driven by erratic cycles of drought and plenty. However, balanced against this theory is the persistence of these mammal communities on Bernier and Dorre Islands for the past 8 000 years since their isolation by rising sea levels. This comparatively long-term survival suggests that the community has a reasonable degree of resilience.

Management to decrease risk of extinction of these species could include:

1) Establishment of other populations, particularly in different regions where climatic fluctuations may be out of synchrony.

2) Avoiding additional major stressors on populations, particular at times of environmental stress. A major change in fire frequency or introduction of alien herbivores may be such stressors.

3) Monitoring of species during periods of environmental stress (unusual sequence of weather, fire).

Any need for custodial management needs to be balanced against the need for an ecosystem that is free of intrusive management from humans (Shepherd and Caughley 1987). Such ecosystems are becoming increasingly rare.

Periods of environmental stress would include years in the lower 5 percentile of the rainfall record: winter (April - September) rainfall < 60 mm cf. median of 172 mm; summer (October - March) rainfall < 4 mm cf. to median of 31 mm; extended periods of below average rainfall (> 20 months); accumulated rainfall deficit of > 120 mm in a 12 month period; lack of early rain coinciding with late arrival of winter rains (< 50 mm of rain falling from January to end of June); and long periods without shift from winter to summer rainfall (e.g. > 5 successive years with less than median summer rainfall of 31 mm) to limit any competitive advantage of one hare-wallaby over the other.

Extensive fire is likely to alter the relative ratios of mammal species on the island, particularly if it changes substantial areas from shrubland to grassland. This may in part depend on survival rates of browsing mammals during and immediately post-fire. If high densities of mammals survive then they may act to suppress regeneration of many shrub species. This process has been suggested to explain the loss of *Acacia* shrubland on Rottnest Island (Storr 1963, Pen and Green 1983). Browsing by a medium-sized macropod (quokka *Setonix brachyurus*) post-fire has largely eliminated the *Acacia* community from the island and this situation has persisted for the past 40 years. The loss of shrub thickets on Bernier and Dorre Islands is likely to disadvantage *L. fasciatus*.

The species of rare and endangered mammals on Bernier and Dorre Islands are represented by few populations. They are extinct as wild populations on mainland Australia, and, at least one species *B. lesueur*, has lost several island populations. The results of our surveys indicate that the remaining populations are subjected to major fluctuations in numbers due to a highly variable climate. However

we judge the risk of extinction of an island population due to such fluctuations to be small compared to the risks posed by colonisation of the islands by exotic mammals.

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