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DEPARTMENT OF ENVIRONMENT AND CONSERVATION
SCIENCE DIVISION

TELEPHONE: (08) 9334 0333
TTY: (08) 9334 0456

ADDRESS:
17 DICK PERRY AVENUE
TECHNOLOGY PARK, WESTERN PRECINCT
KENSINGTON WA 6151

POSTAL:
LOCKED BAG 104
BENTLEY DELIVERY CENTRE
WESTERN AUSTRALIA 6983

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Conserving the Black-flanked Rock-Wallaby (*Petrogale lateralis lateralis*) through Tourism: Development of a habitat ranking system for translocated animals and the need for on-going management

MICHELLE DAVIES[1], DAVID NEWSOME[1*], DARYL MONCRIEFF[2] AND AMANDA SMITH[1]

[1] School of Environmental Science, Murdoch University, South Street, Murdoch, Western Australia, 6150, Australia

[2] Department of Environment and Conservation, Kimberley Region, Western Precinct, Dick Perry Avenue, Kensington, Western Australia, 6151, Australia

* Corresponding author

ABSTRACT

The Black-flanked Rock-Wallaby (*Petrogale lateralis lateralis*) was once widespread throughout Western Australia but due to a combination of factors its range has declined significantly and its present distribution is limited to a few widely scattered isolated populations. It is gazetted as vulnerable under Western Australian legislation and requires active management to ensure its survival. Translocating species to areas of suitable habitat, when coupled with predator control, is an effective method of expanding species distribution as well as increasing population numbers.

This study investigated the requirements for both effective translocation and site assessment in relation to the development of tourism based on black-flanked rock-wallabies. A species-specific habitat ranking system was devised to identify suitable areas for translocated populations. This was followed by an assessment of the tourism potential of the identified sites. When both sets of results were added together potential sites were identified that could satisfy both habitat and tourism requirements. Avon Valley National Park and Billyacatting Nature Reserve were found to be the most suitable sites for translocating rock-wallabies on the basis of suitable habitat and the potential for subsequent development of wildlife tourism.

Viable breeding population size, feral predator control, competing introduced herbivore control and fire management are all identified as aspects that require management action. Tourism management requires stakeholder liaison, possible zoning and separation strategies and appropriate waste disposal at tourism sites. Public contact with translocated animals requires an educative approach that avoids any feeding of wildlife. Relatively close contact between visitors and wildlife may be achieved through a process of habituation. Such strategies should however be subject to review.

Key words: Black-flanked Rock-Wallaby, translocations, habitat ranking, tourism potential, wildlife management

INTRODUCTION

Many species of Australian fauna are threatened with extinction (Ride and Wilson, 1982; Recher, 1990), with the southern arid zone and the Western Australian wheatbelt (agricultural area of Western Australia) seriously affected (Short and Smith, 1994). To aid conservation, Australia requires income to fund environmental protection agencies and national park services (Figgis, 1993). Ecotourism is perceived to be an environmentally benign industry that can generate these much-needed funds (Figgis, 1993). Translocation of a species and the subsequent development of wildlife tourism can assist conservation efforts. Wildlife tourism research is urgently needed in Australia if wildlife tourism is to provide benefits for the much-needed conservation of Australian native wildlife. Wildlife tourism can thus be an instrument of conservation and can benefit both wildlife and local communities. Benefits include education of visitors, economic benefits to local communities and the development of an economic incentive to protect the wildlife on which the tourism is based (Higginbottom *et al.* 2001a).

In the Macropodidae and Potoroidae families (kangaroos, wallabies and rat-kangaroos) the majority of the smaller species have suffered range reduction in areas where humans have settled and eliminated suitable habitat and where introduced species have established (Ride and Wilson, 1982; Morton, 1990). The Black-flanked Rock-Wallaby (*Petrogale lateralis lateralis*) is one such species that has shown considerable decline during the 20th century (Pearson and Kinnear, 1997) and is the focus of this study. The reasons for the decline of the Black-flanked Rock-Wallaby are varied but include predation by foxes and feral cats, degradation of habitat due to introduced grazers such as sheep and rabbits, as well as changed fire regimes (Kinnear *et al.,* 1988; Johnson *et al.*, 1989; Pearson, 1992; Maxwell *et al.*, 1996; Kinnear *et al.,* 1998). Although there is no single cause of decline, Kinnear *et al.*, (1988, 1998) demonstrated that fox predation has played a major role in the reduction of Black-flanked Rock-Wallabies in the wheatbelt.

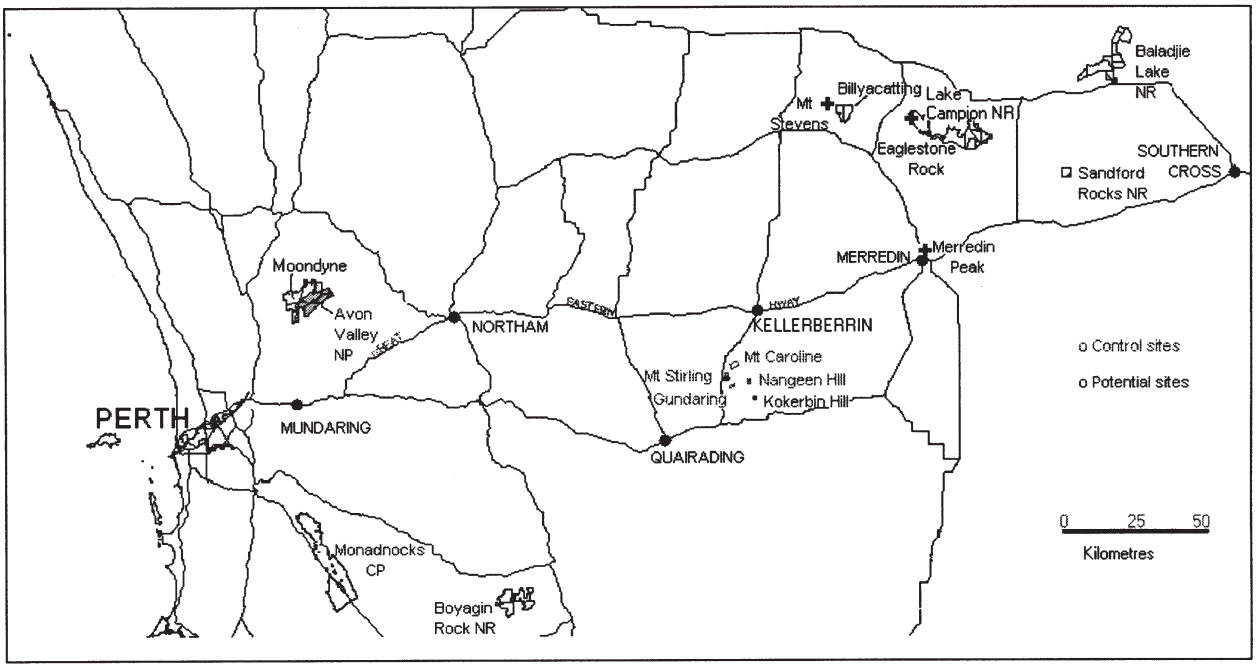

Figure 1. Location of control sites and potential sites.

Currently there are seven wheatbelt Black-flanked Rock-Wallaby populations restricted to isolated granite outcrops (Figure 1) and natural dispersal is difficult due to the surrounding agricultural landscape. Translocations are therefore a necessary management strategy to increase long-term viability of the species. By translocating animals away from the source population, the risks of catastrophic events destroying all the populations are reduced.

Marsupials are particularly important to the tourism image of Australia (Higginbottom *et al.,* 2001b). Croft and Leiper (2001) believed rock-wallabies were good candidates for wildlife tourism as they often inhabit spectacular landscapes, are visible particularly in the cooler parts of the day and most mainland states possess good localities for viewing rock-wallabies. Green *et al.* (2001) also stated rock-wallabies had suitable tourism potential due to their large size compared with other marsupials and their international uniqueness. The vulnerability status of Black-flanked Rock-Wallabies may also add to their appeal as visitors have shown a preference to viewing threatened or unusual animals (Gray, 1993). Therefore an opportunity exists to develop responsible wildlife tourism based around Black-flanked Rock-Wallabies. For rock-wallaby tourism to be successfully developed, research is required on many levels including site surveys to determine habitat suitability and tourism potential.

The aim of this study was to aid the Department of Environment and Conservation (DEC) in identifying translocation sites suitable for rock-wallaby tourism. Selected sites needed to fulfill both habitat requirements for Black-flanked Rock-Wallabies and possess sufficient potential for recreation and tourism. We are not aware of any assessment combining both habitat suitability and wildlife tourism potential that has been previously conducted in Australia.

METHODOLOGY

Site selection

A site survey was conducted on potential translocation sites for Black-flanked Rock-Wallabies in the southwest of Western Australia. A rapid methodology for assessing the recreation potential of reserves in the Merredin District (Fig. 1), developed by Moncrieff (1996), was used as a basis for site selection. The top 21 ranked sites selected in the Merredin District, which received high scores for topographical complexity (a sub-category used in the recreation assessment system) and contained granite outcrops, were initially selected as the study sites. However distance from a major travel route was also factored in. The potential translocation sites in the Merredin District that were assessed included: Sandford Rocks, Baladjie Lake, Eaglestone Rock, Merredin Peak, Mount Stevens and Billyacatting Reserve (Fig. 1). Kokerbin Hill Nature Reserve was also included in the assessment as Black-flanked Rock-Wallabies were recorded here up until 1970 (Kinnear, 1998). Sites closer to Perth such as Boyagin Rock and Monadnocks Conservation Park were also examined. These two sites are established tourism sites and display topographical complexity. The Bibbulmun Track bisects the latter and attracted 35 000 walkers during 1999/2000 (Hunt, 2000).

Avon Valley National Park was also selected, as there is evidence that *P.l.lateralis* formerly occupied this site from an account by John Gould (Eldridge and Close, 1995). Avon Valley National Park is located closer to Perth than the other sites and is an established tourism destination with approximately 10 000 visitors per year. This site was therefore examined to assess whether the vegetation or granite formations were significantly different from the sites where Black-flanked Rock-Wallabies currently occur.

Fox baiting appears to be essential to the survival of the Black-flanked Rock-Wallaby (Kinnear *et al.*, 1988). Of all the potential sites assessed, only Kokerbin Hill, Boyagin Rock, Monadnocks Conservation Park and Avon Valley National Park are fox baited under the Department of Environment and Conservation's current Western Shield baiting strategy.

Development of a habitat ranking system

Four control sites (sites where rock-wallabies are present) and ten potential sites (no rock-wallabies present) were assessed for their suitability as rock-wallaby habitat. All sites were close to a major travel route. Sites in the wheatbelt were close to the Great Eastern Highway and Avon Valley National Park is off Toodyay Road. Monadnocks Conservation Park straddles the Albany Highway and Boyagin Rock is adjacent to the Brookton Highway (Figure 1). All sites were characterised by a large granite outcrop being a predominant feature within the site.

The control sites were used as standards against which desirable habitat characteristics were identified. Potential translocation sites were then compared with the control sites based on these characteristics. Incomplete museum records of the former distribution of the Black-flanked Rock-Wallaby restricted the assessment of sites. The co-ordinates indicated in the museum records of sites of past occurrence in the wheatbelt appear to be of the nearest town and not of the actual record location. Another limitation to including more control sites in the assessment includes the remaining two rock-wallaby colonies occurring on private property potentially restricting access.

No documented systematic assessments of habitat requirements of the Black-flanked Rock-Wallaby has been conducted in Australia, although studies have been undertaken on other rock-wallaby species. Lobert (1988) developed a recording system to describe sites of occurrence of Brush-tailed Rock-Wallabies (*P. penicillata*) in Victoria. Lobert (1988) found the variables most accurate in predicting preferred rock-wallaby habitat included colour of the rock and complexity of the habitat. Colour of rock (which may be important with regards to temperature regulation) could not be applied to the sites in this study due to all the outcrops being composed of granite and consequently of similar composition and colour.

Short (1982) measured six variables which were shown to be significant in predicting the presence of Brush-tailed Rock-Wallabies (*P. penicillata*) in New South Wales. The six significant variables were:

1. The number of ledges
2. Aspect of cliff
3. Number of caves of restricted accessibility
4. Length of ledges
5. Percentage of sheltered sites
6. Number of apparent routes from cliff top to cliff face.

Copely (1990) used a simple ranking system to assess the habitat of Yellow-footed Rock-Wallabies (*P. xanthopus*) in New South Wales. Habitats were scored on their

TABLE 1

Ranking system assessment of rock complexity for black-flanked rock-wallaby habitat

Rock Complexity *	
20	Predominantly weathered rock face consisting of mainly medium boulders, caves, ledges and fissures present
19	Predominately weathered rock face consisting of mainly large boulders, caves, ledges and fissures present
18	Predominately weathered rock face consisting of mainly small boulders, caves, ledges and fissures present
17	Extensively weathered rock faces consisting of mainly medium boulders, caves, ledges and fissures present
16	Extensively weathered rock faces consisting of mainly large boulders, caves, ledges and fissures present
15	Extensively weathered rock faces consisting of mainly small boulders, caves, ledges and fissures present
14	Isolated boulder piles consisting of medium and small boulders, caves, ledges and fissures present
13	Isolated boulder piles consisting of large boulders, caves ledges and fissures present
12	Isolated boulder piles consisting of small sized boulders, caves ledges and fissures present
11	Predominately granite pavement structure with mainly medium boulders, caves, ledges and fissures present
10	Predominately granite pavement structure with mainly large boulders, caves, ledges and fissures present
9	Predominately granite pavement structure with mainly small boulders, caves, ledges and fissures present
8	Predominately weathered rock faces consisting of mainly medium boulders, ledges and fissures present, no caves
7	Predominately weathered rock faces consisting of mainly large boulders, ledges and fissures present, no caves
6	Predominately weathered rock faces consisting of mainly small boulders, ledges and fissures present, no caves
5	Predominately granite pavement structure with mainly medium boulders, ledges and fissures present, no caves
4	Predominately granite pavement structure with mainly large boulders, ledges and fissures present, no caves
3	Predominately granite pavement structure with mainly small boulders, ledges and fissures present, no caves
2	Granite pavement with predominately small boulders, no caves, ledges or fissures present
1	Granite pavement with no boulders

* Rank of 20 represents ideal score with a rank of 1 representing unsuitable habitat for black-flanked rock-wallabies

Large boulders = > 5 metres in diameter
Medium boulders = 1 to 5 metres in diameter
Small boulders = <1 metre in diameter

physical complexity on a scale of one to five. The abundance of rock-wallabies was described as either uncommon or abundant depending on the abundance of scats or animals sighted. It was found that rock-wallaby abundance was positively correlated to habitat complexity. Two physical features, cliffs and large boulders, were seen as critical to rock-wallaby occurrence, although no definition for "large" was given.

Lim and Giles (cited in Lim *et al.*, 1992) developed a more detailed ranking system in 1987 for assessing actual and potential colony sites of Yellow-footed Rock-Wallabies (*P. xanthopus*) in New South Wales. The highest ranked habitat featured steep cliffs, outcrops, gorges, terraces, caves, rock piles and water. Additional points were awarded for boulder size and the smoothness of boulders, with large (>1 metre) smooth boulders receiving the highest score. There was a strong correlation between the presence of rock-wallabies and a high habitat score (Lim *et al.*, 1992).

In summary, the habitat requirements of rock-wallabies have been listed by most researchers as complex boulders with caves and cervices and a food source dominated by grass species (genera not specified). The analysis of the four control sites confirmed these characteristics. It was thus decided to develop a habitat ranking system using these habitat criteria to compare and contrast sites currently supporting Black-flanked Rock-wallabies to sites that appeared to be suitable but lacked rock-wallaby populations. A qualitative rank was assigned to each habitat component. Scores for each component recognised that some were more critical to rock-wallaby survival than others (eg. rock complexity was scored out of twenty whereas the presence or absence of fox control was assigned a score of one or zero).

The variables that were assessed were:

1. Rock complexity
2. Vegetation type
3. Fox control (Absent/Present)
4. Area of suitable habitat (ha)
5. Evidence of past/present distribution
6. Aspect
7. Rock to vegetation ratio

Complexity of the rocky outcrop and the presence of caves, ledges and fissures was considered as one of the most important attributes of a site and thus ranked highly (Table 1). Medium boulders were considered to be more desirable than larger and smaller boulders as this size allowed for the formation of the most suitable caves, ledges and fissures that could be utilised by rock-wallabies.

Flat granite pavement landscapes lacking boulder formations received the lowest score as this habitat failed to provide protection for rock-wallabies. The scores increased with a) increasing complexity and b) area of complexity (i.e. outcrops made up of predominantly granite pavement would score less despite the presence of cracks, ledges and boulders).

If sites received a score of 10 or higher for rock complexity, they were then assessed for vegetation type, presence of fox control, aspect, rock to vegetation ratio and area of suitable rocky habitat (Table 2). Sites failing to score ten or above were regarded as being unsuitable rock-wallaby habitat and excluded from further consideration.

The presence of grass growing on the outcrop would enable rock-wallabies to forage close to their sites of refuge. Proserpine Rock-Wallabies (*P. persephone*) in Queensland were found to require rocky outcrops with a canopy of vine forest in the vicinity of open forests, and vegetation for grazing on the edges of the habitat (Davidson, 1991). A canopy of trees was also considered to be desirable for Black-flanked Rock-Wallabies, as it would provide more protection from predators, in particular wedge-tailed eagles, than open grasslands with sparse tree cover. Vegetation comprising dense woody thickets with patchy grass cover was considered undesirable, as it lacked sufficient grass for foraging. Fox control was an additional managerial advantage to an area but not essential as an area could be fox baited before the translocation of rock-wallabies.

The ratio of rock to vegetation area was considered important as at Mt Caroline rock-wallabies had started to feed on crops in surrounding farmlands. This may be due to the carrying capacity of the habitat being exceeded. This problem has not been encountered at Nangeen Hill as this reserve has a larger area of vegetation surrounding the granite outcrop. A low ratio of rock to vegetation area thus ranked higher.

Area of suitable habitat was considered important, as it would dictate population size. Area of suitable habitat was an estimate of the percentage of suitable habitat multiplied by the area of the outcrop. In sites like the Avon Valley where the granite boulders are spread throughout the park, the total area of suitable habitat was added together to form the estimate, as animals could easily move between these areas.

Evidence of past or present occurrence was also factored in, although this component was not weighted highly due to lack of extensive records of past occurrence. Two sites received a score for evidence of past occurrence, Kokerbin Hill and Avon Valley National Park. All the control sites displayed evidence of present occurrence. This was confirmed by sightings of rock-wallabies and the presence of scats.

Aspect was included in this ranking system, however there are no data on the preference of Black-flanked Rock-Wallabies in relation to aspect. A northerly aspect was shown to be an important factor in studies of Brush-tailed Rock -Wallabies (*P. penicillata*) in New South Wales (Short, 1982). However, Yellow-footed Rock-Wallabies (*P. xanthopus*) were found to favour a southerly aspect in New South Wales (Lim *et al.*, 1992). Aspect was not the most accurate indicator in the presence of Brush-tailed Rock-Wallaby in Victoria (Lobert, 1988).

Due to these conflicting findings, aspect was allocated a low overall weighting. A northerly aspect was assumed to be preferred, as rock-wallabies at Mount Stirling and Gundaring Nature Reserve were observed to inhabit the

TABLE 2

Assessment of habitat characteristics of sites receiving a score of 10 or above in the rock complexity category

Vegetation Type	
12	Grass and trees growing on outcrop with surrounding woodlands and grasslands
11	Grass and trees growing on outcrop with surrounding woodlands, grasslands and thicket
10	Grass and trees growing on outcrop with surrounding grasslands, trees sparse
9	Grass and trees growing on outcrop with surrounding thickets
8	Grass and bushes growing on outcrop with surrounding woodlands and grasslands
7	Grass and bushes growing on outcrop with surrounding woodlands, grasslands and thicket
6	Grass and bushes growing on outcrop with surrounding grasslands, trees sparse
5	Grass and bushes growing on outcrop with surrounding thicket
4	Bare rock outcrop with surrounding woodlands and grasslands
3	Bare rock outcrop with surrounding woodlands, grasslands and thicket
2	Bare rock outcrop with surrounding grasslands, trees sparse
1	Bare rock outcrop with surrounding thicket
Fox Control	
1	Present
0	Absent
Area of Suitable Habitat (Hectares)	
10	>100
9	91-100
8	81-90
7	71-80
6	61-70
5	51-60
4	41-50
3	31-40
2	21-30
1	11-20
0	<10
Evidence of Past/Present Occurrence	
2	Yes
0	No
Aspect	
5	North
4	Northwest/Northeast
3	East/West
2	Southeast/Southwest
1	South
Rock: Vegetation (Ratio)	
10	1: <1
5	1: 1-5
1	1: > 10

northern face of the outcrops, as these faces were more weathered. Kinnear *et al.* (1998) found most refuge sites faced north or northeast at Mount Caroline.

Recreation and tourism assessment

Moncrieff's (1996) recreation and tourism assessment methodology was based on three broad categories: "physical attributes" (maximum score =100), "threats and use" (30), and "current management" (45). In this study, the "current management" was substituted for a rating based on ease of viewing wildlife on the rock outcrops (Table 3). "Current Management" was excluded as the management of the chosen site would alter once rock-wallabies were translocated there. "Viewing wildlife" was allocated a score out of ten, hence the maximum score for the altered recreation and tourism potential ranking system was 140.

Sites that contained exposed complex boulder formations on granite outcrops were awarded a higher score than sites where the most suitable habitat was in a valley and could not be viewed from a distance. Lower scores were also awarded for sites that were densely vegetated around the outcrop, as the rock-wallabies would be more difficult to view from a distance. If sites received a score below five they were excluded and deemed unsuitable for rock-wallaby tourism.

Only sites that received high scores for both rocky complexity (Table 1) and ease of viewing wildlife on rock outcrops (Table 3) were assessed in the recreation assessment system. The sites receiving the highest scores in both the habitat ranking system and the tourism

Table 3
Break down of scores for ease of viewing wildlife on rock outcrops

Score	Vegetation and Position of Outcrop
10	Raised outcrop surrounded by predominantly grasslands and open woodlands around base
9	Raised outcrop surrounded by woodlands around base
8	Raised outcrop surrounded by dense vegetation viewed with ease from surrounding rock platforms
7	Raised outcrop surrounded by dense vegetation
6	Outcrops on a slope surrounded by predominantly grasslands and open woodlands around base
5	Outcrops on a slope surrounded by woodlands around base
4	Outcrops on a slope surrounded by dense vegetation
3	Outcrops in a valley surrounded by predominately grasslands and open woodlands around base
2	Outcrops in a valley surrounded by woodlands at the base
1	Outcrop in a valley surrounded by dense vegetation

potential assessment system would be considered as potential translocation sites.

RESULTS

Potential translocation sites

Sites satisfying both rock complexity requirements and ease of viewing requirements were: Mount Caroline, Nangeen Hill, Mount Stirling, Gundaring, Kokerbin Hill, Sandford Rocks, Baladjie Lake, Billyacatting and Avon Valley (Table 4). Sites failing to satisfy both criteria were Merredin Peak, Eaglestone Rock, Mount Stevens, Boyagin Rock and Monadnocks Conservation Park (Table 4). Sites were further refined based on the categories outlined in Table 2. These results are summarised in Table 5.

By further refining the ranking allocated to each site, it was found that Mount Caroline received the highest score for habitat suitability (35/40). Nangeen Hill and Billyacatting ranked equal second (31/40), with Avon Valley National Park ranking third in habitat suitability (29/40). Gundaring and Mount Stirling received the same score (27/40) and were ranked fourth in habitat suitability. Kokerbin Hill (20/40), Baladjie Lake (18/40) and Sandford Rocks (14/40) scored the lowest.

Table 6 shows Baladjie Lake had the highest score for “physical attributes” and ranked highest overall for tourism potential (107/130). Avon Valley also scored second highest in the assessment (99/130). Mount Caroline, Nangeen Hill, Mount Stirling, Gundaring and Kokerbin Hill all received equal scores for “physical attributes” and “threats and uses” (Table 6). The individual scores for habitat suitability and tourism potential are shown in Figure 2. Just over half the sites

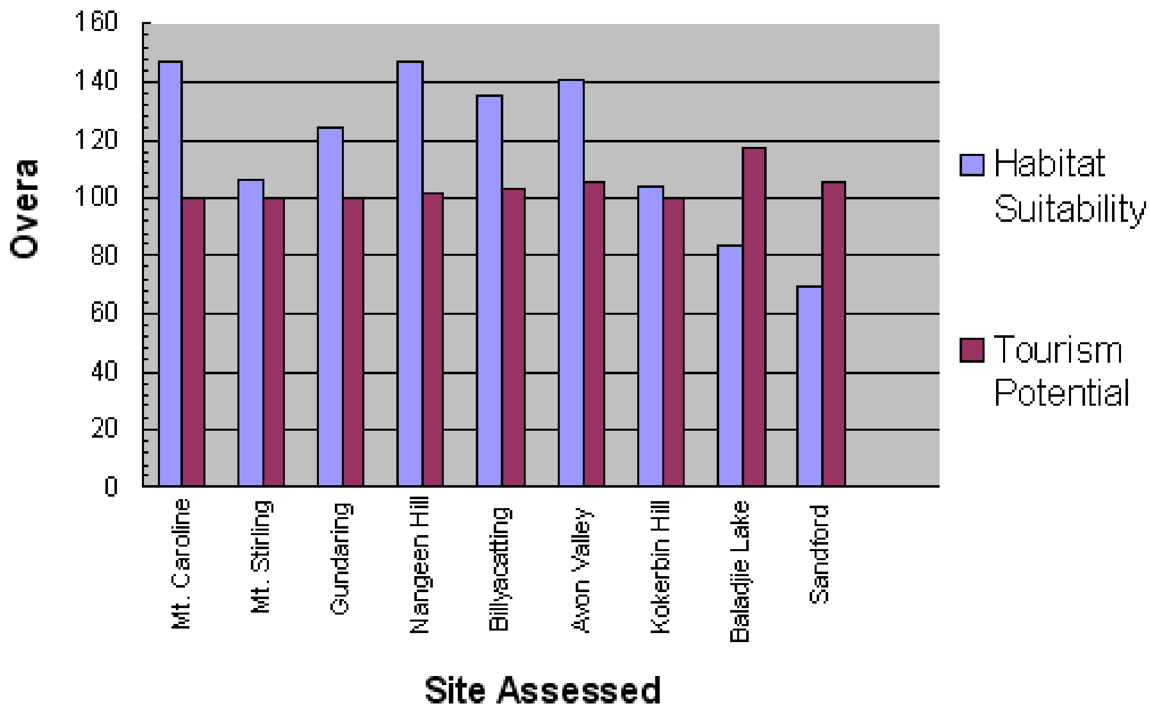

Figure 2. The habitat and tourism rank assigned to each site.

Table 4

Results of the rock complexity and ease of viewing wildlife assessment

SITE	ROCK COMPLEXITY (x/20)*	EASE OF VIEWING WILDLIFE (x/10)*	**ACCEPTED/ REJECTED**
Nangeen Hill	20	10	✔
Avon Valley	20	6	✔
Mount Caroline	16	9	✔
Gundaring	16	9	✔
Kokerbin Hill	16	9	✔
Billyacatting	16	7	✔
Boyagin Rock	14	2	✗
Monadnocks	14	4	✗
Baladjie Lake	11	10	✔
Mount Stirling	10	8	✔
Sandford Rocks	10	8	✔
Eaglestone Rock	7	10	✗
Merredin Peak	2	10	✗
Mount Stevens	2	10	✗

Table 5

Ranking of habitat suitability of potential rock-wallaby sites against actual sites of occurrence

Site (Maximum score)	*Vegetation Type (x/12)*	*Fox Control (x/1)*	*Rock:Veg Ratio (x/10)*	*Area Of Suitable Habitat (x/10)*	*Aspect (x/5)*	*Known Past/ Present Occurrence (x/2)*	*Total (x/40)*
Mt. Caroline	12	1	5	10	5	2	35
Nangeen	10	1	10	3	5	2	31
Billyacatting	11	0	5	10	5	0	31
Avon Valley	12	1	10	1	4	2	29
Gundaring	12	1	5	2	5	2	27
Mt. Stirling	12	1	1	6	5	2	27
Kokerbin	7	0	5	1	5	2	20
Baladjie	8	0	5	0	5	0	18
Sandford	3	0	10	0	1	0	14

Table 6

Tourism potential of sites assessed for rock-wallaby habitat suitability

Site	*Physical Attributes (x/100)*	*Threats and Uses (x/30)*	*Total (x/130)*
Baladjie	95	12	107
Avon Valley	83	16	99
Sandford	80	17	97
Billyacatting	85	11	96
Mt. Caroline	78	13	91
Nangeen	78	13	91
Mt. Stirling	78	13	91
Gundaring	78	13	91
Kokerbin	78	13	91

attained a higher score for habitat suitability than tourism potential.

DISCUSSION

Suitable sites for translocation

Of all the sites examined (potential and control sites) Nangeen Hill would be the best site for rock-wallaby tourism. This site already has a large population of rock-wallabies and the outcrop is surrounded by open grasslands adjacent to the northern faces which allows for ease of viewing rock-wallabies. Several rock-wallabies were observed when this site was assessed, and this was at midday which is not a prime time to see rock-wallabies. The outcrop has a dirt vehicle track, accessible to two-wheel drive vehicles, which encircles the base of the outcrop and aids ease of viewing the rock-wallabies. Nangeen Hill is highly weathered with tumulus boulders predominating and with limited vegetation growing in soil pockets on the outcrop itself therefore providing better viewing opportunities. This is in contrast to Mount Caroline and Gundaring Nature Reserve, which have extensive areas of vegetation growing on the outcrop. Nangeen Hill is located approximately 23 km south of Kellerberrin (Figure 1) and is closer to the Great Eastern Highway than any of the potential sites examined in the wheatbelt, and therefore more convenient for transient travellers to visit. There are no recreational facilities (e.g. rubbish bins, picnic tables, toilets) and no public access to this site as it is surrounded by private property. If this site were opened for rock-wallaby tourism these factors would need to be taken into account and remedied. Nangeen Hill is a nature reserve, and recreation is discouraged under current legislation. It also has the added protection of being gazetted as a 'prohibited area' under the CALM Act in order to protect the rock-wallabies from human disturbance. To develop tourism facilities would require (a) a change from nature reserve status to national park or conservation park, which have a greater emphasis on provision of recreation opportunities, and (b) the lifting of the 'prohibited area' classification.

Notwirhsatnding that Nangeen Hill appears to be the most suitable site for rock-wallaby tourism, translocations still need to be carried out to expand the range of Black-flanked Rock-Wallabies. Rock-wallabies at Mount Caroline are already targeted for translocation as the animals at this site are increasingly foraging further from the reserve and feeding on the crops of surrounding private property (Matt Dowling, *pers. comm*) and therefore may have exceeded the carrying capacity of the site. A site further away from the current populations needs to be considered, even if purely for conservation purposes. A site that is separate from existing colonies will have two purposes. If a catastrophe such as disease or fires threaten the existing colonies, a population at a separate location is less likely to be affected due to the isolating effect of distance. Although linkages between populations help overcome inbreeding, they can also facilitate the spread of catastrophic events as migrating animals can spread disease or fire can move along corridors of natural vegetation (Mangel and Tier, 1994). Avon Valley National Park and Billyacatting Nature Reserve are two potential translocation sites that satisfy the habitat and recreation potential requirements as well as being sites that are separate from the current rock-wallaby colonies.

Considerations for future management of translocated populations

Management of Black-flanked Rock-Wallaby tourism is required at three levels: (1) initial translocations should be carefully managed and monitored to ensure survival and reproductive success, (2) a commitment to the long-term management of the reserve and habitat is also essential, and (3) the long-term management of rock-wallaby and human interactions must be continually

Table 7

Management strategies to increase the success of rock-wallaby translocations and long term management of the reserve and habitat

Management Strategy	Description
MANAGEMENT OF INITIAL TRANSLOCATIONS	
Heterozygosity	• Translocated individuals should be genetically distinct from one another and should possess high levels of heterozygosity to prevent inbreeding and to ensure the founder population has the maximum viability and fecundity
Effective Population Size	• Founder population of 10 to 20 pairs of breeding adults, or as many as can be managed • Long term monitoring of distribution, abundance and genetic variation should be carried out to establish success rate
LONG TERM MANAGEMENT OF THE RESERVE AND HABITAT	
Fox Control	• Achieved by 1080 poisoning or exclusion by fencing
Fire Management	• Firebreaks may need to be managed at the new translocation site to reduce impacts from wild fires. • Fires should be irregular and seasonally spread
Feral Cat and Rabbit Control	• Introduced animals controlled to decrease the stress on translocated populations
Monitoring	o Some or all of the founder individuals be fitted with radio-transmitters. Source population monitored to determine any marked differences between source and translocated populations
LONG TERM MANAGEMENT OF ROCK-WALLABY AND HUMAN INTERACTIONS	
Stakeholder liaison	• Discussions with landholders, local shires and local communities conducted regarding their opinions on rock-wallaby tourism and how it might impact on operational management and social and economic development
Education/ interpretation	• Provide opportunities for people to experience and learn about nature through the provision of information on wildlife and other environmental issues
Public contact	• Provide areas for wildlife observation, nature centres and guided nature walks including spotlighting tours
Waste Disposal	• Litter should be controlled as rock-wallabies are known to feed on discarded food items causing nutritional problems and digestive upsets
Separation and Zoning	• Separating visitors through strategies such as fencing • Dividing the area into different zones such as recreation, access and conservation.
Other Management Strategies	• Limit group numbers • Entry fees

Source: Hair and Pomerantz (1987); Shaw (1987); Kinnear *et al.* (1988); Johnson *et al.* (1989); Spencer (1991); Bolton (1997); Kinnear *et al.* (1998); Lobert (1998); NPWS (2003) monitored to ensure there are no adverse effects. These management strategies are outlined in Table 7.

A high level of heterozygosity should be possessed to prevent inbreeding and to ensure the founder population has the maximum viability and fecundity (Table 7). Eldridge *et al.* (2001) reported evidence of high fecundity levels of recovering wheatbelt rock-wallaby populations as a result of ongoing fox control. Johnson *et al.* (1989) suggested a founder population of 10 to 20 pairs of breeding adults, or as many as can be managed (Table 7). Translocations are deemed successful when the founder population reaches at least 500 individuals and is not being supported through human intervention, such as food provisioning, and are self-sustaining (Bolton, 1997). Although a minimum viable population size of between 50 and 500 should be striven for, the initial and subsequent management will be a significant determinant of success (Johnson *et al.*, 1989).

Bolton (1997) states that conservation objectives have rarely been specifically targeted in ecotourism. The development of rock-wallaby tourism must be managed to be sustainable and this can be achieved by identifying the needs of tourists and employing successful methods of stakeholder and site management that meet the expectations of visitors and by ensuring conservation benefits outweigh any negative impacts arising from tourism activities.

Recreation and tourism management

Stakeholder liaison

Stakeholder cooperation is required and is particularly important in the sustainability of rock-wallaby tourism. Discussions with landholders, local shires and local communities will need to be conducted regarding their opinions on rock-wallaby tourism and how it might impact on operational management and social and economic development (Table 7). For example, landholders may need to cooperate with fox baiting on their property to ensure adequate predator control is practiced.

Zoning and separation of visitors from wildlife

The designation of specific recreation zones can be used to concentrate wider recreational activities like picnicking and can be set in areas that are separate from the outcrops inhabited by rock-wallabies. This can reduce problems associated with inadequate waste disposal. Different levels of access can be planned within the reserve, for example to allow only visitors on foot to enter the zone where the rock-wallabies are located. At the same time sanctuary zones can be designated to act as refuge areas, where public access is either not encouraged or prohibited.

Public contact with translocated animals

No studies of human interaction with Black-flanked Rock-Wallabies have been reported to date. Rock-wallabies live in large communities and like other large macropods tend to feel more secure when in larger groups. Personal observations indicate Black-flanked Rock-Wallabies are curious and only retreat if sudden movements by humans are made or if they are approached too closely. Kinnear (2000) observed that Black-flanked Rock-Wallabies appear to adapt easily and are generally tolerant of human presence.

Higginbottom *et al.* (2001b) stated that visitor surveys and subjective impressions indicated that getting close to macropod species increased visitor satisfaction. If close contact is desired as part of the tourism experience then rock-wallabies may need to be deliberately habituated to human presence. Higginbottom *et al.* (2001b) state this can be achieved by repeated exposure to human visitors who behave in a non-threatening manner. This includes minimising noise and sudden movement, not approaching too closely as well as curbing the approach if the animal indicated a high level of alertness (eg. animal stands upright and faces the visitor before fleeing). The process of habituation is likely to reduce panic responses that result in the separation of groups and especially adults from young. It is also important that individuals do not flee from sheltered sites as rock-wallabies that are displaced from their rocky habitats may become more exposed to predation. A deliberate habituation strategy should focus on getting the animals accustomed to human presence by slowly allowing the controlled presence of small groups under close supervision. This would be best achieved via exposure to humans at regular intervals in order to allow the rock-wallabies to habituate to human presence. By allowing animals to become habituated to visitors, disturbance and potential stress can be reduced (Higginbottom *et al.*, 2001b).

Although close approach may be desired, a safety margin of potential disturbance should be maintained and visitors must not be allowed to approach the rock-wallabies too closely. Changes in the natural behaviour of rock-wallabies would need to be monitored in response to human presence. If rock-wallabies are displaying altered behaviour in relation to visitor presence, then alternative arrangements such as viewing platforms and hides may need to be considered to overcome this problem.

The importance of educational programmes as a management strategy

Shaw (1987) states an important function of wildlife management is to provide opportunities for people to experience and learn about nature through the provision of information on wildlife and other environmental issues (Table 7). Education is considered by Alcock (1991) to be the most important strategy for managing wildlife. A system needs to be in place so that the public can be made aware of rock-wallaby biology and ecology, threats facing Black-flanked Rock-Wallabies, and their conservation.

Various interpretive techniques are available and include the use of signs, guided tours and brochures.

All forms of interpretation have advantages and disadvantages and the effectiveness of the different techniques will depend on both site and visitor characteristics (Newsome *et al.*, 2002). Basic interpretation dealing with the above issues could be in the form of a visitor information stand located at the site entry or take the form of smaller signs throughout the reserve. Guided tours of rock-wallaby sites add the advantages of personal contact. Organised tours can be arranged for the times when the wallabies are active by means of small tours on foot or spotlighting activities at night. The success of such programmes, however, is dependent on the availability of informed and effective interpreters.

In the case of spotlighting tours, visitor satisfaction can be increased if spotlights are of a low intensity to prevent the dazzling and blinding effects of bright lights. Guides and tour operators are in a strong position to manage the use of lights (Newsome *et al.* 2005). Spotlights can be provided to visitors for safety reasons but the visitors should be discouraged from using spotlights on rock-wallabies. Hides and viewing areas can be utilised to concentrate use, for example in the case of Avon Valley National Park, a platform already overlooks an area of complex boulder formation, and, if rock-wallabies colonised this area, visitors could be encouraged to bring binoculars to view the rock-wallabies.

Waste Disposal

Inadequate disposal of litter should be dealt with as rock-wallabies are generalists and Mareeba Rock-Wallabies (*P. mareeba*) have been known to feed on discarded food items including oats, bread, carrots, spaghetti, lettuce, chips, apples, breakfast cereals and potato peels (Hodgson, 1998) (Table 7). None of this foodstuff is the natural food source of rock-wallabies and may cause nutritional problems and disorders of the digestive system. Additionally, rock-wallabies captured in Kokerbin Rock were found with cut feet from broken glass (Moncrieff, 2000). Rubbish bins should be provided at the site if picnicking is allowed and interpretive signs should be erected detailing the negative effects of littering and feeding of wildlife.

CONCLUSION

In 2001, 50 rock-wallabies were translocated to Avon Valley National Park. This site is advantageous for both conservation and tourism, as it is located away from the current colonies. Avon Valley National Park has the benefit of being a site of past occurrence and is currently fox baited. The Park is also an established recreation destination and possesses campsites and walk trails along with other facilities. Other Western Australian translocations of Black-flanked Rock-Wallabies include reintroductions to Paruna Sanctuary (2001), Walyunga National Park (2002) and more recently Cape Le Grand National Park (2003). This study therefore provides an important insight into the factors that need to be considered in conserving vulnerable species using wildlife tourism, and has the potential to be used as a model for other projects of this nature.

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Review of the distribution, causes for the decline and recommendations for management of the quokka, *Setonix brachyurus* (Macropodidae: Marsupialia), an endemic macropodid marsupial from south-west Western Australia

PAUL J. DE TORES[1*], MATT W. HAYWARD[2,3,4], MICHAEL J. DILLON[3] AND ROBERT I. BRAZELL[5]

[1] Department of Environment and Conservation, Wildlife Research Centre, P.O. Box 51 Wanneroo, Western Australia 6946
[2] School of Biological, Earth and Environmental Science, University of New South Wales, Sydney, New South Wales 2052
[3] Department of Environment and Conservation, Dwellingup Research Centre, Banksiadale Road, Dwellingup, Western Australia 6213
[4] Current address: Mammal Research Institute, Polish Academy of Science, 17-230 Biglowieja, Poland
[5] Department of Environment and Conservation, Wellington District, P.O. Box 809 Collie, Western Australia 6225
[*] Contact person for correspondence: Paul de Tores, email: paul.detores@dec.wa.gov.au

ABSTRACT

The former and current distribution of the quokka, *Setonix brachyurus*, was mapped from published and all available unpublished records. At the time of European settlement the quokka was widespread and abundant and its distribution encompassed an area of approximately 41 200 km^2 of south-west Western Australia inclusive of two offshore islands, Bald Island and Rottnest Island. Historical reports indicated an extensive population decline occurred in the 1930s. The decline continued, with a previously undocumented decline apparent in the period from 1980 to 1992. However, this decline may be an artefact of the time scales used for mapping and may well equate with a previously reported decline for a suite of south-west mammals in the 1970s. By 1992 the quokka's distribution had been reduced to an area of approximately 17 800 km^2. An increased awareness of the presence of the quokka on the mainland has resulted in numerous reportings of quokka presence since 1992, has confirmed the existence of several populations at the northern extent of the quokka's known geographic range and indicated the current, 2005, distribution to be similar to that in 1992. However, survey and population estimates at six of these mainland locations from the northern jarrah forest indicated low abundance. There have been no population estimates elsewhere on the mainland. Two populations have been reported from the Swan Coastal Plain, but neither has been confirmed extant.

Predation by the introduced fox, *Vulpes vulpes*, is implicated as a major cause of the quokka's initial decline, while ongoing predation, habitat destruction and modification through altered fire regimes have contributed to the continued decline.

Specific conservation management actions are recommended, namely: (i) Implementing an active adaptive management program in the northern jarrah forest to determine quokka population response to habitat manipulation through the use of fire, fox baiting and pig control; (ii) Surveying the Stirling Range and Green Range populations with emphasis placed on determining population size and population genetic structure; (iii) Surveying the reported occurrences from the Swan Coastal Plain, with emphasis on unambiguously determining presence. If confirmed, priority should be directed to assessing population size and determining the management requirements to ensure persistence of the population; (iv) Surveying southern forest and south coast populations to assess quokka population size, the extent of movement between subpopulations and assessment of the range of habitat types used by quokkas. The latter should be combined with spatial analyses of known extant populations and suitable and potentially suitable habitat; (v) Determining the role of fire in establishing and maintaining preferred habitat of southern forest and south coast populations; and (vi) Establishing a program to assess the potential effects from management operations.

Keywords: quokka, *Setonix brachyurus*, distribution, fox predation, fire, adaptive management

INTRODUCTION

The quokka, *Setonix brachyurus* (Macropodidae: Marsupialia) (Quoy & Gaimard 1830) is a small to medium sized macropodid marsupial, endemic to the mainland of south-west Western Australia and two offshore islands –

Bald Island, east of Albany and Rottnest Island, 20km west of Perth (Fig. 1). Adult males range in weight from 2.7 to 4.2 kg and adult females from 1.6 to 3.5kg (Hayward et al. 2003; Kitchener 1995). The quokka is known to the Aboriginal, or Noongar, people of south-west Western Australia by a range of names including '*Ban-gup*', '*Bungeup*', '*Quak –a*' (Gould 1863; Shortridge 1909), '*kwoka*' and '*bangop*' (Abbott 2001a).

The quokka was the second Australian marsupial recorded by Europeans, the first appears to have been Francis Pelsart's description of the Tammar Wallaby from the Houtman Abrolhos on 1629. The first European record of a quokka is attributed to Samuel Volckertzoon (or Volckersen) who, in 1658, when visiting the then un-named Rottnest Island off the coast near Perth, described the quokka as '*a wild cat resembling a civet-cat but with browner hair*' (Alexander 1914). In 1696 when Willem de Vlamingh visited the island he described the quokka as '*a kind of rat as big as a common cat*' (Alexander 1914). He named the island Rottenest (now Rottnest), meaning rat's nest. The quokka is often erroneously reported by local media as occurring only on Rottnest Island. Its presence on the mainland was described in 1957 as largely unreported (Barker et al. 1957) and it is still widely thought of as only occurring on Rottnest Island.

At the time of European settlement of south-west Western Australia, the mainland distribution of the quokka was thought to extend from the Moore River district 80–100 km north of Perth (Baynes 1979), to areas south and south-east of Perth at locations within the Swan Coastal Plain, the jarrah, *Eucalyptus marginata*, and karri, *E. diversicolor*, forests south-east of Perth, the Cape Leeuwin–Cape Naturaliste region, the south coast and east to the Hunter River east of Bremer Bay (Baynes 1979; Baynes et al. 1975; Glauert 1933; Kitchener 1995; Ride 1970) (Fig. 1). In addition to the Rottnest Island and Bald Island populations, quokkas were reported from Breaksea Island, near Albany (Western Australian Museum records), 'Twin Peak' Island and other off shore islands near Esperance (Shortridge 1909). Subsequent references to the quokka's historic distribution on the mainland, at or prior to the time of European settlement, have included the south coast of Western Australia as far east as Esperance (Shortridge 1909; Troughton 1965).

This inferred former distribution was based on the above reports and location records. All location records were within four biogeographical regions, or bioregions, as identified in the Interim Biogeographical Regionalisation for Australia (IBRA) (Thackway & Cresswell 1995), namely the Swan Coastal Plain, the Jarrah Forest, the Warren and the Esperance Plains bioregions (Fig. 1).

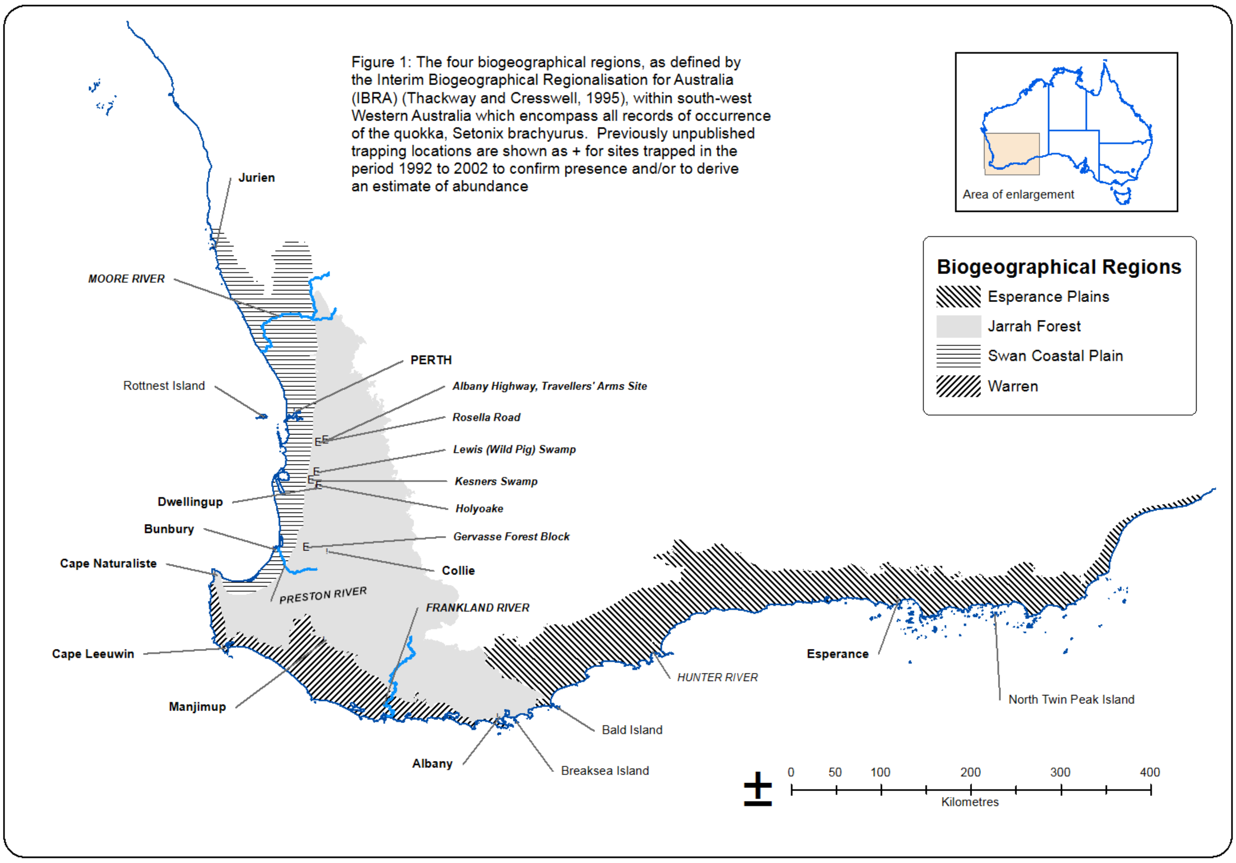

Figure 1. The four biogeographical regions, as defined by the Interim Biogeographical Regionalisation for Australia (IBRA) (Thackway and Cresswell, 1995), within south-west Western Australia which encompass all records of occurrence of the quokka, Setonix brachyurus. Previously unpublished trapping locations are shown as + for sites trapped in the period 1992 to 2002 to confirm presence and/or to derive an estimate of abundance

Various authors have expressed concern at the extent of the quokka's decline from this inferred historic distribution and attributed different levels of threat to its conservation status. Clarke (1948) suggested the quokka was almost confined to Rottnest Island. White (1952), although noting there was a misleading impression of rarity on the mainland, conceded the quokka was becoming less abundant there. Loaring (in Serventy et al. 1954) believed quokkas had vanished from their *'gully haunts'* in the Darling Plateau by the 1920s. Sharman (1954) noted the quokka appeared common only on Rottnest and Bald Islands with isolated colonies at some mainland sites.

Barker et al. (1957) cited a 1957 newspaper article which suggested the quokka was extinct on the mainland. That report generated interest in quokka populations, and in the same year, led to the confirmation of the presence of a small colony of quokkas near Byford, immediately south of the Perth metropolitan area (Barker et al. 1957). Hart et al. (1986) and similarly Perry (1973) also noted there was a widely held, yet incorrect, belief the quokka had become extinct on the mainland after the population crash of the 1930s. This collapse of quokka populations on the mainland in the 1930s is widely reported and Ride (1970) recorded, prior to this collapse, that the quokka was common in the south-west and populations were sufficiently abundant for quokka shooting to be a '*familiar sport'*.

Serventy (in Serventy et al. 1954) reported an apparent increase in quokka numbers in the Darling Range and Manjimup areas in the early 1950s. However, this seems to be contradicted by reports from Loaring and Glauert (also reporting in Serventy et al. 1954). Dell (1983) believed Serventy's (1954) reported increase in numbers of the quokka and other species could not be substantiated and was an artefact of an increased awareness by observers. How et al. (1987), when reporting on a vertebrate fauna survey for the area between Busselton and Albany, believed quokka populations had persisted on the mainland but were rapidly diminishing.

In an attempt to quantify the conservation status and causes of decline for a suite of macropod species, Johnson et al. (1989) concluded the quokka had experienced a substantial (85–90%) decline in its geographic range on the mainland. These authors identified the quokka as warranting a high priority for conservation management.

The quokka is currently listed as a *Threatened Species*, in the sub-category Vulnerable, pursuant to the World Conservation Union (IUCN) Red List of Threatened Species (Hilton-Taylor 2000). It is listed nationally as *Threatened Fauna*, in the sub-category Vulnerable, pursuant to the Commonwealth of Australia's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) criteria for Vulnerable. In 1996 it was placed on the Western Australian list of *'fauna which is rare or likely to become extinct'* pursuant to Section 14(2)(ba) of the *Western Australian Wildlife Conservation Act* 1950.

This paper reviews the distribution of the quokka, assesses the probable causes of the species decline and proposes specific conservation management recommendations. The conservation status is reviewed in a forthcoming publication.

METHODS

Distribution maps and terminology

Location records for the quokka were obtained from published and unpublished accounts of fossil, subfossil and surface cave deposits, published and unpublished records of distribution/presence, database records of the Western Australian Museum (WAM), database records of the Australian Museum, database records of the Western Australian Department of Environment and Conservation (DEC, formerly the Department of Conservation and Land Management, CALM) (CALM unpublished; Gilfillan unpublished). Additional information on WAM records was supplied by Norah Cooper (pers. comm. to PJdeT)[1] and additional sub-fossil records were obtained from searches of the uncatalogued collection of the Palaeontology and Anthropology Sections of the Western Australian Museum (E. Jefferys pers. comm. to MWH)[2].

Records of presence were provided from our previously unpublished field survey and trapping data from the early 1970s to 2002 with additional detailed data from the period 1992 to 2002 from trapping at six locations within the northern jarrah forest – Gervasse Forest Block, Rosella Road, Albany Highway (Travellers' Arms Site), Holyoake Swamp, Kesners Swamp and Lewis (Wild Pig) Swamp (Fig. 1.). Field survey considered quokkas to be present at a site if confirmed through trapping, recent roadkills or by the presence of scats within characteristic runways in densely vegetated areas considered typical of quokka habitat (see Barker et al. 1957; Christensen et al. 1985; Christensen & Kimber 1975; Dillon 1993; Kitchener 1995; Maxwell et al. 1996; Sinclair 1999). The presence of scats in open areas and away from characteristic runways, was considered insufficient to infer presence (Alacs et al. 2003).

Locations from all sources were mapped using the geographic information system (GIS) software ArcGIS (ESRI 1999-2004). Location records were excluded when they were unable to be validated and/or if not supported by location co-ordinates, or if location co-ordinates could not be determined. The inferred pre-European distribution (inclusive of sub-fossil records) was mapped from these records, as was the distribution at six subsequent times, namely at the time of European settlement, at 1920, 1950, 1980, 1992 and 2005. The inferred distribution at the time of European settlement and at 1920 pre-dates arrival of the fox and the first evidence of fox predation in south-west Western Australia. The 1950 distribution includes records from 1921 to

[1] Norah Cooper: Curator of Mammals, Western Australian Museum, Perth
[2] Elizabeth Jefferys: University of New South Wales

1950. The 1980 distribution includes records from 1951 to 1980. The 1992 distribution includes records from 1981 to 1992. The 2005 distribution is inferred from records post 1992, where populations were verified or where there was no evidence to indicate previously known populations had not persisted. These time frames allow quantitative and visual assessment of the decline from the pre-European distribution. Our use of the term 'pre-European distribution' is synonymous with the term 'original distribution' as used by Baynes (1987). The current (2005) distribution was also mapped to depict density of sighting and location records. Density categories were derived through kernel analysis in ArcGIS. Densities reflect the density of sighting/location records and do not necessarily equate with population densities.

Areas surveyed, population estimates and survivorship

Estimates of population size were obtained from published accounts and our previously unpublished survey and trapping records at locations within the northern and southern jarrah forests, where the northern jarrah forest is broadly defined as the jarrah, marri and wandoo forests north of the Preston River (Fig. 1). The southern forest is broadly defined as the jarrah, marri, karri, tingle and wandoo forests south of the Preston River, north and west of the Frankland River. The south coast refers to the area east of the Frankland River (Fig. 1).

The Gervasse site (Fig. 1) is subject to an ongoing monitoring program (capture-mark-release-recapture) and capture data were analysed for eleven trapping sessions conducted in June/July 1992, March 1993, June/July 1993, January 1994, August 1994, April 1995, January 1996, January 1997, February 1998, March 1999 and February 2000. To enable comparison with population estimates from five other northern jarrah forest sites (Hayward et al. 2003), estimates of population size from the Gervasse site were derived from the '*death but no immigration*' Jolly-Seber (JS) model using the software interface modified to accommodate unequal time periods between trapping sessions (Barker & McGlinchy 2001).

'*Known to be alive*' (KTBA) estimates were also derived for the Gervasse site, where an animal trapped at trapping session $t_{(n-i)}$, not trapped at $t_{(n)}$ and subsequently trapped at $t_{(n+i)}$ is assumed to be alive at $t_{(n)}$. The number of captures at the other five sites reported from the northern jarrah forest was too low to derive an estimate of, or index to, population size. Where presence was confirmed, data from these sites are reported as the total number of individuals trapped.

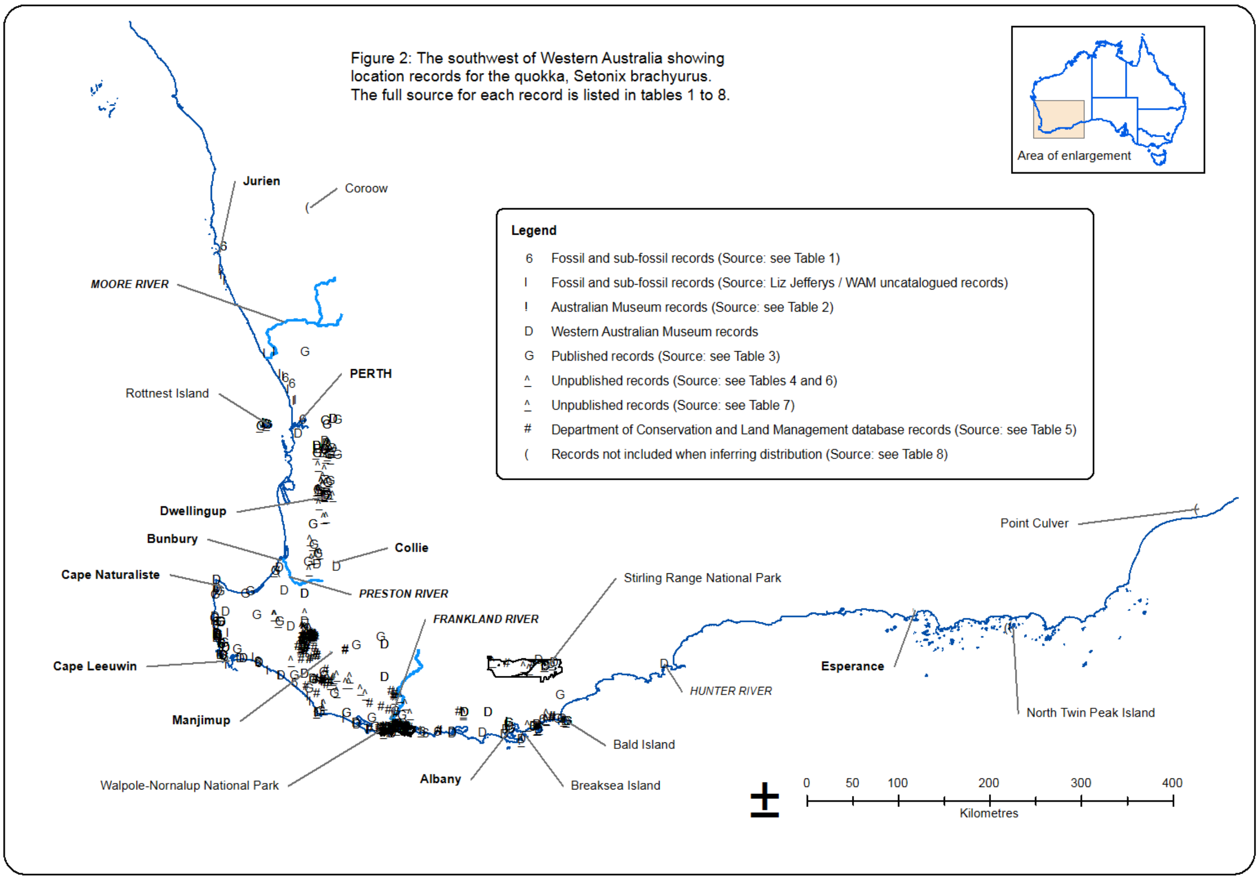

Figure 2. The southwest of Western Australia showing location records for the quokka, Setonix brachyurus. *The full source for each record is listed in tables 1 to 8.*

RESULTS

Records of occurrence

Fossil and subfossil records are shown in Table 1, Australian Museum records in Table 2, published records in Table 3, unpublished records (from various sources) in Table 4, unpublished records from the Department of Conservation and Land Management databases, now Department of Environment and Conservation (DEC) (CALM unpublished; Gilfillan unpublished) in Table 5. Our previously unpublished location data for extant populations are shown in Tables 6 and 7. All records were mapped and shown in Fig. 2. Data from the Western Australian Museum (Kitchener & Vicker 1981) and additional WAM records (WA Museum database records; pers. comm. from E. Jefferys; pers. comm. from N. Cooper) are presented in mapped form only. Five of the records unable to be validated or unable to be confirmed are shown in Table 8. These records are also mapped in Fig. 2, but excluded when inferring distribution. The population translocated to a predator-proof fenced sanctuary (Karakamia Sanctuary, east of Perth) is also listed in Table 8 and mapped in Fig. 2, but also excluded from inferred distribution, as is the captive colony formerly housed at the University of Western Australia and the location of a failed translocation – the Harry Waring Marsupial Reserve, Jandakot (Short et al. 1992). Two unconfirmed records (Muddy Lake, south of Bunbury and a Water Corporation reserve near Dunsborough) are also listed in Table 8 and mapped in Fig. 2, but excluded from inferred distribution mapping.

Estimates of population size and survivorship

The '*deaths but no immigration*' Jolly-Seber estimate of population size for Gervasse was 49 ±7.9 and is shown in Table 7, as are results from opportunistic trapping programs initiated to determine presence at five other sites. Known to be alive (KTBA) estimates for the period 1992 to 2000 for the Gervasse population are shown in Table 9.

DISTRIBUTION

Distribution pre European settlement

There is no evidence to suggest the quokka has extended its distribution since European settlement and all published and unpublished accounts imply a progressive contraction of this distribution. Therefore, distribution pre-European settlement is inferred from current and historically known location records and from subfossil records and is shown in Fig. 3. The age, i.e. sub-fossil, of the Hasting's Cave deposits east of Jurien Bay (Table 1 and Fig. 2) indicate this to be the northern extent of the

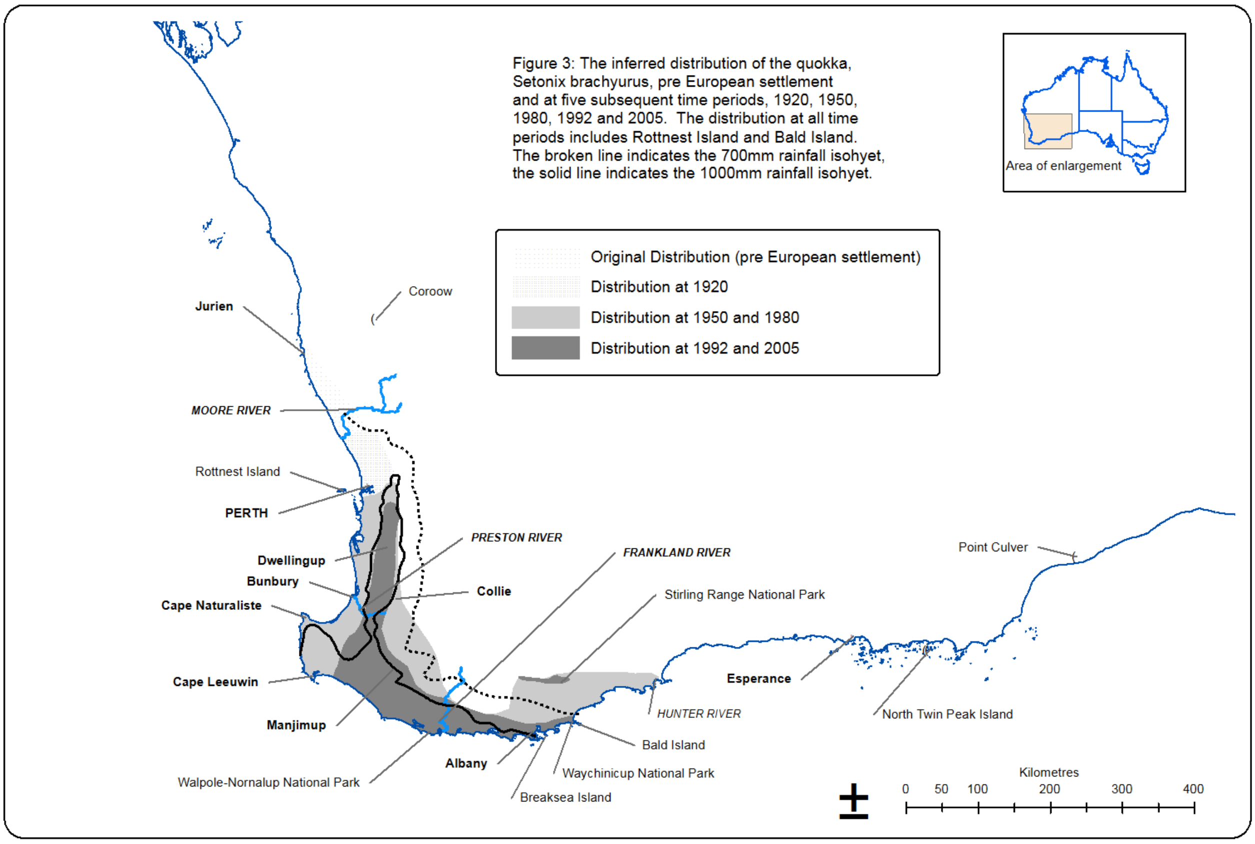

Figure 3. The inferred distribution of the quokka, Setonix brachyurus, *pre European settlement and at five subsequent time periods, 1920, 1950, 1980, 1992 and 2005. The distribution at all time periods includes Rottnest Island and Bald Island. The broken line indicates the 700mm rainfall isohyet, the solid line indicates the 1000mm rainfall isohyet.*

quokka's pre-European distribution, as concluded by Baynes (1979). Sub fossil deposits at Yanchep (Merrilees 1965) and the series of deposits from Perth to Jurien Bay (E. Jefferys pers. comm. to MWH) indicate this distribution was continuous. The Hunter River record (Kitchener & Vicker 1981), east of Albany is the eastern most record. Therefore, the inferred pre-European extent of occurrence on the mainland extends from Jurien Bay, southward through the Swan Coastal Plain, the jarrah and karri forest areas, the Leeuwin-Naturaliste region, the south coast and east to the Hunter River, east of Albany. This distribution encompassed an area of approximately 44 300 km^2, inclusive of Rottnest Island (15.5 km^2) and Bald Island (7.8 km^2). This area is exclusive of Breaksea Island, North Twin Peak Island and South Twin Peak Island and exclusive of the south coast, east of the Hunter River, considered by Shortridge (1909) to be within the quokka's original distribution.

The two records from Breaksea Island are from skulls collected by Ian Abbott[3] in 1975 (Kitchener & Vicker 1981). There have been no further records from Breaksea Island and the true origin of these skulls is unclear. The skulls may be sub-fossil specimens representing a natural population which subsequently died out after it became isolated on the Breaksea peninsula when it was separated from the mainland approximately 7 000 years ago (Ian Abbott pers. comm. to PJdeT). Alternatively, explanations (as proposed by Ian Abbott, pers. comm. to PJdeT) include: (i) quokkas still occur on Breaksea Island but have been overlooked; (ii) sealers known to have been operating in the area from the 1790s, and/or Noongar women held captive on the Island, caught quokkas on the mainland and left their remains on Breaksea Island. This is supported by historical records which refer to sealers marooning Noongar women on islands; and (iii) residents on the Island, including a lighthouse keeper present there from 1858, or other visitors, attempted and failed to establish a quokka population on the Island.

Recent work examining the effect of weeds on nesting seabirds has involved considerable time traversing all vegetation types on Breaksea Island and has failed to detect any sign of quokka activity or presence and studies examining sub-fossil remains of seabirds have not identified fossil or subfossil quokka remains (Peter Collins, pers. comm. to PJdeT)[4]. Although quokka remains may have been overlooked (Peter Collins, pers. comm. to PJdeT), there seems to be insufficient evidence to include Breaksea Island within the original distribution of the quokka.

Shortridge (1909) provided the sole reference to quokka presence on *'Twin Peak Island'*, presumably referring to either North Twin Peak Island or South Twin Peak Island in the Recherche Archipelago, off the coast at Esperance. Glauert (in Serventy et al. 1954) described the quokka as plentiful on Rottnest Island and *'some islands off the south coast'*. However, there are no other records of occurrence of the quokka from the islands off Esperance and numerous authors (Abbott & Burbidge 1995; Burbidge 1977; Calaby 1971; Glauert 1933; Maxwell et al. 1996; Sharman 1954; Waring 1956) list the quokka as present on only Rottnest Island and Bald Island. Quokka presence was not recorded on any of the islands in the Recherche group by Serventy (1953), however, the tammar wallaby, *Macropus eugenii*, was recorded as plentiful on Middle Island and North Twin Peak Island. Similarly, Kabay and Start (1976) were unable to confirm presence of quokkas on either North or South Twin Peak Island when they surveyed both islands in 1976. The tammar and quokka do not occur sympatrically on any island and various hypotheses have been forwarded to explain this (see Clarke 1948; Main 1961; Serventy 1951; Serventy 1953). The most parsimonious explanation for the lack of sympatric occurrence is that the small to medium size insular macropod fauna is determined by the climatic conditions at the time of separation from the mainland, with persistence determined by continued availability of suitable habitat. Where islands are small, inter-specific competition operates and one species only will persist. Main (1961) hypothesised an island area in excess of six square miles was necessary to support a single species of small macropod. This hypothesis is consistent with the occurrence of tammars only on Garden Island and quokkas only on Rottnest Island. It is also consistent with the presence of quokkas only on Bald Island.

Given the size of North and South Twin Peak Island and the presence of the tammar on North Twin Peak Island, it is unlikely the quokka also occurred there. The '*Twin Peak Island'* record of Shortridge (1909) therefore appears to be spurious and we believe the record is a reference to the tammar wallaby, presumably from North Twin Peak Island. Thus, we have interpreted the pre-European distribution of the quokka to be exclusive of the islands of the Recherche and exclusive of the south coast, east of the Hunter River. The absence of quokkas from the fossil and sub fossil records from this region is consistent with this inferred distribution.

The inferred pre-historic distribution is not different from the inferred distribution, pre-European settlement. Although abundant in the fossil record dating to the Pleistocene (Balme et al. 1978) (Table 1), the quokka appears to have been restricted to the south-west corner of Australia. The mainland population was presumably split by rising sea levels, with the Rottnest Island population separated between 6 000 and 8 000 years before present (BP) (Churchill 1959). The Bald Island population was separated almost 10 000 years BP (Storr 1965).

Quokka fossil deposits from Devil's Lair were dated to 35 000 years BP (Balme et al. 1978), although more recent techniques suggest an age in excess of 40 000 years (Turney et al. 2001) (Table 1). Balme et al. (1978) concluded quokkas became increasingly abundant from

[3] Ian Abbott: Science Advisor and Senior Principal Research Scientist, Western Australian Department of Environment and Conservation, Science Division, Kensington

[4] Peter Collins: Fauna Conservation Officer, Western Australian Department of Environment and Conservation, South Coast Region, Albany

32 000 years BP, then showed a slow decline, followed by an increase in abundance. The peak in abundance coincided with a wetter but cooler climate and the period of decline coincided with a period of intense aridity, relative to present conditions. Despite these variations, the quokka was still one of the most abundant species throughout the Devil's Lair deposits (Balme et al. 1978). Balme et al. (1978) concluded the persistence of the quokka throughout this period of climatic variation implies a continuous presence of thickly vegetated watercourses and forest, although the forest species composition may have changed. Importantly, the post-glacial period of aridity experienced in other parts of southern Australia was not as severe in the south-west corner of Australia, thus allowing forest dwelling mammals to persist (Balme et al. 1978).

Distribution at the time of European settlement

The inferred distribution at the time of European settlement is shown in Fig. 3. Published and unpublished reports (Table 3 and 4) indicate the quokka was locally abundant and the distribution encompassed an area of approximately 41 200 km^2. This indicates a relatively minor southern contraction from the pre-European distribution.

With the exception of records north and north-east of Albany, including the Stirling Range National Park, the distribution follows the pattern of rainfall, with records of occurrence confined to areas now receiving an average annual rainfall of 700 mm or more (Fig. 3). Although the distribution is shown as continuous, the Stirling Range and Green Range populations are isolated from all other south coast populations. The Stirling Range population may be in an area of higher rainfall (see climatic influences, below).

Distribution at 1920

The inferred distribution at 1920 shows no contraction from that at the time of European settlement (Fig. 3).

Distribution at 1950

The inferred distribution at 1950 is shown in Fig. 3 encompasses an area of occurrence of approximately 37 800 km^2 and shows a contraction from that at 1920.

Reports of quokka abundance prior to the mid 1930s contrast to later reports (Tables 3 and 4). Prince (1984) included the quokka amongst the species of kangaroos and wallabies commercially exploited in the first 30 years of the 20th century. Records of the specific number of quokkas harvested were not kept and harvests of the quokka and the tammar wallaby were combined with other small macropods. Potential commercial exploitation of the quokka ceased in 1952, with proclamation of the Fauna Protection Act of 1950 (Prince 1984). As none of these harvests was from Rottnest Island (R.I.T. Prince, pers. comm. to PJdeT)[5], the implication is the quokka was sufficiently abundant on the mainland in the early part of the 20th century to enable it to be commercially exploited. These harvested animals were in addition to the large number of quokkas shot in locally organized *'quokka shoots'* which occurred in the 1940s (Les Wilson, pers. comm. to PJdeT)[6] and it seems the quokka was widespread and abundant prior to the 1930s, albeit in restricted habitat (Gould 1863; Perry 1971; Perry 1973; Shortridge 1909; White 1952). Long-term residents from the Northcliffe area (pers. comm. to PJdeT) reported that in the 1930s, and perhaps into the 1940s, quokkas regularly browsed in pasture well away from areas of restricted creekline habitat. Further evidence indicating the quokka was at high density prior to the decline in the 1930s is provided by the 1933 proclamation of the quokka as 'vermin' pursuant to the Vermin Act, 1918 (Government Gazette of Western Australia 1933).

The subsequent decline is reported anecdotally only. This decline is also only partially reflected by the decline in inferred distribution at 1950 (Fig. 3) which shows only a moderate southward contraction from the inferred distribution at 1920. Populations were still present, or inferred by subsequent *'rediscoveries'* to have been present, as far north as the Perth metropolitan area. No westward contraction in range is apparent and similarly, populations persisted on the Swan Coastal Plain. Although the distribution at 1950 shows only a moderate contraction from 1920, the number of known locations clearly declined and abundance at each also appears to have declined. Quokkas may have persisted as far east as the Hunter River area, east of Albany. However, supportive evidence is provided by one WAM registered specimen record only, collected in 1970 (Kitchener & Vicker 1981). The specimen is a part of a mandible (Norah Cooper, pers. comm. to PJdeT), is undated and may be considerably older than the collection date implies. Thus, the westward contraction may have commenced prior to the collection date of the Hunter River specimen and the eastern extent of the distribution at 1950 (and 1980, see below) may have extended no farther than the Waychinicup Bay/Waychinicup National Park and Green Range area (Fig. 3).

Distribution at 1980

The inferred distribution at 1980 is shown in Fig. 3 and shows no contraction from that at 1950. However, as for the pattern of decline described at 1950, records indicate the number of known populations had decreased and most published accounts referred to the quokka as rare on the mainland (Table 3).

Distribution at 1992

The inferred distribution at 1992 is shown in Fig. 3 encompasses an area of approximately 17 800 km^2 and

[5] R.I.T. (Bob) Prince: Senior Research Scientist, Western Australian Department of Environment and Conservation, Science Division, Woodvale

[6] Les Wilson: long-term resident of the Northcliffe area.

shows a marked contraction from the distribution at 1980. With the exception of a recently reported rediscovery at Muddy Lake, south of Bunbury (Dell & Hyder-Griffiths 2002) (Table 4) and an unconfirmed record from the Dunsborough area (Table 8), the last records from the Swan Coastal Plain are from 1961 from Bibra Lake, at the southern outskirts of the Perth metropolitan area (Kitchener & Vicker 1981) and from 1975 and 1976 from the Bunbury/Muddy Lake area (Table 4) (Hart et al. 1986; Kitchener & Vicker 1981). The last confirmed record from the Cape Leeuwin–Cape Naturaliste area is from 1979 from Wardanup Hill, south of Dunsborough (Kitchener & Vicker 1981).

Populations were present, or inferred as still present by subsequent 'rediscoveries', at Churchman Forest Block, within 10 km of the Perth metropolitan area. Exclusive of Bald Island, the eastern most records are from the Waychinicup National Park area east of Albany and Green Range, northeast of Albany. The Stirling Range population(s) is shown as isolated from other south coast populations and may have been isolated prior to 1992.

Current distribution

The inferred current distribution is shown in Figs 3 and 4 and is unchanged from 1992.

Trapping in 1995–96 in the Dwellingup and Manjimup areas at sites known to support quokka populations in the 1990s failed to confirm presence at numerous sites (Dillon 1996) (Table 10). With the exception of the unconfirmed records from Muddy Lake and Dunsborough, quokkas are now considered absent from the Swan Coastal Plain. The skull collected at Muddy Lake (Dell & Hyder-Griffiths 2002) in September 2002 has no associated soft tissue and is not aged (Norah Cooper, pers. comm. to PJdeT). Its collection date does not necessarily infer presence of an extant population at the time of collection. Quokka presence is otherwise only inferred at this location by the presence of runways. There is an unconfirmed report of quokka occurrence from a Water Corporation managed reserve in the Dunsborough area and unsubstantiated anecdotal reports of presence in the Cape Leeuwin–Cape Naturaliste area.

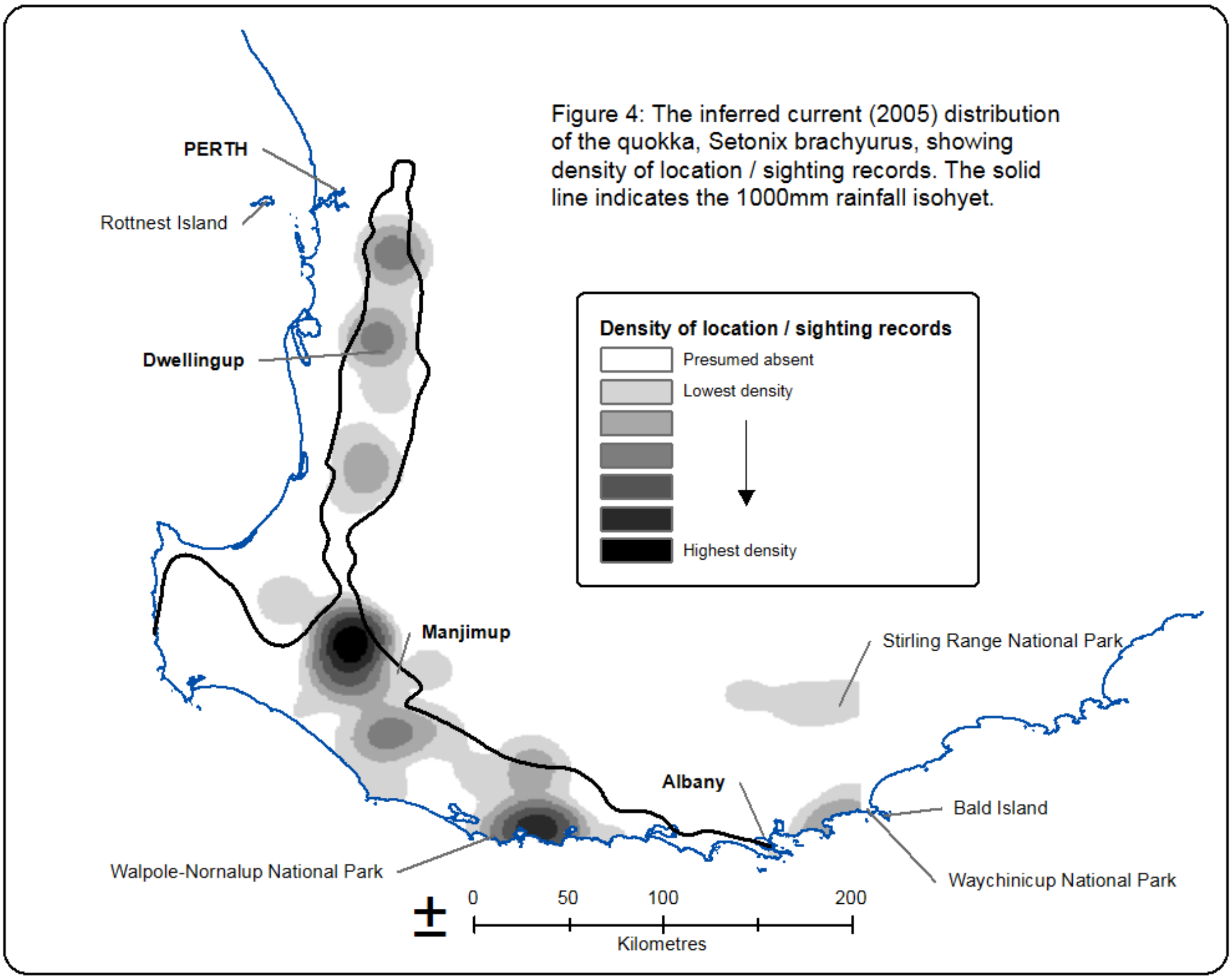

Figure 4. The inferred current (2005) distribution of the quokka, Setonix brachyurus, *showing density of location / sighting records. The solid line indicates the 1000mm rainfall isohyet.*

Presence of suitable habitat and anecdotal reports suggest quokkas may also still occur in the lower catchment of the Blackwood River, north-east of Augusta (Roger Hearn, pers. comm. to PJdeT)[7]. Data unavailable for this review and referred to by Liddelow (2006) indicated several populations may occur west of Nannup. The current inferred distribution (Fig. 3) includes these records, however the pattern of these records of occurrence combined with sites also examined by Liddelow (2006) where quokkas were previously known to occur and are considered to no longer occur, suggest this western forest margin may be experiencing the same decline detected in the northern jarrah forest.

The most northerly records from the Darling Plateau are from Churchman Forest Block, approximately 10 km south-east of the Perth metropolitan area (Table 4). The confirmed sites from the northern jarrah forest extend in a narrow band along the Darling Plateau and are bounded by the 1 000 mm annual rainfall isohyet (Fig. 3). There are no confirmed records of extant populations between Collie (Davis Forest Block) and Nannup (Boronia, Gregory and Helms forest blocks) (Table 6, Fig. 3). With the exception of the records from Boronia Forest Block and records east of Nannup (Liddelow 2006), the Nannup population(s) and forest populations farther south are also almost entirely within the 1 000 mm annual rainfall isohyet (Fig. 3). The most easterly mainland records are from the south coast near Waychinicup National Park, east of Albany, from presence inferred by collection of hair from Green Range north-north-east of Albany (J.A. Friend, pers. comm. to PJdeT)[8] and from the Stirling Range National Park, northeast of Albany. As depicted by the inferred distribution at 1992, the Stirling Range and Green Range population(s) appear to be, and may always have been, isolated from other south coast populations.

Figure 4 shows the current inferred distribution based on records of occurrence from 1992 to present. The density gradient depicted (Fig. 4) reflects the density of sighting/location records. It does not necessarily reflect population densities and the nodes of inferred high population density are, to some extent, likely to be an artefact of proximity to townsites and local interest in reporting sightings.

DISCUSSION

Distribution and population estimates

The contraction of distribution has been greatest from the northern extent of the geographic range and from the Swan Coastal Plain. The northern-most known extant population is approximately 10 km south-east of Perth. With the exception of the unconfirmed records from Muddy Lake and the Water Corporation reserve near Dunsborough, the quokka is now considered absent from the Swan Coastal Plain and the Cape Leeuwin–Cape Naturaliste area and occurs only as far east as Waychinicup National Park (Figs 2 and 3).

Surveys aimed at determining presence in forest areas since the early 1970s have confirmed quokka populations from the northern (Dwellingup) and southern (Manjimup) forest areas are patchy and discontinuous. The known northern limit of the present distribution was extended in 1995 by discovery of a population near Jarrahdale (Rosella Road) (Tables 6 and 7), in 1996 by re-discovery of a population north-east of Jarrahdale (Albany Highway/Travellers' Arms) (Tables 6 and 7) and in 2001 and 2002 by discovery of populations within Churchman Forest Block, 10 km south-east of the Perth metropolitan area (John Liddington, pers. comm. to PJdeT, Table 4)[9]. Although there are in excess of 40 records of occurrence in the northern jarrah forest post 1992 (Tables 3, 4, 5, 6 and 7), several of these records of occurrence may constitute a single population. Equally importantly, confirmation of presence does not equate with persistence of a population. Figure 4 should therefore be interpreted cautiously, as each sighting/location record does not necessarily reflect a separate population and the density gradient depicted reflects the density of location/sighting records, not population density. Although the nodes which depict highest density in the southern forest, near Manjimup, and the south coast, near Walpole-Nornalup National Park, concur with our observational and unquantified survey data which suggest these areas support the highest density populations (exclusive of Rottenest Island), these nodes also reflect proximity to townsites or areas where there is local interest in reporting sightings. Therefore, the high density nodes are also likely to reflect the level of local survey effort and the level of local interest in reporting sighting records. They should not be seen as quantified estimates of abundance.

Estimates of abundance were available from six sites only, rarely reported more than twenty to thirty individuals and often comprised considerably fewer (Table 3 and 7). The Gervasse population is the only known population shown to support in excess of forty individuals (Table 7). The northern-most sites appear to be at critically low density. The Rosella Road population is thought to be at risk of local extinction (Hayward et al. 2003). The Wild Pig Swamp (Lewis Swamp) site supported quokkas in the early 1990s (Dillon 1993), however despite the evidence of fresh activity, trapping failed to confirm quokka presence when trapped in 1995 (de Tores, Dillon, Tomkinson and Buehrig, Tables 6 and 7) and in 1998–2000 (Hayward et al. 2003). The Holyoake site is thought to be locally extinct (our data and Hayward et al. 2003).

Results from published accounts (Christensen et al.

[7] Roger Hearn: Regional Ecologist, Western Australian Department of Environment and Conservation, Manjimup

[8] J.A. Friend: Principal Research Scientist, Western Australian Department of Environment and Conservation, Science Division, Albany

[9] John Liddington: Water Authority of Western Australia, Armadale

1985) and our trapping surveys (Tables 6 and 7) have consistently returned low capture rates from these forest areas. Capture rates of 0.3 (Dillon 1993) and 0.07 to 0.99 (Hayward et al. 2003) quokkas per 100 trap nights for sites in the Dwellingup area and 1.2 per 100 trap nights over three sites north of Dwellingup (Sinclair 1999), are representative of trapping success at these low density sites.

Hayward et al. (2003) believed the northern jarrah forest population formerly constituted a functional metapopulation which is now under threat of collapse. Collapse of this metapopulation, or collapse of the remaining catchment-confined populations, would result in a considerable contraction of the quokkas' distribution. Given the lag time required to detect a decline in a population, we believe there is an urgent need for a coordinated and site-prioritised monitoring program at known quokka sites and appropriate quantitative analyses of monitoring results (see section on management recommendations).

An additional series of surveys has been conducted post collation of the data reported here (Graeme Liddelow[10] and Alan Wright[11], pers. com. to PJdeT) and indicate presence of quokkas at numerous additional locations within the southern forest and northern jarrah forest. However, no data were collected on population size or movement between populations. The likelihood of persistence of these populations is unknown.

Habitat use

Hayward (unpublished, reported in summary in de Tores et al. 2004) concluded all extant northern jarrah forest populations were associated with creeklines characterised and dominated by the ti-tree, *Taxandria linearifolia* (formerly *Agonis linearifolia*), and further concluded quokka populations from the northern jarrah forest are restricted to areas supporting a structural mosaic of burnt and unburnt vegetation. These findings concur with records from the mid 1970s to 2002 (our records, various unpublished accounts and confirmed sightings).

Hayward (unpublished, reported in summary in de Tores et al. 2004) also examined 66 sites in the northern jarrah forest to assess quokka presence/absence. General Linear Modeling (GLM) and model selection through use of a mixed approach of stepwise removal of variables and the Information-Theoretic approach and Akaike Information Criterion (AIC) (Burnham & Anderson 2002) was used to identify the 'best' model to describe the preferred habitat of the quokka. We do not advocate this mixed approach and recommend use of the Information-Theoretic approach and selection from a set of *a priori* candidate models for any further analyses.

From the mixed approach, three models equally well described the preferred habitat. The explanatory variables of the preferred models were:

(i) the number of 1080 meat baits delivered per hectare (an increased number of baits was correlated with quokka presence);

(ii) the average age of the swamp in terms of years since last burn (there was a positive correlation between years since last burn and quokka presence);

(iii) a habitat factor score (NJF4) (characterised by possessing large areas of *Taxandria* swamp burnt five to nine years previously – positively correlated with quokka presence);

(iv) a habitat factor score (NJF2) (characterized by a high proportion of jarrah – marri open forest and *Taxandria* swamp burnt 15–19 years previously – this variable was negatively correlated with quokka presence); and

(v) increasing distance to anthropogenic disturbance.

Hayward (unpublished, reported in summary in de Tores et al. 2004) concluded these features highlight the importance of a mosaic of age classes within the swamp. This mosaic needs to support early (< 10 years post-fire) and late (long unburnt) seral stages. The intermediate seral stage (15–19 years post fire) is avoided. Therefore, this is a mosaic of specific age classes (young and old) rather than simply a mosaic of mixed age classes. We recommend adopting an active adaptive management program to determine whether conservation management of the quokka can be improved, through the use of fire, to create and maintain this preferred mosaic (see management recommendations section).

The relative importance to the quokka of plant species adapted to different fire intervals also needs to be assessed. For example, species such as *Taxandria linearifolia* will rapidly generate from root stocks and provide a dense cover within one year post a spring fire (Kimber 1974), whereas many other species from riparian zones generate from seed and are adapted to longer intervals between fire (Abbott 1999; Burrows & Wardell-Johnson 2003). Potential conflict with other conservation management priorities must also be addressed. For example, riparian systems supporting quokka populations may also support fire sensitive relictual plant taxa and communities (Burrows & Wardell-Johnson 2003). Therefore, we caution that any imposed fire regime and adaptive management approach should be supported by an appropriate level of monitoring of all species potentially affected by the regime.

Although present in the northern jarrah forest, the habitat occupied there suggests the quokka is not a forest-dwelling species, or more specifically, is not a species of the more open northern jarrah forest. Historic accounts of the appearance of the south-west forests and the pattern of burning by Noongar people in northern jarrah forest have been interpreted by Hallam (1975) as indicating the forests '*comprised tall, straight, mature trees, all frequently scorched but clear of undergrowth and easy to move through*'. If the forest structure was as described by Hallam (1975), it would not have been

[10] Graeme Liddelow: Senior Technical Officer, Western Australian Department of Environment and Conservation, Science Division, Manjimup

[11] Alan Wright: Nature Conservation Officer, Western Australian Department of Environment and Conservation, Swan Region, Jarrahdale

conducive to a contiguous distribution of a species dependent upon swamp and creekline vegetation and may have restricted the quokka to discrete catchments, with minimal dispersal and movement of individuals between catchments.

In southern forest areas, populations appear to be less discrete and the quokka inhabits a broader range of habitats including ti-tree thickets in the upper reaches of creek systems, dense streamside beds of rushes, karri regrowth, ridges supporting karri and tingle, *Eucalyptus guilfoylei* and *E. jacksonii*, forests (Christensen et al. 1985) and occurs widely within forest areas supporting an understorey of spreading sword-sedge, *Lepidosperma effusum*, and *Anarthria scabra* (Greg Freebury, pers. comm. to PJdeT)[12]. Populations from the south coast also appear to be less discrete than the northern jarrah forest populations and occur from Walpole-Nornalup National Park to the Mt Manypeaks area, northeast of Albany (Fig. 3). The extent of mixing (dispersal, immigration and emigration) between sub-populations from the southern forest and the extent of mixing between sub-populations from the south coast areas is not known.

Population genetics – the northern jarrah forest metapopulation

Hayward et al. (2003) hypothesised the northern jarrah forest formerly supported a metapopulation which is now in a state of 'terminal collapse'. Conversely, results from a study on the genetic structure (Alacs 2001) of the same populations revealed these northern jarrah forest populations showed no evidence of mixing. The latter study suggests these populations may never have constituted a single metapopulation. However, the two findings are not mutually exclusive. Alacs (2001) and Hayward et al. (2003) examined the same geographically separated populations (different catchments) from within the northern jarrah forest. We hypothesise there may have been mixing (gene flow) within catchments, but little or no mixing between catchments. Each catchment may have constituted a functional metapopulation.

Historical evidence from the Swan Coastal Plain is consistent with this hypothesis and suggests the populations from the Coastal Plain were discrete and confined to individual swamps and/or catchments or sub-catchments. We further hypothesise the populations from the northern jarrah forest, although confined to catchments or sub-catchments, mixed with populations from the same catchment on the Swan Coastal Plain. Hence metapopulations may have existed, but under this scenario, each catchment or subcatchment would have supported a metapopulation. With progressive fragmentation of suitable habitat in the jarrah forest and on the coastal plain (draining of swamps and increased distances between suitable habitat patches), movement between habitat fragments would have been less frequent and eventually ceased.

Factors influencing decline of the quokka

Numerous studies have attempted to determine the causes of the widespread decline in Australia's mammalian fauna since European settlement (see for example Burbidge & McKenzie 1989; Calaby & Grigg 1989; Calver & Dell 1998a; Calver & Dell 1998b; Morton 1990; Recher & Lim 1990; Short et al. 2002; Short & Calaby 2001; Smith & Quinn 1996; Wilson & Friend 1999). These reviews have been selective and addressed some, but not all of the plausible causes for decline. In a comprehensive analysis, Abbott (2001b) reviewed the role of fifteen possible causes for the decline of the bilby, *Macrotis lagotis.* His conclusion concurred with Watts (1969) i.e. that the fox was *'the necessary and sufficient factor associated with regional declines'* of the bilby.

Different studies have attributed the decline in distribution and abundance of the quokka to specific, but varying causes. A marked decline of the quokka was recorded during the 1930s (White 1952). Christensen (1978; Christensen 1980b) presented evidence for a decline in a range of mammal species from south-west Western Australia in the period from 1973 to 1978 and believed this decline was the result of an increased level of predation by foxes. Christensen (1978) further suggested this increase in fox predation coincided with a cessation of widespread 1080 baiting for rabbits, which in turn led to a reduction of secondary poisoning of foxes. King et al. (1981) concurred with this belief. The phenomenon of secondary poisoning of foxes was subsequently demonstrated by Algar and Kinnear (1996). Our data suggest a period of marked decline in the extent of occurrence between 1980 and 1992 (Fig. 3). However, this period of decline may be an artefact of the time periods used for mapping. The mapped decline may reflect the decline identified by Christensen (1978).

A widespread decline of many species, particularly in more arid areas, was recorded in the 1880s (Shortridge 1909). However, Shortridge (1909) also noted the mammals of the south-west, to as far north as the Moore River, had not *'disappeared in the same extraordinary way'*. Burbidge and McKenzie (1989) attributed the modern (post 1900) decline of Western Australia's non-volant terrestrial, critical weight range (35 g–5.5 kg) mammalian fauna to environmental changes since European settlement. They believed these changes reduced available productivity by diverting resources to humans and introduced species and reduced vegetative cover through grazing and altered fire regimes. Critical weight range mammals suffered the greatest declines due to their limited mobility and relatively high metabolic requirements (Burbidge & McKenzie 1989). They further identified factors likely to ameliorate susceptibility to decline and believed critical weight range mammal species with the ability to use, or with a requirement for rockpiles were afforded additional protection. Kinnear et al. (1988) had previously identified the predation

[12] Greg Freebury: Operations Officer – Nature Conservation, Western Australian Department of Environment and Conservation, South Coast Region, Albany

refuge value of rockpiles and subsequently (Kinnear et al. 1998) provided more empirical evidence for this. Burbidge and McKenzie (1989) believed species using burrows, sheltering in hollow logs or to some extent, those with an arboreal habit, would also be afforded protection from predation. We believe the quokka, with a requirement for a vegetation mosaic which includes areas difficult to penetrate, represents a further group of critical weight range mammal fauna benefiting from use of a predation refuge, analogous to the rock wallaby use of rockpiles. However, we caution that although refuges may provide temporal respite from predation, long-term persistence of predation may still lead to local and regional extinctions, despite the presence of refuges.

Burbidge and McKenzie (1989) claimed the arid zone fauna were most at risk and fauna from the mesic zone were somewhat buffered from the changes which resulted in reduced resource availability. The more mesic south-west Western Australian environment may have buffered the fauna from this initial decline. Recent research suggests fauna from mesic areas are no longer secure (Woinarski et al. 2001). Mesic areas may have more available environmental productivity and may tolerate longer periods of the various disturbances responsible for the decline observed in arid areas. However, continued depletion of environmental resources and a reduction in refugia may be contributing to a more modern decline. The decline of the quokka is consistent with this pattern, with the distribution contracting from the more arid northern and west coast areas, while populations from the more mesic southern forest and south coast areas have persisted (Figs 3 and 4).

Predation by the dingo, European red fox and feral cat and interaction with other species

Three eutherian predators, the dingo, *Canis lupus dingo*, the European red fox, *Vulpes vulpes,* and the cat, *Felis catus,* have been introduced to Australia since the arrival of humans. These eutherian predators acted on a predator-naïve marsupial prey which had not interacted with medium-sized cursorial predators for the preceding 20 000 to 30 000 years (Johnson et al. 1989).

The Dingo

The dingo was introduced to Australia by Asian seafarers approximately 3 500 to 4 000 years ago (Corbett 1995b). Where present, the primary prey of the dingo is usually medium sized mammals (Corbett 1995a) and large macropods (Corbett & Newsome 1987). However, dingoes will prey upon a wide range of species (Corbett & Newsome 1987; Newsome et al. 1983; Robertshaw & Harden 1985; Thomson 1992; Whitehouse 1977) and the preferred prey in any particular area appears to be determined not only by prey abundance, but by prey availability (Corbett 1995a; Corbett & Newsome 1987; Vernes et al. 2001). In north-west Western Australia, Thomson (1992) found large prey items, mostly kangaroos, featured prominently, with smaller prey items taken less often. Taking smaller prey was associated with a breakdown of dingo packs and an increase in the number of solitary dingoes (Thomson 1992).

In south-west Western Australia, the quokka was common prior to the 1930s and may have been an occasional prey item for the dingo, although the quokka's preference for densely-vegetated habitat may have offered refuge from predation. However, the established presence of the dingo within the region prior to the modern decline of the quokka, implies dingo predation was not the major cause of that decline. Our own observations indicate dingoes are now exceedingly rare in the jarrah forest and are thus unlikely to be generating predation pressure of any consequence on quokka populations. Historically, the dingo is believed to have had little major impact on the majority of Australian fauna with the exception of the Thylacine, *Thylacinus cynocephalus*, and the Tasmanian devil, *Sarcophilus harrisii*, (see Corbett 1995b; Jones 1995; Rounsevell & Mooney 1995).

The impact of the dingo on Australian native fauna may have been minimised through competitive inhibition by the sympatric mesopredator, humans. Similarly, dingoes may exhibit an indirect effect as a mesopredator (Newsome 2001). Dingoes are thought to prey on the European red fox and the feral cat where they occur sympatrically in the Nullarbor region of Western Australia (Marsack & Campbell 1990), however Marsack and Campbell (1990) implied the evidence for this was circumstantial. Thomson (1992), as part of an extensive study in north-west Western Australia, found the feral cat was present as a prey item only once, and the fox was not present at all in the stomach contents from a sample of 95 dingoes. Newsome et al. (1983) recorded the fox and the cat present in 1.6 and 0.3 percent respectively from the stomach contents of 530 dingoes in a trapping and dietary analysis study in south-eastern Australia. The lack of any other comprehensive data supporting the assertion of intraguild predation suggests dingoes are more likely to competitively inhibit foxes and cats than prey directly on them.

The European red fox

The red fox was introduced to eastern Australia in the late 1860s to 1870s (Rolls 1969; Troughton 1965) and had spread to the south-west of Western Australia by the early 1930s (Gooding 1955; Jarman 1986; King & Smith 1985; Long 1988). The arrival of the fox in south-west Western Australia coincides with the reported decline of the quokka (White 1952) and numerous small to medium size terrestrial native mammals from mainland Australia (Burbidge & McKenzie 1989; Daubney et al. undated; Friend 1990; Jenkins 1974; Richards & Short 1996). Numerous authors have suggested the fox was responsible for this fauna decline, see for example the review by Abbott (2001b). Although it is only relatively recently that the fox has been empirically linked to the suppression of native mammal populations (see Kinnear et al. 1988; Kinnear et al. 1998), it seems very likely foxes were responsible for the initial decline of the quokka on the mainland and have contributed to its continued decline. The abundance of quokkas on Rottnest Island in the absence of foxes (Dunnet 1963; Holsworth 1964; Holsworth 1967; Kitchener 1970; Shield 1959) is consistent with this hypothesis. Further evidence of the effect of foxes on quokkas comes from a series of reintroductions, and ultimate failure, of nearly 700 Rottnest Island quokkas between 1972 and 1983 to a fenced, but not fox-proof, enclosure at Jandakot, near Perth (Short et al. 1992) (Table 8). By 1988 only nine quokkas remained in the 254 ha enclosure. The low survivorship was attributed to predation by foxes and feral cats (Short et al. 1992).

The fox is now generally accepted as a significant predator of medium size terrestrial native Australian mammals. Recognition has been at a national and state level, as demonstrated by the Commonwealth of Australia's *Threat Abatement Plan for Predation by the European Red Fox* (Biodiversity Group Environment Australia 1999) and two recently published state plans for control of the red fox – the *Victorian Pest Management. A framework for Action. Fox Management Strategy* (DNRE 2002) and the *New South Wales Threat Abatement Plan for Predation by the Red Fox* (Vulpes vulpes) (NSW NPWS 2001). Fauna management programs in Western Australia have recognised the importance of fox control and the Western Australian Department of Environment and Conservation (DEC) has implemented a broad scale fox control and fauna recovery program, *Western Shield*. The program is focused on recovery of threatened fauna through effective fox control and translocation of threatened fauna species in the presence of fox control.

The predecessor to *Western Shield* was Operation Foxglove, a large scale experimental 1080 baiting program within the northern jarrah forest of south-west Western Australia (de Tores 1999). The areas baited within the 550 000 ha study area of Operation Foxglove, combined with local baiting at the Gervasse site, include or abutted all but one of the known extant occurrences of the quokka in the northern jarrah forest. The Foxglove baiting program commenced in 1994 and, despite the fact that quokka populations have not shown an increase in abundance since this baiting program commenced (Hayward et al. 2003), we hypothesise the quokka has persisted in the northern jarrah forest as a result of this baiting and further believe effective long term conservation of the quokka requires implementing and maintaining fox control programs (see management recommendations).

The feral cat

Aborigines from the desert regions of central Australia and central Western Australia believe cats to have either always been present or to have arrived *'from the west'* (Burbidge & McKenzie 1989). Although far from claiming the assertion as definitive, Gaynor (2000) believed this arrival from the west may have been a result of cats escaping from Dutch shipwrecks off the west coast of Australia. Dickman (1996) noted cats could have been introduced to north-western Australia as early as the 16th Century. However, Abbott (2002), from a detailed search of historical records, concluded cats were not present on mainland Australia prior to European settlement. Abbott (2002) presented a compelling argument and conceptual model to support his belief that cats spread from multiple points of introduction at coastal locations in the period 1824 to 1886. Abbott (2002) and others before him (see Morton 1990) also argued there is insufficient evidence to support the assertion that cats were responsible for any mammal extinctions from arid Australia. However, there is general consensus in the literature (see Dickman 1996) to suggest the cat has contributed to the decline of many species. Although there is some empirical evidence correlating the presence of cats with extinctions of critical weight range mammals from islands (Burbidge & Manly 2002) and empirical evidence indicating predation by feral cats led to reduced population sizes of small native vertebrates (Risbey et al. 2000), we caution against inferring a causal relationship between cat predation and fauna extinctions on the mainland generally, and between cat predation and quokka decline specifically.

Abbott (2002), citing Catling , Coman (1991) and Dickman (1996) noted the optimal prey size for cats was approximately 200g. The weight of adult quokkas ranges from 1.6 to 3.5kg for females and 2.7 to 4.2 kg for males (Hayward et al. 2003; Kitchener 1995), which suggests if cats prey on quokkas, predation may be restricted to juveniles, or will favour predation of juveniles. Circumstantial evidence suggests feral cats prey on the young of bridled nailtail wallabies, *Onychogalea fraenata*, (Horsup & Evans 1993) and the brush-tailed rock-wallaby, *Petrogale penicillata*, (Short et al. 1992). More convincing evidence was presented implicating the cat as a significant predator of juvenile and adult allied rock-wallabies, *Petrogale assimilis*, (Spencer 1991). All three species are larger than the quokka (Eldridge & Close 1995; Evans & Gordon 1995; Prince 1995), suggesting cats may well prey on juvenile and/or adult quokkas.

Cats have also been identified as predators of several species of Australian mammals with adult body weights greater than 200 g. For example, cats were responsible for between 25 and 32% of predation events of adult woylies, *Bettongia penicillata*, at translocation release sites in the northern jarrah forest (de Tores 1999) and responsible for predation of adult brushtail possums, *Trichosurus vulpecula*, in the same study (de Tores, Himbeck, MacArthur, Maxwell, White and Rosier, unpublished radio telemetry data). Cats have also been reported as preying on adult rufous hare-wallabies, *Lagorchestes hirsutus*, (Gibson et al. 1994), the burrowing bettong, *Bettongia lesueur*, (Christensen & Burrows 1994), the numbat, *Myrmecobius fasciatus*, (Friend & Thomas 1994) and the western ringtail possum (de Tores 2005). Short et al. (1992) concluded cat predation contributed to the failure of a translocation of the banded hare-wallaby, *Lagostrophus fasciatus*. The above suggests cats prey on a suite of native mammal fauna, inclusive of species larger than 200g and have the potential to prey on quokkas. Short et al. (1992) further concluded direct predation by foxes and cats was a more plausible explanation, than overgrazing by rabbits and other macropods, for the failure of the quokka translocations to Jandakot in the 1970s.

However, the failure of the Jandakot translocations and the suspicion that cat predation contributed to those failures are insufficient to conclude cat predation was responsible for the initial and continued decline of quokka populations on the mainland. Equally confounding is the co-existence of cats and quokkas on Rottnest Island with no discernable reduction in quokka abundance. Similarly confounding is the presence of cats in Tasmania with no discernable reduction in quokka-size prey species.

Molsher (1999) concluded, from an experimental study at Lake Burrendong, New South Wales, interspecific competition between foxes and cats was the most likely mechanism limiting feral cats. Interspecific competition between cats and foxes was also thought to be a possible explanation for the observed increase in cat numbers when fox density was experimentally reduced at Heirisson Prong, north-west Western Australia (Risbey et al. 2000). Such a response (mesopredator release) is a potential outcome of DEC's large-scale fox control and fauna recovery program, *Western Shield*. However, the lack of records of cat predation from Rottnest Island and the absence of evidence to support the assertion that the cat was responsible for other mammal extinctions (Abbott 2002), suggests cats are unlikely to be solely or primarily responsible for the widespread decline of the quokka.

Other predators and interactions

Other predators are unlikely to have been responsible for the decline in quokka populations. Nocturnal birds of prey are reported to have been responsible for fossil deposits from several cave sites (see Table 1 – owl accumulated fossil deposits). Two owl species from the south-west of Western Australia, the barking owl, *Ninox connivens*, and the masked owl, *Tyto novaehollandiae*, have been recorded taking prey as large as young rabbits (Schodde & Tidemann 1982), so could presumably prey on juvenile or sub-adult quokkas. Although Johnstone (cited as a pers. comm. by Abbott 1999) regarded the barking owl as a species favouring swamps and edges of rivers, it is not a forest species (Abbott 1999) and was not recorded at any of the seventy forest sites surveyed by Liddelow et al. (2002). The masked owl is infrequently recorded in forest (Abbott 1999) and is more common in woodland or at the interface of agricultural land and forest (Liddelow et al. 2002). Therefore, neither species is likely to have been responsible for the decline of the quokka, particularly within forest areas. The presence of quokka bones recovered from a wedge-tail eagle's eyrie on Bald Island (Storr 1965) indicates the quokka may be an occasional prey item of the wedge-tail eagle. However, we caution against inferring presence of a prey species in the diet of a predator equates with a predation induced decline of the detected prey species. The quokka's diurnal use of densely vegetated swamps within forest areas on the mainland (Christensen et al. 1985; Storr 1964b; White 1952), use of Spreading Sword-sedge, *Lepidosperma effusum*, and *Anarthria scabra* habitat within other forest areas and use of heath habitat on the south coast further minimises the risk of predation by eagles.

Large predatory snakes, e.g. the carpet python, *Morelia spilota*, and to a lesser extent goannas, *Varanus* spp., are able to prey upon species such as the southern brown bandicoot, *Isoodon obesulus*, the common brushtail possum, *Trichosurus vulpecula* , the brush-tailed bettong, *Bettongia penicillata*, (de Tores, Himbeck, MacArthur, Maxwell, White and Rosier, unpublished radio telemetry data), the western ringtail possum, *Pseudocheirus occidentalis*, (de Tores 2005) and the tammar wallaby, *Macropus eugenii*, (David Pearson, pers. comm. to MWH)[13] and may also pose a predation threat to sub-adult quokkas. However, these predators have co-existed with the quokka in the south-west of Western Australia throughout the quokkas existence and there is no evidence to suggest they initiated the decline in quokka abundance. The co-existence of high density populations of the carpet python and the tammar wallaby on Garden Island is consistent with this hypothesis.

The feral pig, *Sus scrofa*, an introduced opportunistic omnivore, is present in forest areas of south-west Western Australia and most climatic regions in Australia (Pavlov 1995). In addition to the commercial health risks posed, where investigated, pigs have been found to pose a significant environmental and management problem (Pavlov et al. 1992). Ecological damage associated with pig activity (rooting) in wet tropical forests in Queensland was shown to vary with forest type, with wet sclerophyll forest sites showing the greatest disturbance (Laurance & Harrington 1997). Our observations (MJD in particular) have confirmed the presence of pigs at numerous quokka sites and, although not supported by any quantitative data, there appears to be a trend of increasing occurrence of pig activity and pig abundance at quokka sites in the south-west forests (MJD, personal observations; Graeme Liddelow, pers. comm. to PJdeT). Non-target captures of quokkas at sites trapped for pig control purposes (see records by Liddington and Staines in Table 4 for the years 2001 and 2002) may indicate an overlap of quokka and pig preferred habitat within the south-west forests. The relatively sedentary nature of pigs (Caley 1997; Saunders & Kay 1996) and the potential for pigs to significantly disturb quokka habitat by creating large openings and easier access for foxes, may pose an additional threat to the conservation status of the quokka.

Climatic influences

The mainland quokka populations appear to have been historically limited to areas of the south-west of Western

[13] David Pearson: Principal Research Scientist, Western Australian Department of Environment and Conservation, Science Division, Woodvale

Australia with an annual average rainfall in excess of 700 mm. The current distribution of the quokka closely follows the limit of the 1 000 mm rainfall isohyet and, for all but the eastern extent of the distribution near the Stirling Range National Park, appears to be limited to areas with an annual average rainfall of 700 mm. or more (Figs 3 and 4). This may reflect the quokka's relatively high water requirements (Main & Yadav 1971).

Populations in the vicinity of Stirling Range and Green Range appear to be isolated from all other south coast populations and also appear to be within a lower rainfall zone (Figs 3 and 4). The locations of rainfall recording stations provided by the Australian Bureau of Meteorology (BoM) indicate stations are located to the north and south of the Stirling Range, with no stations in the immediate vicinity of the known extant quokka populations. The Stirling Range may be in a pocket of higher, orographically generated rainfall, not detected by the BoM rainfall recording stations and not reflected in the pattern of rainfall isohyets. This hypothesis is supported by the presence of an isolated population of the red flowering gum, *Corymbia ficifolia*, (Brown et al. 1998) and the occurrence several wet region bird species (Ian Abbott, pers. comm. to PJdeT) in the Stirling Range. The *Corymbia ficifolia* population is 100 km north of its main distribution and the species is thought to be a relic from a past wetter climate (Brown et al. 1998). Further evidence of this orographic effect was provided by Courtney (1993) who prepared a rainfall isohyet map depicting the highest peaks of the Stirling Range as receiving more than 700mm of rainfall annually. The Stirling Range quokka population(s) may have been traditionally isolated or may represent a remnant of a once contiguous population. In either case, the status and security of these isolated populations and the isolated occurrence at Green Range warrant further investigation.

The Rottnest Island population suffers seasonal mortality over summer and this has been attributed indirectly to dehydration (Barker 1961; Holsworth 1964; Main et al. 1959; Packer 1968; Storr 1964b). Nonetheless, quokkas persisted in the fossil record from south-west Western Australia throughout periods of significant climatic variation from warm and wet to glacial aridity. Cook (1960) suggested climate change was the cause of the modern decline of the quokka. There seems to be insufficient evidence to attribute climate change alone as the major cause of the decline of the quokka since the 1930s. However, Balme et al. noted the persistence of the quokka in the fossil record through periods of aridity may have been because the south-west corner of Australia did not experience the extremes in aridity experienced by other parts of southern Australia. Therefore, the consequences of increasing aridity associated with current patterns of climate change should be seen as a potential threat to the continued persistence of the quokka.

European colonisation and development

Reports from naturalists in the early 1900s indicated the quokka was common prior to and until the 1930s (Gould 1863; Shortridge 1909; White 1952) and, with very few exceptions, most reports suggest quokkas were restricted to specific habitats (see Holsworth 1967; Storr 1964b). Much of the coastal heath and shrubland habitats in the south-west of Western Australia where quokkas once occurred (Shortridge 1909; White 1952) have been cleared for urban development. The coastal plain, from north of Perth to Busselton (Fig. 1) has few remaining pockets of undisturbed vegetation and the remaining fragments are small and easily invaded by introduced predators. The areas known to have historically supported quokka populations from the Swan Coastal Plain were swamps or low lying seasonally waterlogged areas. These coastal plain swamps have been progressively drained, with very few retaining their original drainage patterns. Similarly, the upper reaches of many creek systems in the forested areas of the Darling Range have been cleared for agriculture, dammed to supply water to Perth or split from connecting habitat by roads to such an extent that the remaining quokka habitat is highly fragmented and in places may be too small to support viable populations.

Other factors associated with European colonisation may have similarly affected the quokka. Calver and Dell (1998b) believed all mammal species from the south-west forests of Western Australia historically had a wider distribution and suggested the extant mammal fauna may be resilient to changes in forest structure. However, they cautioned this resilience may not be the case and emphasised the importance of experimentally demonstrating that there are no direct and indirect links between forestry practices and declines in distribution and abundance on the suite of resident native fauna from the south-west of Western Australia. Increases in predation rates (Wayne et al. 2000), increases in the area of edge affected habitat (Wilson & Friend 1999), increases in interpatch distances (Hayward et al. 2003) and increases in roading disturbance (Calver & Dell 1998a) may be indirect effects from management of the jarrah forest. The effect of these activities on quokka populations has not been quantified. Roading and other disturbances associated with mining and harvesting, resulting in removal of habitat and alteration of drainage patterns, also have the potential to contribute to increases in interpatch distances. Construction of logging access roads in 2001–2002 in Nairn Forest Block in the southern forest region of south-west Western Australia has been implicated as an example of the detrimental effects from harvesting and the associated roading activities. Post commencement of roading there was an observed increase in the number of reported quokka roadkills. A minimum of 10 quokka roadkills was reported by a single observer within a six month period in close proximity to, and coinciding with roading activity at Nairn Forest Block (John Austin, pers. comm. to PJdeT)[14]. However, there are alternative and equally plausible explanations

[14] John Austin: Long-term local resident, Northcliffe, Western Australia

for this increase in observed roadkills. Quokkas may have been attracted to areas of new growth resulting from recent burns of roadside verges. This explanation is also consistent with the quokkas' preference for a vegetation mosaic which includes recently burnt areas (de Tores et al. 2004). Nonetheless, this uncertainty highlights the need to identity the cause of the large number of roadkills and to quantify the direct and indirect effects from anthropogenic disturbance.

Fire

The Noongar people have occupied the south-west corner of Australia for at least the last 40 000 years (Balme et al. 1978; Merrilees et al. 1973) and possibly longer (Turney et al. 2001). In the period prior to European settlement, the Noongar people of the south-west are thought to have burnt the jarrah forest, with low intensity fires, with a minimum fire interval of two to three years in the moist to high rainfall areas, and two to five years in the forest areas with lower annual rainfall and lower fuel accumulation rates (Burrows et al. 1995). Burrows et al. (1995) concluded this pattern of burning would have led to a vegetation mosaic which would have included patches of unburnt forest, with most patches *'being less than 6 years since last fire'* (see also Wilson & Friend 1999). Riparian environments may have experienced longer intervals between fires (Abbott 2000; Burrows & Friend 1998).

Ward et al. (2001) (see also Ward & Sneeuwjagt 1999) believed examining fire scars on grass trees, *Xanthorrhoea* spp., provided a more sensitive technique for determining fire history. From examination of grass trees, Ward et al. (2001) believed Noongar burning, or the pre-European frequency of burning in the jarrah forest, was once every three to four years. Lamont et al. (2003) cautioned that the susceptibility of grass trees to fire, and therefore their ability to reflect fire history, depends on their location in the landscape. Burrows and Wardell-Johnson (2003) further cautioned against interpreting historic patterns of fire on a regional scale on the basis of patterns observed among individual grass trees. The findings of Ward et al. (2001) suggested a shorter interval between fires than concluded by Burrows et al. (1995). However, both studies indicated the frequency of burning in forest areas of south-west Western Australia has changed from the frequency used by the Noongar people. Ward and Sneeuwjagt (1999) further implied these changes also apply to coastal areas. Abbott (2003) suggested the interval between fires set by the Noongar people in coastal areas may have been as short as two to four years.

Alterations to fire regimes following European settlement have been implicated with declines in fauna abundance and range (see review by Wilson & Friend 1999). Burrows et al. (1995) believed three distinct fire regime periods or eras could be defined for the forests of south-west Western Australia post European settlement, namely (i) the first European era (1855–1920) where there was a cessation of Noongar burning practices which led to longer intervals between fires and more intense fires; (ii) the second European era (1920–1965) when forestry practices adopted a policy of fire exclusion. Burning was restricted to strategic buffers and fire suppression purposes. Much of the forest remained unburnt and large high intensity wildfires occurred, fuelled by logging debris and naturally occurring high fuel loads; (iii) the third European era (1965–1995) where fuel reduction burning was based on a six to ten year rotation. Although fire frequency for this period was comparable to the pre-European regimes, fire intensity was higher, fuelled primarily by logging debris (Burrows et al. 1995). Towards the end of this third era, and from 1962 in particular, the area burnt by prescribed fire greatly increased (Lachie McCaw[15] pers. comm. to PJdeT and unpublished data). This was a reflection of the then Forest Department's expanded program of broad-scale burning which commenced after 1954 (McCaw et al. 2005; Wallace 1966).

Although this third 'era' encompasses the period 1980 to 1992, i.e. the period within which our data indicate a large contraction in the distribution of the quokka, no direct causal relationship can be drawn, particularly as the areas of greatest quokka decline are outside forest areas subject to this fire regime. Fire regimes in forest areas post 1995 have been similar to the third European era described by Burrows et al. (1995). Discussions with Departmental operational staff involved in prescription burning, combined with the reported reduction in the extent of the area burnt annually in the south-west of Western Australia, indicated a trend of progressively decreasing prescribed-burn fire frequency in the south-west. The 1998–99 prescribed burn program achieved less than 50% of the planned prescribed burning program and was the lowest achieved since 1961 (CALM 1999). The areas *'prescription burnt'* in the south-west forest regions in 1999–2000, 2000–2001 and 2001–2002 were 134 308, 87 866 and 74 739 ha. respectively (CALM 2000; CALM 2001; CALM 2002). From 2002 on this trend of decreasing area burnt annually has been reversed, with 144 835 ha burnt as part of prescribed burns in 2002–2003 and 192 119 ha in 2003–2004 (CALM 2003; CALM 2004). We caution that increasing the area *'prescription burnt'* alone does not equate with burning to provide the preferred habitat mosaic. Our personal observations (PJdeT) suggest broad scale burning has a tendency to use natural barriers as fire boundaries. The *Taxandria linearifolia* creeklines often act as such natural barriers and the long term effect has been to encroach upon these barriers and progressively reduce the size and extent of the *T. linearifolia* creeklines. This type of encroachment does not equate with providing the burn conducive to maintaining the preferred habitat of the quokka. However, effective use of prescribed burns does provide the opportunity to use fire to create the quokka's preferred habitat mosaic as described by

[15] Lachie McCaw: Senior Research Scientist, Western Australian Department of Environment and Conservation, Science Division, Manjimup

Hayward (2002) and Hayward (unpublished, reported in summary in de Tores et al. 2004).

The finding by Hayward (unpublished, reported in summary in de Tores et al. 2004) is only partly consistent with findings from a small-scale study (Christensen & Kimber 1975) specifically examining the effect of fire on the quokka in forest sites near Dwellingup in the 1970s. Christensen and Kimber (1975) concluded quokkas returned to swamps to forage almost immediately after a burn, showed an influx of new individuals (i.e. previously un-trapped animals) and became resident 18 months after the fire. There appeared to be no resident quokka population where vegetative cover was entirely removed by the fire (Christensen & Kimber 1975). An older (unburnt for 15 years) site trapped in that study led the authors to conclude quokkas desert sites unburnt for 15 years and have a preference for a spatial mosaic or patchy burn which provide areas of refuge and areas of foraging habitat (Christensen & Kimber 1975). Hayward (unpublished, reported in summary in de Tores et al. 2004) came to a different conclusion and suggested this 15 to 19 year post-fire component of the mosaic did not represent the upper fuel age of the quokkas preferred mosaic. Hayward (unpublished, reported in summary in de Tores et al. 2004) showed this component of the mosaic was negatively correlated with quokka presence (avoided by quokkas) and the preferred mosaic included an additional component which was long unburnt (see section on habitat use). We therefore suggest a burning regime which will create and maintain the mosaic identified by Hayward (unpublished, reported in summary in de Tores et al. 2004) is required in the northern jarrah forest. This would necessitate different burning regimes from those currently used at quokka sites in the northern jarrah forest (see section on management recommendations).

Small, scattered populations are also likely to be susceptible to stochastic events such as wildfires which may result in localised and more extensive extinctions. Kirke (1983) reported quokkas fleeing from wildfires at Green Range, north of Albany. Similarly, in the Northcliffe area, quokkas observed in large numbers in the 1940s and earlier, and known to feed in paddocks away from vegetated creeklines, were reported as last seen in number at this location when fleeing from a fire in the 1940s (Laurie Wilson, pers. comm. to PJdeT)[16]. Numerous quokkas were also observed in an open paddock after fleeing a wildfire in the Allen Road/Hilltop Road area in Walpole-Nornalup National Park, circa 1987 (John Asher, pers. comm. to PJdeT)[17]. Quokkas are now reported to have repopulated this area and are thought to be in large numbers (Greg Freebury, pers. comm. to PJdeT).

The only known record of occurrence from Karnet Forest Block, west of Jarrahdale, is from quokkas observed fleeing a fire in 1991 (unpublished records from A.N. Start, Table 4). A high-intensity wildfire burnt a large portion of the Stirling Range National Park in November 2000 (pers. obs. of MWH) and numerous quokka deaths were reported. A similar fire in the Stirling Range National Park in 1991 was thought to have been equally damaging to quokkas. However, quokkas were reported to have repopulated burnt areas in subsequent years (Sinclair 1999). A large number of quokka deaths was also recorded as a result of a wildfire in the Nuyts Wilderness area, near Walpole in 2001 (Middleton 2001). Quokkas have subsequently been detected in unburnt patches within the boundary of the Nuyts fire and quokka presence has been inferred at three locations immediately outside the burn boundary. Presence was inferred by detection of scats within typical quokka runways in dense patches of Spreading Sword-sedge, *Lepidosperma effusum*, and *Anarthria scabra* (Greg Freebury, pers. comm. to PJdeT). With the exception of the program established to monitor recovery from the Nuyts fire, the extent of documenting any recovery from these stochastic events has been largely anecdotal.

The quokka appears to be capable of persisting in a fire-prone environment and the absence of low intensity fire from many sites may be a contributing factor to the collapse of the northern jarrah forest metapopulation as described by Hayward et al. (2003). However, there is sufficient evidence from the northern jarrah forest to suggest quokka populations there are dependent on the presence of a structural mosaic which incorporates areas burnt within the previous nine years, but also has a large overall fuel age (i.e. must also include areas long unburnt) (Hayward, unpublished, reported in summary in de Tores et al. 2004).

Further support for the requirement of a mosaic, and not simply a requirement for the presence of fire within the past nine years, is provided by the results from surveys in 1995–1996 (Dillon 1996). From 28 northern and southern forest locations previously known to support quokka populations, nine no longer supported quokkas and seven of these nine sites had been burnt within the previous 10 years (Table 10) (Dillon 1996). Although these areas provide the component of the mosaic which has been burnt within the last 9 to 10 years, they may no longer support areas of long unburnt habitat.

A fire regime of low intensity burns and with a frequency comparable to the third European era of Burrows et al. (1995) may be appropriate to generate the vegetation mosaic preferred by the quokka. However, no single fire regime will benefit all taxa. Of particular concern is the threat to the Noisy Scrub-bird, *Atrichornis clamosus*. The noisy scrub-bird has a preferred habitat of densely vegetated creekline and gully vegetation (Abbott 1999; Burbidge 2003). A too frequent burning regime of creeklines where it and the quokka are sympatric may compromise noisy scrub-bird habitat and *'even a mild fire can render an area unsuitable for many years'* (Burbidge 2003). Although the only known locations where extant populations of the noisy scrub-bird and quokka occur sympatrically are at Two Peoples

[16] Laurie Wilson: Long-term local resident, Northcliffe, Western Australia

[17] John Asher: Environmental Officer, Western Australian Department of Environment and Conservation, Nature Conservation Division, Bunbury

Bay, on the south coast, the noisy scrub-bird has recently been translocated to sites within the northern jarrah forest where quokkas may also occur. Therefore, there is the potential for conflicting fire management requirements at these translocation release sites.

There are also indirect detrimental effects from fire. Christensen (1980a) recorded increases in the predation rate on the brush-tailed bettong following fire. This type of indirect effect may also result in localised increased predation risk for other mammal populations. Kinnear et al. (Kinnear et al. 1988) suggested this type of indirect threat may increase the risk of localised extinctions.

Hunting by Aboriginal people

Gardner (1957), citing John Lort Stokes, referred to observations of Aboriginal people burning the bush for the purpose of catching snakes, lizards and wallabies. These prey were speared as they fled the burning vegetation. Gould (1863) and Evans (undated) were more specific and noted quokkas were eaten by Aboriginal people. Evans (undated) noted the Aboriginal people from the Northcliffe area supplemented their diet with quokka, kangaroo and marron. Gould (1863) noted quokkas were killed in great numbers at the end of the season by Aboriginal people. Gould's (1863) description of Aboriginal people burning the bush to flush out their prey is consistent with Gardner's (1957) description. The end of the season referred to by Gould (1863) is no doubt a reference to the end of summer, as Meagher (1974), citing numerous historical records, noted towards the end of summer, Aboriginal people set fire to the bush to drive the wallabies from their retreats. Green (1989) referred to use of fire at Bald Head in January (mid summer) to '*burn off the land for wallaby*' and the January reference of '*brought home … three wallaby from Bald Head where the Aborigines had fired the land to hunt*' indicates burning for this purpose was not restricted to the end of the summer season. At other times of the year dogs were used to drive out prey (Meagher 1974).

Although Aboriginal people may have been responsible for exterminating some island populations of macropods (Abbott 1980), there is no evidence to suggest Aboriginal hunting of the quokka contributed to the species' decline.

Disease

Reports from studies of colonies of captive quokkas show the susceptibility of the species to disease (see Bradshaw 1991). Anecdotal accounts in 1967 suggested a fatal herpes epidemic transmitted by a handler affected a captive quokka colony (Burnet 1968). *Salmonella* infections are common in the Rottnest Island and Bald Island quokka populations but far less so on the mainland (Hart 1977; Hart et al. 1986). Hart (1981) found captured mainland quokkas died within 24 hours of exposure to bags in which Rottnest Island quokkas had been held. These deaths were attributed to infections from *Salmonella meunchen*. Hart (1981) hypothesised these deaths may have been the result of cross infection from use of the Rottenest Island bags, but conceded *S. meunchen* may have been present at an undetectably low level in the mainland quokka population and became lethal only when the animals were stressed through trapping.

Barker et al. (1957) recorded the presence of the parasite *Ixodes australiensis* in mainland populations of the quokka and several other parasites and diseases have been isolated from quokkas.

Mass mortality of quokkas was reported from the Northcliffe area where swamps were reportedly '*full of quokka bodies*' in the early 1920s (George Gardner cited as a pers. comm. by How et al. 1987). How et al. (1987) attributed this to disease. Similarly, there are records of an epidemic within the quokka population in the Warren River area, near Manjimup in 1921 (Aldrich 1921; Lane-Poole 1921; Weston 1921). Unexplained quokka deaths were also reported from Crown reserves in the vicinity of Yallingup in 1933 (Aldrich 1933). Other references (Cook 1960; Perry 1973; Waring 1956; White 1952) also indicated mass deaths occurred as a result of disease in the 1930s. Mass deaths have recently been attributed to surplus killing by foxes (Short et al. 2002).

The decline in arid zone mammals of the late 1800s noted by Shortridge (1909) and reported from the Nullarbor Plain (Richards & Short 1996), has been suggested to be a result of a *'strange virus'* which Richards and Short (1996) suggest, albeit based on anecdotal accounts, may have been the protozoan parasitic disease toxoplasmosis, passed on from feral cats. Toxoplasmosis was first recorded in the Rottnest Island quokkas in 1961 (Gibb et al. 1966) and has been reported in other marsupials including the eastern barred bandicoot, *Perameles gunnii*, (Lenghaus et al. 1990), the western ringtail possum, *Pseudocheirus occidentalis*, (de Tores 2005) and the chuditch, *Dasyurus geoffroii*, (Haigh et al. 1994). Berdoy et al. (2000) noted toxoplasmosis may alter the behaviour of its intermediate hosts and increase its susceptibility to predation.

White (1952) believed fox predation, competition with rabbits, destruction of habitat through clearing and bushfires were supplementary to disease as the causal factor for the quokkas' virtual disappearance on the mainland. Despite the references to quokkas dying from disease in the 1920s (Aldrich 1921; Lane-Poole 1921; Weston 1921) and the 1930s (Cook 1960; Perry 1973; Waring 1956; White 1952), the persistence of quokkas on Rottnest Island and Bald Island during these periods suggests disease was not the major contributor to their decline, or alternatively, if disease was responsible for the decline on the mainland, it did not have the same effect on, or did not reach, Rottnest Island or Bald Island. It was during this period of decline on the mainland in the 1930s when the quokka was no doubt at high density on Rottnest Island, as it was in this period when it was first referred to as a pest on Rottnest Island (Storr 1963).

Although White (1952) believed a decline caused by predation, competition and habitat destruction was supplementary to that caused by disease and Cook (1960) linked the decline of the quokka with disease, Recher and Lim (1990) considered disease to be a contributing, not causal, factor to the decline of the Australia's mammal fauna. Johnson et al. (1989) discounted disease as a factor associated with the decline of critical weight range macropods altogether. Dickman (1992) noted there was no evidence to indicate widespread disease as the cause of the decline of mammals within Australasia. We concur with these authors and suggest there is insufficient evidence to conclude disease alone was the cause of the decline of the quokka. However, we caution against trivializing the potential effects from disease. The 1826 King George's Sound record of Quoy and Giamard noted the quokka specimen described '*was recently dead when we found it, probably from disease*' (Alexander 1916). If disease was the cause of death, it is reasonable to hypothesise disease was brought to King George's Sound by Europeans. Although the Rottnest Island population appears to be secure, its possible exposure to disease as a result of human contact should be seen as a potential threat. Introduction of a disease, or a single catastrophic event, could result in a chance extinction of this insular population.

Management recommendations

The northern jarrah forest

We recommend an active adaptive management approach for conservation management of the quokka within the northern jarrah forest. The active adaptive management approach requires implementing an agreed experimental approach (i.e. agreed to by all stakeholders), whereby a set of models and management actions have been formulated and appropriate monitoring protocols established. We believe monitoring should be focused on examining the response of the quokka to a variety of management practices.

Quantified data has shown the northern jarrah forest populations are at low density. Despite the presence of fox baiting, these populations have not responded and predation is still potentially limiting population response. Based on the rapid rate of fox re-invasion of the northern jarrah forest post aerial baiting events (de Tores 1999), the lower probability of survivorship of the woylie, *Bettongia penicillata*, in treatments baited four times per year compared with six times per year, and the significantly lower levels of survivorship in areas abutting agricultural land (de Tores 1999), we recommend the active adaptive management program incorporates an assessment of the effectiveness of an increased frequency of 1080 baiting.

The northern jarrah forest populations are highly fragmented, the populations are not mixing and the preferred habitat within the *Taxandria* swamps is a complex mosaic of recently burnt and long unburnt areas. An additional requirement of the preferred mosaic is to have a minimal area burnt 15 to 19 years previously. The preferred spatial configuration of these seral stages is not known – specifically, the relative proportion of each required seral stage is not known and the upper limit of 'time since last fire' , i.e. the maximum period of time without fire within the long unburnt component of the mosaic, is not known. Fire management practices which selectively burn long unburnt components of the mosaic may be detrimental to the long-term conservation of quokkas in the northern jarrah forest. This practice has the potential to increase fragmentation of quokka habitat by removing a component of the preferred mosaic. This practice should not be seen as a method for creation of quokka habitat, and, at best, constitutes a program more akin to a trial and error approach than an adaptive management program.

Therefore, we recommend the active adaptive management program should assign high priority to spatial analyses of existing, historic and potential quokka sites in the northern jarrah forest, with the objective of stratifying the existing *Taxandria* mosaic (with strata based on the number of years post fire) and determining whether any of these swamps can be better managed through the use of fire. Under this scenario, fire would be used to create the preferred mosaic. We also recommend monitoring should incorporate genetic analyses to test the northern jarrah forest metapopulation hypothesis. We further advocate any monitoring program associated with quokka conservation needs to incorporate a component to enable quantitative assessment of pig damage to quokka habitat. Although we advocate use of conventional trapping techniques to determine quokka abundance, we caution against the overuse of invasive trapping and strongly recommend use of alternative methods where applicable. These methods include molecular techniques (Alacs et al. 2003). We also recommend development of techniques to quantify abundance based on the extent of activity in quokka-like runways. Currently assessment of activity in runways can measure activity levels only and should not be extrapolated to infer abundance. Further development of the technique adopted by Hayward et al. (2005) is recommended.

The active adaptive management program should specify quantifiable conservation outcomes. Such measurable long-term conservation outcomes include determining:

- the number of known extant quokka sites where the preferred structural mosaic has been established through the use of fire;
- the number of new sites where the preferred structural mosaic has been created through the use of fire;
- the number of sites where quokka populations remain stable or show an increase in abundance (as measured through survival analyses and population estimates, respectively);
- the number of sites currently thought to be supporting potentially suitable habitat, where quokka presence has not been detected/confirmed, and where, post habitat manipulation, quokka presence is confirmed and a population established;

- the number of sites where population mixing has been confirmed (i.e. sites where animals have been known to disperse to and where the source site is still viable [the source sites can be identified through the use of molecular techniques, and population viability can be determined by conventional monitoring [trapping] and population modeling]).

The Swan Coastal Plain

High priority is recommended to unambiguously determine quokka presence at Muddy Lake and the water authority reserve near Dunsborough. If presence is confirmed, we recommend a monitoring program be implemented to ensure any trend of increase or decrease in population can be detected. The requirement for introduced predator control and habitat manipulation should also be assessed. Minimal data were available on quokka presence elsewhere on the Swan Coastal Plain. We recommend a review of the former known locations from the Swan Coastal Plain (historically these were swamps), assessment of quokka presence at these sites and examination of the effects from draining these swamps. If appropriate, and where possible, the conservation value of re-instating former drainage patterns should be examined.

The southern forest and south coast

The dearth of information on the size of each population/sub-population from the southern forest and south coast areas should be addressed. We recommend an initial approach of confirming presence, through trapping, at sites where quokkas are thought to occur. We further recommend undertaking spatial analysis of these extant populations and locations of known and potentially suitable habitat in conjunction with a survey and monitoring program to assess population size. The extent of dispersal/immigration/emigration between habitat patches should be quantified to determine whether the sub-populations constitute a functional metapopulation, discrete sub-populations or a panmictic population. This process would enable populations of high conservation value to be identified, where conservation value is assessed in terms of the population's strategic value locally, regionally and globally as determined by its geographic location, demographics, genetic structure and importance as a source population for re-stocking other populations/subpopulations.

As a matter of urgency, we recommend a more rigorous and strategic approach be implemented to assess the potential effect from timber harvesting and associated operational activities. Assessment should identify the extent of quokka habitat to be modified, destroyed or retained by each proposed operation, the size of the population(s) affected by the proposed operation, the conservation significance of the population, the potential for dispersal, numbers likely to disperse and dispersal patterns, availability of suitable habitat within dispersal distances, population size within areas of suitable habitat within dispersal distance and the potential effect on these populations.

We recommend investigation of the population(s) from the Stirling Range to assess the security of these populations. Survey is recommended to assess population size, habitat used and the security of this habitat from stochastic events, in particular from wildfire. We also recommend examination of the genetic structure to determine whether the Stirling Range and Green Range population(s) was, or is still, contiguous with other south coast populations.

CONCLUSION

The distribution of the quokka appears to have been traditionally limited by climate and by rainfall in particular. Reduction in availability of suitable habitat, in conjunction with predation and changed fire regimes, appear to have limited this distribution, or more specifically has further confined the quokka to specific habitats within the limits of its geographic range.

For the quokka, like numerous other native mammal species, the arrival of Europeans to Australia coincided with a slow but continual decline in abundance and range (Fig. 3). From 1900 in particular, the increasing human population in the south-west of Western Australia resulted in anthropogenic disturbances including vegetation clearance, logging, mining, hunting and changed fire regimes. Introduced predators have been implicated in 40% of historic extinctions (Caughley & Gunn 1996) and it seems likely that predation pressure from the introduced red fox, in conjunction with continued habitat alteration through fire exclusion and colonisation, further compromised the conservation status of the quokka.

However, the quokka, like many Australian native mammals (Wilson & Friend 1999) appears to be resilient to individual disturbance factors but also appears to be increasingly susceptible to the cumulative effect of multiple factors. None of these factors has occurred in isolation. Many commenced more or less in synchrony with the arrival of the fox (Recher & Lim 1990) and all continue to operate.

Although there is considerable agreement that multiple factors combined to contribute to the decline, there is also considerable disagreement as to the ultimate cause of the decline of critical weight range mammals since European arrival (see Burbidge & McKenzie 1989; Lunney et al. 2001; Morton 1990; Recher & Lim 1990; Short et al. 2002; Short & Calaby 2001; Smith & Quinn 1996; Wilson & Friend 1999). Abbott (2001b) concluded the fox was the primary agent responsible for the decline of the bilby. However, a single explanatory hypothesis to account for past and continuing declines is unlikely to be applicable to all species and it would seem logical that each species is affected to a differing degree by each factor. Similarly, the relative importance of any factor will vary spatially for each species. Kinnear et al. (2002) proposed two hypotheses, niche loss/damage and predation, to account for the initial and continued decline of Australia's critical weight range mammal fauna. The hypotheses are not necessarily mutually exclusive (Kinnear et al. 2002). There is a wealth of evidence linking two factors to the decline of the quokka; predation and a loss of the quokkas' preferred habitat mosaic. The latter equates with the niche loss/damage hypothesis proposed by Kinnear et al. (2002). We believe the two hypotheses, niche loss/damage and predation, when acting in concert, are sufficient to account for the pattern of decline of the quokka.

Islands, although not immune from disturbance factors, often act as refuges for threatened species largely because the factors responsible for the decline on the mainland are often absent from islands (Dickman 1992). The quokka population on Rottnest Island may provide clues to the significance of the various disturbance factors which led to its decline on the mainland. Compared to the mainland, the Rottnest Island population has a higher susceptibility to disease (*Salmonella*) (Hart et al. 1986), encounters seasonal aridity leading to summer mortality (Hodgkin & Sheard 1959; Shield 1964) and a period of anoestrus (Shield 1964). Rottnest Island and mainland south-west Western Australia have experienced the effects of development and have been subject to extensive habitat fragmentation. The success of the quokka population on Rottnest Island, despite these disturbances, suggests the species is quite resilient. With respect to disturbance factors, the most significant difference between Rottnest Island and the south-west mainland appears to be the presence of the fox on the mainland. Recent interesting advances in our understanding of the effect of the fox on native fauna reinforce this conclusion. The predation efficiency of foxes combined with the inadequate anti-predator defences of a predator-naïve fauna may lead to *'high and unsustainable'* levels of predation (Short et al. 2002). Short et al. (2002) concluded this is the case for the Australian mammal fauna which has evolved in relative isolation since the break-up of Gondwana 50-60 million years BP (Heatwole 1987). Short et al. (2002) further concluded surplus killing may be an outward sign of this mismatch and provided case studies to support their assertion that the declines of many prey species, and in particular those species with limited refugia, may be a result of surplus killing by foxes.

The hypothesis that species with little or no refuge would have suffered most from this predation (Short et al. 2002) is consistent with the pattern of decline of critical weight range mammals in the arid zone described by Burbidge and McKenzie (1989). The quokka is now restricted to areas of refuge (islands and dense vegetation on the mainland). The presence of this latter refuge seems likely to have been the sole factor staving off extinction resulting from fox predation and the combined effects of altered fire regimes and habitat loss.

With the continued depletion of resources (nutrients, water, refuge), which have previously buffered the fauna decline in the more mesic areas of the mainland (Recher & Lim 1990; Woinarski et al. 2001), the buffering capability may be in the process of being compromised. Further extinctions may result (Recher & Lim 1990; Woinarski et al. 2001) and the assumption that critical weight range mammals in mesic areas are secure (Burbidge & McKenzie 1989) may no longer be valid.

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Table 1

Fossil and sub-fossil records of *Setonix brachyurus*. The site names are listed in a north to south latitudinal cline and are mapped in Figure 2. Bolding and an asterisk indicate the deposits at that site are considered to be part of the original (modern) mammal fauna as noted by the source for the record or as inferred by the age of the deposit. Bolding only indicates a more subjective assessment of age, where deposits were implied as part of the original (modern) mammal fauna. The abbreviation BP means before present.

Site name	Location	Description	Comment	Age	Source	Comment on *Setonix* record
Hastings Cave / Drovers Cave *	8 km north east of Jurien, approx 210 km north of Perth	Described by (Lundelius 1957; Lundelius 1960) as entrance formed by collapse of roof. Cave formed from arches developing (coherence) over dissolved aeolian calcarenite (Baynes 1979).	Hastings Cave / Drover's Cave listed by (Lundelius 1957) as representative of Jurien Bay caves. Bone deposits were concentrated near cave mouth (Lundelius 1957) and thought to be derived from owl pellets. Concurs with Baynes (1979). Fragmentation of bones of larger mammals considered to be indicative of mammalian predator accumulation (Baynes 1979), with a minor contribution as a result of human occupation.	5 900 ± 140 years BP (Lundelius 1960), however Lundelius (1957) reported top most foot of surface deposits to represent fauna prior to effect of introduced species. Also listed presence of rabbits and house mouse and interpreted this as indicating younger deposits. Baynes (1979) listed ages (Hastings Cave) as 400 ± 70 years BP at a depth of 10 mm to 11 400 ± 200 years BP at 2.98m.	Baynes (1979)	Listed from 1 layer only, mammal occurrences were from deposits considered to less than 1,000 years old and considered to be part of the original fauna
					Lundelius (1960)	Lower levels only
					Merrilees (1968)	Merrilees noted the only records of *Setonix* from the Moore River – Dongara region are from lower parts of Hastings Cave deposit. However, Jefferys (pers comm. to MWH) subsequently listed *Setonix* occurrence at Echidna Cave (Dongara), an un-named cave near the northern boundary of Nambung National Park, House Cave (Moore – Dongara river area), Greensand Cliffs (Gingin) and McIntyre Gully (Gingin)
Yanchep *	North of Perth	A complete quokka skeleton recovered in 1965 registered with the WAM as part of the fossil collection.		The skull was penetrated by a small iron stake implanted during the animal's life time, thereby inferring persistence of quokkas in Perth area in modern times	(Merrilees 1965)	Skeleton with iron rod through skull
Orchestra Shell Cave	Wanneroo, North of Perth. Location noted as approx 16km south of Yanchep cave described by Lundelius (1957)	4 stratigraphic levels, progressive faunal impoverishment towards top.	Lair, deposits presumed to be accumulated by *Sarcophilus*.	not specified	Archer (1974b)	Lower two levels
Murray Cave	Approximately 40km north of Perth	Considered to represent a carnivore's accumulation, typical of *Sarcophilus*		3 090 ± 90 years BP. Contains youngest dated occurrence (from charcoal at 1–7cm depth) of thylacine	(Archer 1974a)	
Rainbow Cave *	1 km inland, 1.5km south of the mouth of the Margaret river, south-west Western Australia	Collapsed limestone cave, 30m deep, 15m wide		Lilley (1993) aged at 340 ± 45 years BP at depth of 5–10cm; 790 ± 50 years BP at depth of 25–30cm; 8340 ± 45 years BP at depth of 35–40cm; 4150 ± 70 years BP at depth of 70–75cm; and a second age of 1030 ± 50	Lilley (1993)	At depths of 10,15, 25, 35, 50 and 75cm. Deposits above 30cm are therefore presumably from the modern fauna

				years BP was determined at depth of 25–30cm		
Mammoth Cave	Margaret River area, south west Western Australia	Was the first cave in Western Australia to yield fossil vertebrate remains & described by Glauert (1948). Originally recognised as having two stratigraphic units: a yellow-red sand layer above coarse red sand. Both layers capped with travertine (Lundelius 1960). Remnants of a previously longer tunnel in calcareous aeolianites	Deposits considered by Glauert (1948) to be water lain. Merrilees (1968) considered deposits were more consistent with talus and not water transported as suggested by Glauert	Lundelius (1960) dated deposits from the upper sand layer as greater than 37 000 years BP. Merrilees (1968) dated upper parts of deposit as 31,000 years BP	Glauert (1948) Cook (1963) Merrilees (1968) Lundelius (1960)	
Margaret River caves		not described	Glauert (1926) referred to collections from 'certain caves near the Margaret River in the extreme South-West'. Location taken nominally here as Mammoth Cave	Pleistocene	Glauert (1926)	
Harley's Cave	Cape Leeuwin – Cape Naturaliste region, south west Western Australia	not described	Listed by Merrilees (1968) as representative of specimens collected by Lowry (1967) from surface litter from caves in Cape Leeuwin–Cape Naturaliste region. However, no indication of these collections being made by Lowry (1967) who discussed geomorphology	Listed as fauna characteristic of the region for some hundred to a few thousand years prior to European settlement	Merrilees (1968)	
Lake Cave	Margaret River area, south west Western Australia	not described		not given	Glauert (1948)	
Devil's Lair, or Nannup Cave of Lundelius (1960; 1966) and Cook (1960). *	South west of Witchcliffe, south west Western Australia	Small cave in aeolian calcarenite. Travertine floor over red clayey sands thought to be washed in. Deposits described from two levels: immediately below travertine floor; and at depth of 4 feet.	Deposits considered (Lundelius 1960) to be a result of *Sarcophilus*, hence the name Devil's Lair. Dortch and Merrilees (1971) described as artefacts and food remains presumably left as a result of Aboriginal use of the cave. Some remains may have been left by *Sarcophilus*. Baynes et al. (1975) considered upper layers may have been accumulated by humans and believed *Sarcophilus* was responsible for subsequently 'working over' the deposits.	Surficial layers described as recent as 320 years BP. Other deposits extending to 35,160 years BP Balme et al. (1978). Lundelius (1960) dated the upper level 8,500 ± 160 years BP, with deposits at 4 feet as 12,175 ± 275 years BP Dortch and Merrilees (1973) listed uppermost stratigraphic unit to be less than 12,000 years old, with other major stratigraphic units as 19,000 – 25,000 years old and the bottom deposit more than 31,000 years old. Subsequent dating techniques supported these dates for upper layers and indicated lower levels may be in excess of 40,000 years old (Turney et al. 2001).	Dortch and Merrilees (1971) Dortch and Merrilees (1973) Lundelius (1966) Balme et al. (1978) Baynes et al. (1975) Lundelius (1960) Cook (1960)	Represented consistently throughout deposit (all ages) [Balme et al. (1978)] Deposits considered to be part of the modern fauna (occurring in the area immediately pre European arrival) [Baynes et al. (1975)] Both levels [Lundelius (1960)]

Table 1 (cont.)

Site name	Location	Description	Comment	Age	Source	Comment on *Setonix* record
Strong's Cave, or Strongs' Cave of Cook (1963)	7 miles south of Mammoth Cave	As for Mammoth Cave has a complex development history. Main deposits in entrance chamber. Has talus slope undermined by stream action & central portion of talus collapsing. Material washed and transported by stream and then mixed with sedimentary deposits		Central portion of talus slope has more recent, young deposits, but excavations from stream bed considered older, but younger than Mammoth Cave. Some of Mammoth Cave deposits not present in Strong's Cave also imply Strong's Cave deposits may be younger	Cook (1963) Merrilees (1968)	Teeth only
Two small un-named caves (Cave 1 and Cave 3)	Near Turner Brook, Augusta	Surface/sub-surface cave deposits within 8cm of surface (Cave 1) and 13cm of surface (Cave 3)	Deposits included unworn *Sarcophilus* teeth with poorly formed roots. Interpreted as juvenile animals. This, combined with known geographic range of medium size owl species and the inaccessibility of caves, suggests deposits a result of owl predation.	430 ± 160 BP based on radio carbon dated hair from Cave 1. Cave 3 may be older. Neither cave had deposits of the introduced mammals (house mouse, black rat or rabbit), all of which may have arrived post accumulation of deposits	Archer and Baynes (1972)	Present in Cave 3 only
Bride's Cave	Margaret River area, south west Western Australia	not described		not given	Glauert (1948)	
Skull Cave	Cape Leeuwin region of south west Western Australia	Comprised of a large main chamber with partially collapsed roof and a smaller chamber leading from western part of main chamber. Both chambers partially filled with sandy sediments, possibly washed in	May have functioned as a pit trap with additional deposits resulting from use by owls	Upper layer (21–28cm) aged at 2,900 ± 80 years BP Intermediate layer (100–115cm) 7,875 ± 100 years BP. Depth of 190cm considered late Pleistocene	Porter (1979)	Present at depths to 170cm
Scott River	Coastal dunes south of the Scott River	Exposed fossil soils and surface deposits from mobile-partly stabilised sand dunes		not given, presence of fox and rabbit remains imply deposit is mix of fossil and modern animal remains	Butler (1969)	
Scott River Area *	Between Ledge Point and Black Point	Bones collected from sand dunes	collected in period 12 March 1976 to 22 March 1976	not dated, presumably sub fossil or recent. Presence of rabbit remains with other specimens implies these are recent (part of the modern fauna)	Kabay and Start (1976)	Presumably sub fossil or recent

Warren River / Donnelly River area	Described as bounded by the Warren and Donnelly rivers, the south coast and Vasse Highway. Bone material from Yeagerup Sand Dunes	Specimens collected from sand dunes	collected in period 27 to 31 May 1976	not dated, presumably sub fossil or recent	Kabay and Start (1976)	Presumably sub fossil or recent
Norman's Beach / Plantagenet	Sand blowout south of Plantagenet location 4348 and 1 km east of Norman's Beach	described only as bone(s) collected	collected in period 15 to 20 August 1976	not dated, presumably sub fossil or recent	Kabay and Start (1976)	Presumably sub fossil or recent
Walpole	Described as coastal sand blow out, Walpole area	Species listed as obtained in sand dunes	collected in period 15 to 20 August 1976	not dated, however the presence of rabbit and fox remains with other specimens collected implies these are recent deposits (part of the modern fauna)	Kabay and Start (1976)	Presumably sub fossil or recent
Two Peoples Bay Nature Reserve	East of Albany	Species listed as obtained in sand dunes	collected in period 23 April 1976 to 5 May 1976 and 15 to 20 August 1976	not dated, presumably sub fossil or recent. Presence of rabbit remains with other specimens implies these are recent (part of the modern fauna)	Kabay and Start (1976)	Presumably sub fossil or recent
Plantagenet	Sand dunes, south of Plantagenet Location 4130	described only as bone(s) collected	collected in period 15 to 20 August 1976	not dated, presumably sub fossil or recent	Kabay and Start (1976)	Presumably sub fossil or recent
William Bay National Park		Species listed as material picked up in sand dunes	collected in period 4 to 10 February 1976	not dated, presumably sub fossil or recent	Kabay and Start (1976)	Presumably sub fossil or recent
Boat Harbour	Sand blowout at Boat Harbour east of Reserve 7723	described only as bone(s) collected	collected in period 15 to 20 August 1976	not dated, presumably sub fossil or recent	Kabay and Start (1976)	Presumably sub fossil or recent

Table 2

Australian Museum records of the quokka, *Setonix brachyurus*. Additional records by Masters lacking location records are not shown.

Year of collection	Location	Collector	Form of specimens	Comments	Australian Museum Registration number
Undated	Rottnest Island		brain in Formalin		M 18429
Undated	Rottnest Island	G. P. Whitley-Staff	skull and mandibles	Shown as G. P. Whitney-Staff in Australian Museum database	S 1936
Undated	Rottnest Island	G. P. Whitley-Staff	skull only	Shown as G. P. Whitney-Staff in Australian Museum database	S 1937
Undated	Rottnest Island	G. P. Whitley-Staff	skull, odd mandible	Shown as G. P. Whitney-Staff in Australian Museum database	S 1938
Undated	Rottnest Island	Taronga Park Trust	skin		M 7994
Undated	Rottnest Island	Taronga Park Zoo	skin skull		M 8177
1866	King George's Sound	Masters	mount	Year of collection nominally shown here as 1866, as Masters is known to have collected in King George's Sound area from Jan to April 1866 (Abbott 1999; Glauert 1950) and Sept 1868 to April 1869 (Glauert 1950), however this record not listed by Krefft (1867; 1869). No co-ordinates listed, co-ordinates for Albany used, however Masters known to have collected as far north as the Pallinup River (Salt River) (Glauert 1950) and the Stirling Range (Abbott 1999)	P 1048
1866	King George's Sound	Masters	mount	See comment for record P 1048	P 1049
1866	King George's Sound	Masters	spirit	See comment for record P 1048	P 1060
1866	King George's Sound	Masters	spirit	See comment for record P 1048	P 1061
1866	King George's Sound	Masters	spirit	See comment for record P 1048	P 1062
1920	Nornalup near Denmark	A. S. Le Souef	skin skull	Year of collection not listed. Nominally listed here 1920 as Le Souef known to have collected in Porongurup area in 1920 (Abbott 1999). Co-ordinates map to Southern Ocean, directly south of Nornalup Inlet and Walpole, corrected to map near Nornalup	M 4212
1920	Nornalup, near Denmark	A. S. Le Souef	skull only	No co-ordinates with this record, corrected co-ordinates for Le Souef record (M 4212) used. Other comments for record M 4212 apply.	S 1799
1920	Nornalup, near Denmark	A. S. Le Souef	skull only	No co-ordinates with this record, corrected co-ordinates for Le Souef record (M 4212) used. Other comments for record M 4212 apply.	S 1800
1921	King River, 10 miles from Albany	E. Le G. Troughton J. Wright	skin skull	Shown as LE G. Troughton in Australian Museum database	M 3083
1921	King River, 10 miles from Albany	E. Le G. Troughton J. Wright	skin skull	Shown as LE G. Troughton in Australian Museum database	M 3084
1921	King River, 10 miles from Albany	E. Le G. Troughton J. Wright		Shown as LE G. Troughton in Australian Museum database	M 3085

1921	King River, 10 miles from Albany	E. Le G. Troughton J. Wright	skin skull	Shown as LE G. Troughton in Australian Museum database	M 3086
1921	Princess Royal Bay, Albany	E. Le G. Troughton J. Wright	skin skull	Shown as LE G. Troughton in Australian Museum database. Co-ordinates (35 deg 3 min South and 117 deg 53min East) map to within Princess Royal Harbour, corrected to map to map on Princess Royal Harbour foreshore near Albany townsite	M 3087
1935	Rottnest Island	S. Larnach	spirit		M 18214
1935	Rottnest Island	S. Larnach	spirit		M 18215
1935	Rottnest Island	S. Larnach	spirit		M 18216
1935	Rottnest Island	S. Larnach	spirit		M 18217
1935	Rottnest Island	S. Larnach	spirit		M 18218
1935	Rottnest Island	S. Larnach	spirit		M 18219
1961	Rottnest Island	Taronga Park	skin skull		M 9056
1987	edge of Lake Bagdad, Rottnest Island	Gavin Gattenby	skeleton		M 18626
1997	Rottnest Island	E. Dovey	skull		M 33146

Table 3

Published records of occurrence of the quokka, *Setonix brachyurus*. Records are listed chronologically.

Year of record	**Location or Site name**	**Source**	**Comment**
1658	Rottnest Island	Samuel Volckersen (Volckertzoon), cited by (Alexander 1914) Glauert (1950)	Considered the first record of quokka sighting by a European and only the second record of a marsupial from Australia by a European
1696	Rottnest Island	Willem de Vlamingh, cited by (Alexander 1914) Glauert (1950)	Mistook the quokka on Rottnest island for ' … A kind of rat as big as a common cat … '
1801	Rottnest Island	M. Freycinet,, cited by Alexander (1916)	M. Freycinet, observed a quadruped 'which the old Dutch navigators actually mistook for a rat'
1826	King George's Sound	Records of Quoy and Gaimard as cited by Alexander (1916)	Reported the new species, the specimen described as recently dead and ... 'probably from disease'
1829	King George's Sound	Scott Nind, cited by (Alexander 1916) and Glauert (1950)	Scott Nind, medical officer at the King George's Sound penal settlement recorded the presence of the quokka
1829	Rottnest Island	Dr T.B. Wilson, cited by Alexander (1918)	Dr T.B. Wilson, visitor to the Swan River Settlement, when visiting Rottnest Island recorded 'the dogs caught two wallabi'
1830	King George Sound	Walton (1988)	The type specimen of Quoy and Gaimard
1837	Swan River, Perth	George Gray, cited by	Glauert (1950) reported Gray's list of species from the Swan River. The list included the quokka Kitchener et al. (1978)
		Glauert (1950)	noted Gray's reference to 'Swan River' may have included the Darling Range & the York & Avon River valleys. Nominally mapped as Piesse Brook
1842	Coastal areas	Gilbert, cited by Gould (1863)	Gilbert found the quokka abundant in all the swampy tracts which 'skirt nearly the whole of Western Australia at a short distance from the sea'. Presumably this was referring to the south west of WA only. Gilbert was known to have visited WA and collected from this area in 1839–1840 and 1842–1843 Abbott (1999). Date nominally listed here as 1842 and locations nominally shown as Albany and Margaret River area
1905	Bald Island	Shortridge (1909)	see note 1, below
1905	Rottnest Island	Shortridge (1909)	see note 1, below
1905	Margaret River, Burnside	Shortridge (1909)	see note 1, below
1905	Busselton, Yallingup	Shortridge (1909)	see note 1, below
1905	Albany, King River	Shortridge (1909)	see note 1, below
1905	Albany, King River	Thomas (1906)	Descriptions of collections made by Shortridge. Listed as collected during end of 1904 and during 1905. Nominally listed here as 1905 and mapped as same location as Shortridge (1909) for King River

1905	Albany, Big Grove, King George's Sound	Thomas (1906)	Descriptions of collections made by Shortridge. Listed as collected during end of 1904 and during 1905. Nominally listed here as 1905 and nominally mapped as the between Albany and King River
1907	Margaret River area	W. H. Loaring, cited by White (1952)	Quokkas recorded as very numerous 1907–1910. Location nominally mapped as creekline in forested area, immediately west of Margaret River
1912	Irwin Inlet – Mt Frankland area	Diaries of S.W. Jackson, cited by Abbott (1998)	Jackson's diaries for 1912–1913 record '*caught a wallaby in trap*' and sleeping under sword grass here (Deep River) interpreted by Abbott as referring to quokkas. Nominally shown as 1912 and nominally mapped as Deep River.
1919	Lower Blackwood Valley	Perry (1971)	Recorded the quokka as numerous and frequently seen in the Lower Blackwood valley. Approximate location only
1920	Margaret River	Hoy, cited by Short and Calaby (2001)	From collections by Charles Hoy, 1919–1922. Hoy collected 9 specimens from the Margaret River area in 1920. With the exception of *Trichosurus vulpecula*, he described none of the collected mammals as plentiful. The quokka was described as seldom seen (due to nocturnal habits). Location nominally mapped as immediately northwest of Margaret River
1920	Un-named cave near Gingin	Roe (1971)	Roe (1971) recorded this location as a fossil/subfossil record and noted long term residents were aware quokkas (along with boodies, *Bettongia lesueur*, and bilbies, *Macrotis lagotis*) were present in the district until arrival of the fox
1920	Bickley, Darling Scarp, now considered a suburb of Perth	W. H. Loaring, cited by White (1952)	Noted as particularly plentiful in the early 1920s with extensive runways in thick scrub bordering streams
1920	Darling Range, Piesse Brook- Bickley	W.H. Loaring in Serventy et al. (1954)	The quokka described to have 'vanished from its gully haunts … 30 years ago'. This record is nominally shown as present here 30 years earlier (1920) and location mapped as Piesse Brook (Piesse Gully)
1922	Yarloop, Logue Brook, Darling Range between Perth and Harvey	White (1952)	Recorded as numerous in low tangled scrub when author was a schoolboy and still plentiful until 1926 when he left school. Approximate location only, nominally mapped as upper catchment of Logue Brook and date nominally shown 1922
1929	Busselton	White (1952)	Recorded as 'in great numbers', location approximate
1929	Cape Leeuwin – Cape Naturaliste	White (1952)	Recorded as 'in great numbers', location approximate
1920s/ 1930s	Helena River, near Mundaring	Perry (1973)	Recorded as abundant in dense low cover along creeks and river courses from valley of Helena River eastwards. Location identified as Greystones pine plantation which was planted by Dick Perry in the 1920s/1930s and record assumed to be from the 1920s to 1930s (Ian Abbott, pers. com. to PJdeT).
1930	Northcliffe area	Daubney et al. (undated)	Discussions between one of us (PJdeT) and local landholders plus reports in Daubney et al. (undated) indicate the quokka was considerably more abundant in the Northcliffe area prior to the arrival of the fox. Gladys Buckingham, school teacher in Northcliffe, recalled of the 1930s 'every swamp was a maze of tracks and tunnels of wallabies, quokkas, bandicoots …' (Daubney et al. undated). Location approximate and mapped as immediately east of Northcliffe townsite, date here nominally listed as 1930
1931	Vasse Estuary, near Busselton	White (1952)	Quokkas 'in numbers' in low scrub between coastal dunes, location approximate
1932	Pine plantations, Pemberton	Stewart (1936)	Recorded as responsible for damage to pine plantations within karri forest areas and recorded grazing up to 2 kms from swamps. Location mapped here nominally as pine plantations, immediately east of Pemberton
1932	Rottnest Island	Storr (1963)	Storr cited H.T.Pearse, as the first reference (1932) to the large number of quokkas on Rottnest Island being regarded as a pest

Table 3 (cont.)

Year of record	Location or Site name	Source	Comment
1933	Comments on general distribution	Glauert (1933)	Published to indicate the present range (in 1933) of marsupial fauna in Western Australia and as an update to the distributions described by Shortridge (1909). Described distribution of the quokka as extending from Moore River to the south coast and inclusive of Rottnest Island and Bald Island. No reference to the presence on the islands off Esperance as suggested by Shortridge. Described as abundant in suitable swampy localities. Nominally mapped here as Albany and Dwellingup, Holyoake
1933	Bickley, Darling Scarp, now considered a suburb of Perth	W. H. Loaring, cited by White (1952)	Quokkas still present in gullies in 1933–34
1933	Margaret River area	W. H. Loaring, cited by White (1952)	Quokkas reported as far less plentiful than previously recorded in 1907–10. Location nominally mapped as for 1907–1910 and as creekline in forested area, immediately west of Margaret River
1933	Canal Rocks, near Yallingup	White (1952)	Recorded as particularly numerous in 1933, still present 4 years later, less noticeable within a few years
1954	Manjimup, Perup area	A.D. Jones in Serventy et al. (1954)	Recognised the area bounded by the Tone and Perup rivers, northward to latitude 34 degrees 12 minutes South was rich in marsupials. Date nominally listed here as 1954 and location mapped as within the Perup Forest, and between Tone & Perup rivers, northeast of Manjimup
1954	Manjimup, Morallup	A.D. Jones in Serventy et al. (1954)	Record reported to A.D. Jones (in Serventy et al. 1954) as a sighting 10 miles north of Mordallup. Presumably this is a reference to Morallup, which places this record approximately 23km northeast of Manjimup. Date nominally listed here as 1954
1954	Comments on general distribution	L. Glauert in Serventy et al. (1954)	Described as plentiful on Rottnest Island and 'some islands off the south coast' and in swampy country in the lower south west. Nominally mapped here as Albany and the Broke Inlet (D'Entrecasteaux) areas, the latter as mapped by Christensen et al. (1985)
1954	Comments on general distribution (cont) from L. Glauert in Seventy et al. (1954)	L. Glauert in Serventy et al. (1954)	Described as no longer present in the valleys of the Darling Range. Presumably the 'islands' reference is referring to Bald Island, but this may also be a reference to the islands of Esperance which were otherwise referred to only by Shortridge (1909).
1954	Yarloop, Darling Range between Perth and Harvey	Serventy et al. (1954)	Serventy noted quokkas seen occasionally, with plenty of signs in all swamps. Nominally recorded as 1954. Exact location unclear, nominally mapped as Logue Brook area and the same location as White (1952). Serventy's report appears to contradict the reports of Glauert and Loaring, both also in Serventy et al. (1954), who believed quokkas had vanished from gully haunts of the Darling Range 30 years previously. However, the area referred to by Serventy et al. (1954) is 100km South of the section of Darling Range Loaring and Glauert may have been referring to.
1954	Manjimup, near Broke Inlet turnoff	Serventy et al. (1954)	Recorded as first record for 10 years. Nominally recorded as 1954, exact location unclear. Possibly referring to the 'Broke Inlet turn-off' from the South Western Highway (Manjimup-Walpole Highway), mapped at this location
1954	Toolbrunup, Stirling Ranges	Sharman (1954)	Examined quokka chromosome number and urogenital system and compared with related species. Noted quokkas formerly widely distributed, now common only on Rottnest and Bald islands. Noted a skull collected from Stirling Ranges. Location nominally shown as Bluff Knoll, Stirling Range.

1955	Walpole	J.A. Rate, cited by Barker et al. (1957)	Capture of an immature quokka. Approximate location only, nominally mapped as within Walpole-Nornalup National Park
1956	Rottnest Island	Dunnet (1963)	Examined quokka sub populations at Bagdad and Serpentine soaks at eastern/central area of Rottnest Island in the period 1954–1958. Nominally listed here as 1956, see also Dunnet (1962). Estimates of population size were variable and differed between and within sampling periods. Dunnet cautioned these estimates were also subject to bias
1956	Albany Highway, near Travellers' Arms (southeast of Perth)	R. Aitken, cited by Barker et al. (1957)	Two roadkill records. Location approximate only and identified from map in Sadleir (1959). See 1966 record by Kent Williams (Table 4) and 1996 record by de Tores, Dillon, Tomkinson and Buehrig (Table 6)
1956	Rottnest Island	Shield (1959)	450 quokkas sampled in 1956–57 as part of study assessing whether quokka population was limited by environmental/ physiological factors. No estimate of the size of the Rottnest population
1956	Rottnest Island	Waring (1956)	Noted quokkas known from two off-shore islands only (Rottnest and Bald) and considered the only mainland population to be 'a remnant population in Karri forest' in the south-west. Referred to the Rottnest population as consisting of 'perhaps 5,000 individuals'.
1957	Byford, Manjedal Brook on the southeast edge of the Perth metropolitan area	Barker et al. (1957)	Three quokkas trapped in the period 8 May to 6 June 1957. Trapping survey initiated in response to a newspaper article which suggested quokkas had become extinct on the mainland.
1958	Rottnest Island	Herrick (1961)	Examined adrenal function of the quokka and included animals collected from Rottnest Island (Summer 1958) and observations from two sites on Rottnest
1958	Manjedal Brook, north of Jarrahdale	Storr (1964b)	Study of quokka habitat, no estimates of population size. Presumably the site(s) used by Sadleir (1959) and Barker et al. (1957)
1958	Rottnest Island	Storr (1964a)	Nutritional study, 511 quokkas caught over unspecified number of monthly visits in 1958. No estimate of population size
1959	Rottnest Island	Holsworth (1967)	Examined home range and territory use in the period 1954 to 1964. Nominally shown here as 1959. No estimate of population size, however showed variation in the number of individual animals caught from 38 in 1960 to 813 in 1963
1959	Bald Island	Storr (1965)	Recorded quokkas as abundant, occurring from sea level to the peak, but density varied greatly
1959	Waychinicup	Storr (1965)	None trapped or snared, abundant evidence in 'swampy valleys draining into the lower Waychinicup'. Exact location not given, mapped as approximate location only.
1963	Rottnest Island	Packer (1965)	Observational study in 1963, no estimate of population size
1967	Rottnest Island	Nicholls (1971)	Caught and monitored 27 quokkas from West End of Rottnest Island to determine home range and movements, 1967–1968. No estimate of population/sub-population size
1969	Rottnest Island	Kitchener (1973)	Recorded an average of 53 resident quokkas at the Barkers Swamp study site, with average density of 1 quokka per 0.06ha and noted this was considerably greater than the average of 1 quokka per 0.4 – 1.2ha recorded by Main and Yadav (1971). The localised high density at Barkers Swamp was considered to reflect the localised high quality site and the high density was maintained by 'recruitment of considerable number of quokkas into the local population'
1970	Rottnest Island	Kitchener (1972)	Reported on observed behaviours, interactions and dominance of sub population at Barkers Swamp. Sub population estimated by direct count during nocturnal observations. However, subpopulation estimate not reported

Table 3 (cont.)

Year of record	Location or Site name	Source	Comment
1970	Darling Range, close to Perth	Ride (1970)	Recorded as rare on the mainland, known only from a few swampy valleys in the Darling Range. Nominally shown here as Dwellingup (Holyoake) where known to occur in the 1970s
1971	Comments on general distribution	Calaby (1971)	Calaby noted the quokka was known from a few swampy areas on the mainland and was still common on Rottnest and Bald islands. Nominally mapped as Dwellingup, Holyoake
1971	Rottnest Island	Main and Yadav (1971)	Reviewed the conservation information for macropods from Barrow Island and compared this to other islands. Gave an estimate of quokka population density for Rottnest Island as ranging from 1 quokka per 1.2ha to 1 per 0.4ha. However, no data supplied to show how these values were derived and density may have been determined on basis of the entire island being occupied. Date nominally shown here as 1971
1971	Bald Island	Main and Yadav (1971)	Gave an estimate of quokka population size at Bald Island as ranging from 600–1900 quokkas (if entire island was occupied). Qualified, in recognition not all of the island was occupied, to give an upper estimate of 600. Date nominally listed here as 1971
1971	Dwellingup	Schmidt and Mason (1973)	Recorded a suite of mammal species in forest near Dwellingup in 1971 and concluded populations were concentrated in swamps and other areas of dense vegetation. Quokkas included in list of species recorded, no site details, nominally mapped here as Holyoake
1972	Dwellingup, Wrens Road Swamp (east)	Christensen and Kimber (1975)	Population trapped (1972–74) before and after a partial burn. Trap success rate increased after the burn. Indices to abundance imply moderate size population, however no estimate of population size. Date assumed to be 1972, see Christensen (undated) in table of unpublished records
1972	Albany Highway, southeast of Perth	Crabb (1973)	Roadkill, near the ‘27 mile peg on Albany Highway’
1974	Dwellingup, Duncans Road Swamp	Christensen and Kimber (1975)	Population trapped 1972–74. This site unburnt, cf Wrens Road. Trap success comparable to post burn capture success at Wrens Road. Indices to abundance imply a moderate size population, no estimate of population size. Date nominally shown as 1974
1975	Karri, northwest of Northcliffe	Christensen et al. (1985)	Listed and mapped by Christensen et al. (1985) as Survey Area L, Karri. See note 2, below
1975	Yeagarup, between the Donnelly and Warren rivers	Christensen et al. (1985)	Listed and mapped by Christensen et al. (1985) as Survey Area A, Yeagarup . See note 2, below
1975	Mitchell, north northwest of Walpole	Christensen et al. (1985)	Listed and mapped by Christensen et al. (1985) as Survey Area I, Mitchell. See note 2, below
1975	Soho, northeast of Walpole	Christensen et al. (1985)	Listed and mapped by Christensen et al. (1985) as Survey Area H, Soho. See note 2, below
1975	Boranup, south of Margaret River	Christensen et al. (1985)	Listed and mapped by Christensen et al. (1985) as Survey Area D, Boranup. See note 2, below

1975	Giants, between Nornalup Inlet and Irwin Inlet, east of Nornalup	Christensen et al. (1985)	Listed and mapped by Christensen et al. (1985) as Survey Area O, Giants. See note 2, below
1975	Dombakup, west northwest of Northcliffe	Christensen et al. (1985)	One of two sites listed and mapped by Christensen et al. (1985) as Survey Area C, Dombakup. See note 2, below
1975	Woolbales, southeast of Broke Inlet	Christensen et al. (1985)	Listed and mapped by Christensen et al. (1985) as Survey Area B, Woolbales. See note 2, below
1975	Dombakup, west of Broke Inlet (D'Entrecasteaux National Park)	Christensen et al. (1985)	One of two sites listed and mapped by Christensen et al. (1985) as Survey Area C, Dombakup. See note 2, below
1975	Sunklands, south-southeast of Busselton	Christensen et al. (1985)	Listed and mapped by Christensen et al. (1985) as Survey Area E, Sunklands. See note 2, below
1976	Nannup, Mowen/Stoats Road Crossing	Hart et al. (1986)	Trapped as part of comparative study of *Salmonella* infection. Implied to be at low density
1976	Muddy Lake, south of Bunbury	Hart et al. (1986)	Trapped as part of comparative study of *Salmonella* infection. Implied to be at low density
1976	Dwellingup, Holyoake	Hart et al. (1986)	Reported high trap yield (10 animals from 100 trap nights) using elaborate traps comprised of fence lines and enclosures, where multiple trap nights assumed for each trap
1976	Byford	Hart et al. (1986)	Trapped as part of comparative study of *Salmonella* infection. Implied to be at low density. Presumably same site as trapped by Barker et al. (1957) and Sadleir (1959)
1977	Dwellingup, Holyoake	Hart et al. (1986)	Reported high trap yield (27 animals from 204 trap nights) using elaborate traps comprised of fence lines and enclosures, where multiple trap nights assumed for each trap
1980	Bald island	Hart et al. (1986)	14 quokkas caught from a single one-night trip. No estimate of abundance reported, however population level reported to fluctuate as a result of summer starvation
1983	Darling Scarp	Dell (1983)	This publication produced to update the Western Australian Museum mammal records with recent observations and review the literature. The quokka was listed as one of several species to have declined. Nominally mapped here as Dwellingup, Urbrae Forest Block
1983	Green Range, 60km northeast of Albany	Kirke (1983)	Quokkas reported as fleeing from burning bushland. Skeleton subsequently collected. The only record at this location prior to this was from Pearce (1969), see 1969 entry in Table 4, Unpublished Records.
1985	Waychinicup Inlet, east of Albany	Hart et al. (1986)	Trapped as part of comparative study of *Salmonella* infection. Population implied to be at low density
1985	Pt D'Entrecasteaux	How et al. (1987)	Survey conducted in the period March 1985, October to November 1985 and January to February 1986. Nominally shown here as 1985. Quokka reported from only 1 of 10 locations surveyed. This record of presence implied by How et al. (1987) to be questionable. Location approximate only

Table 3 (cont.)

Year of record	Location or Site name	Source	Comment
1985	Pemberton and Dwellingup	Mead et al. (1985)	Animals collected from mainland (Dwellingup and Pemberton) and islands for laboratory assessment of tolerance to 1080. Sample size not specified and no estimate of population size at collection point. Date nominally shown here as 1985. Location mapped nominally as state forest, immediately east of Pemberton and Dwellingup (Holyoake)
1985	Bald Island	Mead et al. (1985)	Animals collected for laboratory assessment of tolerance to 1080. Sample size not specified and no estimate of population size at collection point. Date nominally shown here as 1985
1985	Rottnest Island	Mead et al. (1985)	Animals collected for laboratory assessment of tolerance to 1080. Sample size not specified and no estimate of population size at collection point. Date nominally shown here as 1985
2000	Collie, Victor Road, Hamilton Forest Block	Hayward et al.(2003)	Trapped over the period 1998–2000. Population estimated to be 9 +/- 1 (Jolly-Seber mark-recapture derived estimates)
2000	Collie/Harvey, Hadfield Forest Block	Hayward et al.(2003)	Trapped over the period 1998–2000. Population estimated to be 29 +/- 5 (Jolly-Seber mark-recapture derived estimates)
2000	Dwellingup, Kesners Swamp, Turner Forest Block	Hayward et al.(2003)	Trapped over the period 1998–2000. Population estimated to be 36 +/- 6 (Jolly-Seber mark-recapture derived estimates)
2000	Jarrahdale, Chandler Road Site, Chandler Forest Block	Hayward et al.(2003)	Trapped over the period 1998–2000. Population estimated to be 10 (Jolly-Seber mark-recapture derived estimates)
2000	Jarrahdale, Rosella Road, Gordon Forest Block	Hayward et al.(2003)	Trapped over the period 1998–2000. No population estimate, only one animal trapped

Notes:

1. Shortridge collected 38 specimens and described the quokka as plentiful among coastal thickets and swamps of the south west, not extending inland. The distribution was recorded as extending from the Moore River in the north, and mapped to include the south coast as far east as Esperance. The eastern extent appears to be based of reports from Twin Peak & other islands off Esperance. This is the only report of quokka occurrence from the islands off Esperance and no collections have been documented from these islands. Shortridge's record is assumed to be referring to tammars, see text.
2. Christensen et al. (1985) from surveys 1970–1982 noted the quokka as widespread and locally common. Estimates of population size were not provided and locations are approximate and remapped from map on p4 of Christensen et al. (1985). Date nominally shown as 1975

Table 4

Unpublished records of occurrence of the quokka, *Setonix brachyurus*. Records are listed chronologically.

Year of record	Location or Site name	Source	Comment
1940	Northcliffe, Bashford Road area, 10km east of Northcliffe	L. Wilson (personal communication to PJdeT)	Quokkas observed in large numbers in 1940s and earlier and known to feed in paddocks away from vegetated creeklines. Reported as 'last seen in number when fleeing from fire' in the 1940s. Location approximate and shown nominally as 1940
1958	Rottnest Island	Sadleir (1959)	Conducted a trapping program at the Byford/Manjedal Swamp site on the mainland and Rottnest Island to examine physiological differences between the two populations
1958	Byford, Manjedal Swamp/Brook	Sadleir (1959)	Trapped at Manjedal Swamp in April – May and September – October 1958. Six quokkas only caught, all in the April – May period
1962	Rottnest Island	Holsworth (1964)	Trapped in period May 1961 to May 1963 and incorporated data from 1954 to 1961 and from December 1963 to April 1964. Nominally shown here as 1962. Population estimates were derived for 4 areas within the West End only. Each area was comprised of several group territories. Population estimates were described by Holsworth as stable for the period 1955 to 1963, however data indicates large variations in abundance.
1965	Travellers' Arms, Albany Highway, south-east of the Perth metropolitan area	Kent Williams (pers. comm. to PJdeT)	Quokkas successfully trapped in 1965 at swamp on the opposite side of Albany highway from the Travellers' Arms Hotel. Subsequent trapping in the same year, post fire was unable to confirm continued presence. See record for 1996 (Table 6) when presence at this location was re-confirmed
1969	Two Peoples Bay Nature Reserve, near CSIRO hut	Bannister (1970)	Reported carcass found in 1969 by N. Robinson, in thick scrub at bottom of a shallow gully, near CSIRO hut. Old evidence and no indication of recent activity when surveyed by Bannister (1970). Location mapped here is approximate
1969	Rottnest Island	Kitchener (1970)	Estimated a mean monthly population size from a study area comprised of 48 quadrats, each 12m x 12m at Barkers Swamp, near the centre/eastern end of the Island. Estimates derived from data collected in the period December 1967 to December 1969. Listed here as 1969. Estimates were from direct observations and included permanent and temporary residents, recruits and transients. Mean monthly estimate was approximately 45 adults and 13 juveniles within the Barkers Swamp study site.
1969	Green Range, 50 miles (30km) northeast of Albany	Pearce (1969)	Local landholder recorded the presence of small kangaroos. Subsequent investigation by WA Department of Fisheries Fauna Warden detected spoor consistent with quokka. Drawing of spoor provided in Departmental file – we have presumed this to be a quokka. Presence recorded here in 1983, see 1983 entry in Table 3.
1970	Two Peoples Bay Nature Reserve, near weather station above CSIRO hut	Bannister (1970)	Unable to confirm by trapping, presence inferred by runs and scats detected in thickly vegetated gullies, near weather station above CSIRO hut. Location mapped here is approximate
1970	Two Peoples Bay Nature Reserve, south-west of Pt Gardner	Bannister (1970)	Unable to confirm by trapping, presence inferred by runs and scats detected in thickly vegetated gullies, bottom of valley, south-west of Pt Gardner
1970	Two Peoples Bay Nature Reserve, Moates Lagoon	Bannister (1970)	Unable to confirm by trapping, presence inferred by runs and scats detected in thickly vegetated gullies, thick swampy areas at west end of Moates Lagoon

Table 4 (cont.)

Year of record	Location or Site name	Source	Comment
1972	Dwellingup, Wrens Road Swamp (west), Urbrae Forest Block	Christensen (undated)	Trapping program before (August to November 1972) and after (12 to 21 December 1972) a low intensity burn of 60% of quokka habitat within the swamp. No estimates of density, however a total of 22 individuals trapped.
1972	Dwellingup, Wrens Road Swamp (east), White Forest Block	Christensen (undated)	Trapping program before (August to November 1972) and after (12 to 21 December 1972) a low intensity burn of 60% of quokka habitat within the swamp. No estimates of density, however a total of 22 individuals trapped.
1975	Denbarker, 5km east of Denbarker Road bridge over Mitchell River	Kabay and Start (1976), note 1, below	150 cage trap nights and 180 snare trap nights over 9 nights (28–30 July 1975 and 11–20 August 1975). Six quokkas trapped or snared
1975	Mount Manypeaks, North of Mount Manypeaks	Kabay and Start (1976), note 1, below	130 cage trap nights over three nights plus 60 snare trap nights over three nights (5–7 July 1975). One quokka only seen, runways and scats found
1975	Two Peoples Bay, Mt Gardner	Kabay and Start (1976), note 1, below	180 cage trap nights over 4 nights (1–8 July 1975). No quokka captures, but presence inferred by presence of scats and runways in gullies and in dense heath bordering gullies
1975	Nannup, Mowen Road creek crossing, east of its junction with Stoats Road	Kabay and Start (1976), note 1, below	Surveyed June 1975 with 50 cage trap nights and 10 snare trap nights over one night (in period 6–17 June 1975). Three quokkas trapped, scats and runways present
1976	Bald Island	Kabay and Start (1976), note 1, below	360 cage trap nights over three nights (29 May – 3 June 1976). One quokka trapped, large number seen and a number of skulls collected
1976	Two Peoples Bay, 'Robinson's Gully'	Kabay and Start (1976), note 1, below	360 cage trap nights over 4–9 nights at a range of locations (13 April – 2 May 1976). Two juvenile quokkas trapped at 'Robinson's Gully'. Approximate location only mapped here
1976	Bunbury, Muddy Lake, 11km South of Bunbury	Kabay and Start (1976), note 1, below	150 cage trap nights over three nights June 1975 (10–12 June 1975). Quokka skeletal material recovered, runways and scats common. No live animals trapped in June 1975, but were seen subsequently (4 Feb 1976) by these investigators. Co-ordinates corrected to plot to location of Muddy Lake
1977	Dwellingup, Holyoake	Hart (1977)	Trapped 10 individual quokkas over the period 6–11 November 1976 and 27 over the period 17–24 March 1977
1979	Jandakot	Austin (1979)	Estimated population size of a translocated, fenced population, where 393 quokkas ex Rottnest Island had been released in the period 1972–1978. Population estimated to be approximately 84 animals in 1979. Translocated population subsequently shown to have failed to persist
1982	Jarrahdale (Mundilup Forest Block)	D. Giles (personal communication to PJdeT)	Record of roadkill(s) reported from the early 1980s (nominally 1982) by local landholder. Reported to Doug Giles, Department of Conservation and Land Management, Jarrahdale
1986	Stirling Range National Park – Bluff Knoll (1986–1991)	A.N. Start, note 2 below	Confirmed records of presence (sightings) by Allan Rose in the period from 1986 to 1991. Nominally listed and mapped here as 1986, see also record for 1991

1988	Walpole-Nornalup National Park, Nuyts Wilderness	K. Gillen, note 2 below	Records of scats and runways (east of Mt Hopkins, Karri Hill Gully east of Crystal Lake and south of Deep River) over the period June 1986 to June 1988. Nominally shown here as 1988 and mapped at east of Crystal Lake
1988	Mount Manypeaks area	K. Gillen, note 2, below	Several records of quokka scats and runways noted in period September 1987 to September 1989. Mapped location is approximate only and listed as 1988
1989	Mount Frankland National Park, Middle Road	A.N. Start, note 2 below	Incidental sighting by Andrew Morton. Sighting of one animal only
1989	Two Peoples Bay Nature Reserve, Mt Gardner area	K. Gillen, note 2 below	Multiple records of quokka scats and runways noted in period June 1985 to July 1991. Three confirmed sightings in July 1988 (Lower Robinson's Gully/Coffin Gully), July 1989 (Coffin Gully) and July 1990 (Robinson's Gully/Coffin Gully)
1989	Bald Island	K. Gillen, note 2 below	Record of scats and subsequent quokka sighting on rocks near western shore
1991	Stirling Range National Park, Success Ridge Track	Smith, R.	Carcass recorded by Bob Smith (CALM Manjimup), via Lachie McCaw (CALM Manjimup). Quokka thought to be displaced as a result of fire
1991	Nannup, Lewana Plantation	A.N. Start, note 2 below	Carcass of juvenile fox-killed quokka collected in pine plantation. Approximate mapping of location only. No details of source population
1991	Stirling Range National Park - Bluff Knoll (1986–1991)	A.N. Start, note 2 below	Confirmed records of presence (sightings) by Allan Rose in the period from 1986 to 1991. Nominally listed here as 1991, see also 1986 record above. Area burnt in April 1991 and only one record at this location since (see 1991 record below). Presence otherwise suggested by scats, see 1995 record of Barrett (1996).
1991	Stirling Range National Park - Bluff Knoll (1991)	A.N. Start, note 2 below	Carcass (bones only) collected by Allan Rose. Presumed killed as a result of fire
1991	Jarrahdale, Rosella Road, Gordon Forest Block	A.N. Start, note 2 below	Presence reported from scat only. Subsequently trapped to confirm presence in 1995 (previously unpublished results, see Table 9) and to estimate population size 1998–2000 (Hayward et al. 2003)
1991	Jarrahdale, Karnet Forest Block	A.N. Start, note 2 below	Sighted by Grant Pronk when flushed from vegetation as escaping bushfire
1992	Walpole, Roe Forest Block	A.N. Start, note 2 below	Known for one roadkill carcass recorded by Phil Durell
1994	Mt Manypeaks	K. Gillen, note 2 below	Reported as dead sub-adult male
1994	Two Peoples Bay Nature Reserve	(Sinclair 1999)	None caught during Sinclair's survey period. Subsequently caught (by WA Dept of Conservation and Land Management staff) from December 1994 onwards from several different locations. Location co-ordinates here are therefore approximate
1995	Stirling Range National Park - Ellen Peak	Barrett (1996)	Presence indicated by detection of hair (hair tube). Fresh scats and runways also observed by Sinclair (1999).
1995	Stirling Range National Park - Toolbrunup Peak	Barrett (1996)	Presence indicated by detection of scats
1995	Stirling Range National Park - Bluff Knoll	Barrett (1996)	Presence indicated by detection of scats from southern slopes and cascade area

Table 4 (cont.)

Year of record	Location or Site name	Source	Comment
1995	Mount Manypeaks Nature Reserve	Barrett (1996)	Presence indicated by detection of hair (hair tube)
1995	Stirling Range National Park - Hume Peak	Barrett (1996)	Presence indicated by detection of scats
1996	Pemberton, Poole Forest Block (second site)	G. Liddelow, note 3 below	Approximate date. Abundance rated as 1 (low) on scale of 1–3 for extent of visible activity (scats within runways, extent of runways and spoor)
1996	Pemberton, Tinkers Brook, Sutton Forest Block	G. Liddelow, note 3 below	Approximate date. Abundance rated as 1 (low) on scale of 1–3 for extent of visible activity (scats within runways, extent of runways and spoor)
1996	Pemberton, Poole Forest Block	G. Liddelow, note 3 below	Approximate date. Abundance rated as 1 (low) on scale of 1–3 for extent of visible activity (scats within runways, extent of runways and spoor)
1996	Jarrahdale, Chandler Road Orchard	D. Giles (personal communication to PJdeT)	Known from one sighted individual. Presumable contiguous and/or from Chandler Road population
1996	Stirling Range National Park, Chester Pass Road	Sinclair (1999)	Noted as a single dead animal found on Chester Pass Road in 1996. Date provided and location given to Mark Roddy, Park Ranger, as opposite Toll Peak car park, Chester Pass Road
1997	Jarrahdale, Gordon Forest Block	P. Batt Giles (personal communication to PJdeT)	Identified from extensive runways, may be continuos with the Rosella Road population
1998	Two Peoples Bay Nature Reserve, Mt Gardner area	Friend and Butler (nominally 1998)	Incidental, non-target capture of quokkas at 3 sites at Two Peoples Bay Nature Reserve when monitoring/surveying for Gilbert's potoroo. Sites were East Firebreak, Lower Firebreak & West 6. Mapped here as 1 location, near Mt Gardner
1999	Two Peoples Bay Nature Reserve, Mt Gardner area	Friend and Butler (nominally 1999)	Incidental, non-target capture of quokkas at 4 sites at Two Peoples Bay Nature Reserve when monitoring/surveying for Gilbert's potoroo. Sites were East Firebreak, Lower Firebreak, North Firebreak & Hakea. Mapped here as 1 location, near Mt Gardner
2001	Perth water supply catchment, Churchman Forest Block	J. Liddington (personal communication to PJdeT)	One individual quokka trapped as a non-target incidental capture when trapping for pigs. First reported capture from this site
2001	Perth water supply catchment, water catchment exclusion within Churchman Forest Block	J. Liddington (personal communication to PJdeT)	Quokka caught as a non-target incidental capture when trapping for pigs. Second capture from this section of catchment
2002	Perth water supply catchment, Churchman Forest Block (second site)	J. Liddington (personal communication to PJdeT)	Quokka caught as a non-target incidental capture when trapping for pigs. Third capture from this section of catchment

2002	Perth water supply catchment, Churchman Forest Block (third site)	J. Liddington (personal communication to PJdeT)	Confirmed roadkill. Fourth record within 12–15 months from this section of catchment
2002	Northcliffe, Nairn Forest Block	M. Sheehan (personal communication to PJdeT)	Roadside sighting of live quokkas and several confirmed roadkill records. Roadkills appear to be associated with disturbance resulting from roading activity, prior to timber harvesting
2002	Dwellingup, Urbrae Forest Block	R. Staines (personal communication to PJdeT)	Three quokkas trapped and one carcass found in period 21 February to 11 March 2002. Trapped quokkas were non-target incidental captures when trapping for pigs. Within 3.5km of sub catchment where Christensen (undated) trapped in 1972
2002	Dwellingup, Kyabram Brook, Park Forest Block	R. Staines (personal communication to PJdeT)	Within Alcoa's Willowdale mine site. Trapped as a non-target incidental capture when trapping for pigs. Known at this site from one capture only
2002	Quarrum Nature Reserve, east of Walpole	G. Freebury (personal communication to PJdeT)	Quokka presence confidently inferred by detection of scats in characteristic quokka runways
2002	Peak Forest Block, North of Walpole	G. Freebury (personal communication to PJdeT)	Quokka presence confidently inferred by detection of scats in characteristic quokka runways
2002	Muddy Lake, south of Bunbury	(Dell & Hyder-Griffiths 2002)	The authors reported 'road kill specimens had been collected recently' and 'carcasses had been brought … in … up until about two years ago'. A skull collected form the site on 25 September 2002 has been confirmed as a quokka (WAM record M54132), however the skull is not aged (Norah Cooper, pers. comm. to PJdeT) and quokka presence is otherwise only inferred from presence of runways
2003	Dwellingup (Banksiadale Forest Block) - within Alcoa's Huntly Mine Site mining envelope	M. Burt (personal communication to PJdeT)	Roadkill. Carcass reported to Merv Burt, Dwellingup. Carcass confirmed at swamp site, not collected
2003	Del Park Road, Dwellingup (Turner/Marrinup Forest Block)	M. Burt (personal communication to PJdeT)	Roadkill. Carcass reported and collected by Merv Burt, Dwellingup. Decomposed carcass collected
2003	Bighill Brook (Nairn Forest Block)	M. Sheehan (personal communication to PJdeT)	Roadkill, Wheatley Coast Road, 300m Northcliffe side of Bighill Brook
2003	Nannup (Boronia Forest Block)	G. Voigt (personal communication to PJdeT)	Characteristic quokka runways identified and confirmed as quokka by G. Liddelow, Department of Conservation and Land Management. Identified prior to proposed silvicultural burn
2003	Nannup (Nelson Forest Block)	M. Maxwell (personal communication to PJdeT)	Department of Conservation and Land Management Blackwood District record no 70, nocturnal sighting
2003	Nannup (Beaton Forest Block)	M. Maxwell (personal communication to PJdeT)	Department of Conservation and Land Management Blackwood District record no 74. Dead, presumably a roadkill
2003	Nannup (Gregory Forest Block)	M. Maxwell (personal communication to PJdeT)	Department of Conservation and Land Management Blackwood District record no 76. Dead, presumably a roadkill

Table 4 (cont.)

Year of record	Location or Site name	Source	Comment
2003	Mt Chudalup, Windy Harbour Road	M. Sheehan (personal communication to PJdeT)	Two quokkas, night sighting, eastern side of road near 'waterpoint' at Mt Chudalup monadnock
2003	Karri Gully, Dalgarup Forest, Brockman highway, between Nannup and Bridgetown	K. Redman (personal communication to PJdeT)	Three separate road kill records on Brockman Highway, between Nannup and Bridgetown, all within the first half of 2003
2003	Salmon Beach Road, off Windy Harbour Road	M. Sheehan (personal communication to PJdeT)	Four separate sightings over three weeks on roadside in coastal heath/stunted peppermint, near pump shed
2003	Jarrahdale, Frollet Plantation (between Mundlimup and Cobiac forest blocks)	D. Giles (personal communication to PJdeT)	Four quokkas sighted fleeing a burn
2003	Northcliffe, Wheatley Coast Road	P. Sargison (personal communication to PJdeT)	One sub-adult male roadkill, 200–300m south of Orchid Road, on eastern side of Wheatley Coast Road. Carcass retained for collection by Department of Conservation and Land Management staff
2003	Nannup/Bridgetown, Brockman Highway	K. Redman (personal communication to PJdeT)	One adult male road kill. Half way between Nannup and Bridgetown – 400m W of Jarrah Park
2003	Green Range	J.A. Friend (personal communication to PJdeT)	Hair sample collected when surveying (hair tubes) for Gilbert's Potoroo.

Notes:

1 Kabay and Start (1976) Sought information from the public, from field staff from relevant government agencies and carried out biological survey to detect the presence of Gilbert's potoroo, *Potorous tridactylus gilbertii*, (*now P. gilbertii*) and the broad faced potoroo, *P. platyops*, in the period April 1975 to October 1976. Quokka presence was also recorded at numerous sites investigated.

2. Unpublished database records of A.N. Start, Western Australian Department of Conservation and Land Management.

3. Unpublished records from incidental sightings and opportunistic trapping by G. Liddelow, Western Australian Department of Conservation and Land Management

Table 5

Records of occurrence of the quokka, *Setonix brachyurus*, extracted from unpublished Department of Conservation and Land Management databases (CALM unpublished; Gilfillan unpublished). Original source for most records was Departmental operational district staff. Records are predominantly from incidental and opportunistic sightings. Records are listed chronologically.

Date of record	**Location**	**Comment**
1987	Pemberton, Brockman National Park, near Pemberton-Northcliffe Road	carcass – 3 animals
1992	William Bay National Park	Information forwarded by Greg Freebury, WA Department of Conservation and Land Management. Date is estimate. Diurnal sighting of 1 individual
1993	Pemberton, Brockman National Park	roadkill
1994	Manjimup, Lewin Forest Block, Davidson Road / Pine Creek gully system	No other details
1994	Manjimup, Lewin Forest Block. Davidson Road / Pine Creek gully system	
1994	Manjimup, 7 Day Road / Court Rd	No other details
1994	Manjimup	
1995	Manjimup, Lewin Forest Block, Junction Davidson & Easter Rd	No other details
1995	Manjimup, Andrew Forest Block	No other details
1995	Manjimup, Lewin Forest Block, junction of Davidson and Easter roads	No other details
1995	Manjimup, Lewin Forest Block, junction of Davidson and Easter roads	
1995	Manjimup, Lewin Forest Block, junction Davidson and Easter roads	
1995	Manjimup, Andrew Forest Block	
1996	Walpole-Nornalup National Park, Cemetery Road Reserve 31362	
1996	Walpole-Nornalup National Park, Monastery Road, 1.5 km from South Coast Highway	
1996	Walpole-Nornalup National Park, South Coast Highway, 0.5 km west of Gully Road	
1996	Walpole-Nornalup National Park, near Spike Road Reserve 31362	
1996	Walpole-Nornalup National Park, Frankland River, near Monastery Landing	
1996	Walpole-Nornalup National Park, Cemetery Road Reserve 31362	
1996	Walpole-Nornalup National Park, Allen Road, 0.5 km from Hilltop Road	
1996	Walpole-Nornalup National Park, Pool Road	
1996	Walpole-Nornalup National Park, eastern boundary of Reserve 31362	
1996	Walpole, Valley of the Giants, Valley of the Giants Road	
1996	Walpole, Loc. 10190, 1 km northwest of junction of Jones Road and Hilltop Road	
1996	Walpole, Valley of the Giants, Bohall Road, 2.5 km from South Coast Highway	
1996	Walpole, Valley of the Giants, I km along track running southeast of Pedro firebreak	

Table 5 (cont.)

Date of record	Location	Comment
1996	Walpole, Valley of the Giants, northern end of Twin Creek Road	
1996	Walpole, Valley of the Giants, Court Road, 1 km from South Coast Hwy	
1996	Walpole, Valley of the Giants, South Coast Highway, 250 m west of Conspicuous Beach Road.	
1996	Walpole, 1.5 km northwest of junction of Jones Road and Hilltop Road	
1996	Walpole, Valley of the Giants, Valley of the Giants Road	
1996	Walpole-Nornalup National Park, Monastery Road, 0.5 km west of Zig Zag Road	
1996	Walpole, Valley of the Giants, Valley of the Giants Road	
1996	Walpole, Valley of the Giants, Rate Road 3.3 km north of South Coast Hwy	
1996	Pemberton, Brockman NP, adjacent to farmland	Diurnal sighting of 2 quokka disturbed by and escaping from machine (dozer) disturbance
1996	Walpole, Valley of the Giants, South Coast Hwy, 1.1 km east of Conspicuous Beach Road	
1996	Frankland, Ford Road 3 km from Talbot Road	
1996	Walpole Inlet, near Collier Creek, eastern edge	
1996	Nornalup, Nornalup Bridge, South Coast Highway.	
1996	Manjimup, Solai Forest Block, Solai Rd HC6395	No other details
1996	Walpole, Valley of the Giants, South Coast Highway, 1km south of 28 Mile Road	
1996	Manjimup, Yardup Forest Block, 1km North along Edwards Road from Perup Road	Database records indicate two different sightings, same day. The source is identified for one sighting only and is possibly a duplicate record. The Yardup record(s), combined with the 1954 record by A.D. Jones in Serventy et al. (1954) represent the only quokka records from the Perup forest.
1996	Manjimup, Lewin Forest Block, Easter & Eastwin roads	No other details
1996	Manjimup, Nelson Forest Block, Bibbulmun Track approx 500m south of Willow Springs	No other details
1996	Walpole, Valley of the Giants, near South Coast Highway, 2 km west of Nut Road	
1996	Manjimup, Solai Forest Block, Solai Road	
1996	Manjimup, Yardup Forest Block, 1km north along Edwards Road from Perup Road	No other details
1996	Roe, first creek system west of Claude Road, on Roe Road. (near Mt. Roe)	
1996	D'Entrecasteaux National Park, Mandalay Beach Road, near beach	
1996	Walpole-Nornalup National Park, Tinglewood Road, 1.5 km from South Coast Highway	
1996	Manjimup, Nelson Forest Block, Bibbulmun Track approx 500m south of Willow Springs	
1996	Walpole, Keystone Rd. 1.5 km north of South Coast Highway	

Date of record	Location	Comment
1996	Manjimup, Easter Forest Block, Easter and Eastwin roads	
1996	Walpole-Nornalup National Park, Shelleys Beach	
1996	Walpole-Nornalup National Park, South Coast Highway, 0.75 km west of Tinglewood Road	
1996	Walpole-Nornalup National Park, walking track between Sealers Cove and Circus Beach	
1996	Walpole-Nornalup National Park, gully north-northwest of Circus Beach	
1996	Walpole-Nornalup National Park, 1 km northwest of Circus Beach	
1996	Walpole, Rest Point Road, 1 km from South Coast Highway	
1996	Denbarker, Denmark- Mt. Barker Road, near Mitchell River Bridge	
1997	Manjimup, Netic Forest Block, Pool Road	
1997	Walpole, Approximately 200m east of the junction of Tree Top Walk Road and Valley of the Giants Road on Valley of the Giants Road	Roadkill
1997	Pemberton, D'Entrecasteaux National Park, near Landslide Road in aerial burn area DC16	diurnal sighting of 1 adult quokka
1997	Walpole, Valley of the Giants Road approximately 200m west of the Tree Top Walk turn-off	Roadkill, carcass identified
1997	Manjimup, Graphite Forest Block, Austin Road	
1997	Manjimup, Andrew Forest Block, Top Road	
1997	Manjimup, Netic Forest Block, Netic quokka exclusion (WHAT IS THIS)	
1997	Manjimup, Netic Forest Block, Pool Road	
1997	Manjimup, Netic Forest Block, junction of Sexton and Parky Roads	
1997	Manjimup, Netic Forest Block, Sexton Road	
1997	Manjimup, Netic Forest Block, Kanny Road	
1997	Manjimup, Andrew Forest Block, Dalberg Road waterpoint – 2.5 km west of Austin Road	
1997	Pemberton, D'Entrecasteaux National Park	Roadkill on Salmon Beach Road 1km from Windy Harbour. Definite signs of quokka activity in 4year old heath north of road
1997	Manjimup, Mack Forest Block, Well Road	No other details
1997	Manjimup, Netic Forest Block, Kanny / Parky Roads	
1997	Pemberton, Crowea Forest Block, McAlpine Road waterpoint	Presence inferred by signs (scats, runways)
1997	Walpole, Walpole-Nornalup National Park, walk trail from town to Coalmine Beach	Diurnal sighting of one individual, crossing walk trail
1997	Manjimup, Solai Forest Block, Monk / Solai Roads	
1997	Pemberton, Crowea Forest Block, thick ti-tree between coupes on Crowea Road	Presence inferred by signs (scats, runways)
1997	Pemberton, Crowea Forest Block	Diurnal sighting
1997	Pemberton, Crowea Forest Block, track crossing Orchid Rd, 1.1km from Crowea Road	
1997	Pemberton, Crowea Forest Block, south-west corner 1984 regen on south side of road	Presence inferred by signs (scats, runways)

Table 5 (cont.)

Date of record	Location	Comment
1997	Pemberton, Crowea Forest Block, McAlpine Road, water point near Hawkins Road and Dan Road	Presence inferred by signs (scats, runways)
1997	Pemberton, Crowea Forest Block, Rowney Road north of Crowea Rd	Presence inferred by signs (scats, runways)
1997	Pemberton, Crowea Forest Block, Karri/Marri gully 1.9km from Wheatley Coast Road	
1997	Pemberton, Crowea Forest Block, track crossing Cederman Road 400m from Wheatley Coast Road. Karri/Marri regrowth	
1997	Walpole, Wye Forest Block	Presence inferred by signs (spoor)
1997	Manjimup, Mack Forest Block, Mt Mack Road / Tom Road intersection	
1997	Manjimup, Netic Forest Block, Pool Road	No other details
1997	Walpole, Rocky Forest Block	No detail, presumably a sighting
1997	Walpole, Rocky Forest Block	Old (not fresh) evidence in unburnt gully
1997	Walpole, Sharpe Forest Block	Presumably determined by evidence of activity, at creek in Sharpe Block (North of Sharpe 6), flows into the Deep River
1997	Manjimup, Solai Forest Block, Monk / Solai Roads	No other details
1997	Manjimup, Andrew Forest Block, Top Road	No other details
1997	Manjimup, Graphite Forest Block, Austin Road	No other details
1997	Manjimup, Graphite Forest Block, Cow Brook – Davidson Road	No other details
1997	Manjimup, Gordon Forest Block, Mobil Road	No other details
1997	Manjimup, Andrew Forest Block, Dalberg Road waterpoint – 2.5 km	No other details
	west of Austin Road	
1997	Manjimup, Mack Forest Block, McNab Well	No other details
1997	Manjimup, Netic Forest Block, Penny Road	No other details
1997	Manjimup, Netic Forest Block, Kanny Road	No other details
1997	Manjimup, Netic Forest Block, Kanny / Parky Roads	No other details
1997	Manjimup, Netic Forest Block, Junction of Sexton and Parky Roads	No other details
1997	Manjimup, Netic Forest Block, Pool Road	No other details
1997	Manjimup, Netic Forest Block	No other details
1997	Manjimup, Mack Forest Block, Mt Mack Road / Tom Road intersection	No other details
1997	Walpole, Rocky Forest Block	Recorded as gully crossing road, presumably presence inferred by evidence of activity
1997	Manjimup, Mack Forest Block, McNab Well	
1997	Manjimup, Gordon Forest Block, Mobil Road	
1997	Manjimup, Netic Forest Block, Penny Road	
1997	Manjimup, Graphite Forest Block, Cow Brook – Davidson Road	
1997	Manjimup, Netic Forest Block, Sexton Road	No other details

Date of record	Location	Comment
1997	Walpole, Ford Road approximately 2.0km south west from the corner of Ford and Collis roads	diurnal sighting of 1 quokka crossing road
1997	Walpole, approximately 200m west of the Conspicuous Beach turn-off on the South Coast Highway (northern verge)	Roadkill
1997	Manjimup, Mack Forest Block, Well Road	
1998	Walpole, Walpole-Nornalup National Park, Valley of the Giants old carpark	diurnal sighting of 1 quokka crossing carpark
1998	Walpole, Walpole-Nornalup National Park, Valley of the Giants Road, approximately 500m south of Howe Road	night sighting of adult quokka crossing road
1998	Walpole, 100m west on Beardmore and Thomson roads	diurnal sighting of 1 quokka crossing road
1998	Walpole, approximately 400m west of the Jack Rate Lookout on the South West Highway	nocturnal sighting of 1 quokka at roadside
1999	Walpole, South Coast Highway approximately 3.5km east of Walpole	Roadkill 1 adult
1999	Walpole, Jones Road, 1km south of Clarke Road	Nocturnal sighting of 3 quokkas, at least 1 adult. Runways present in vegetation
1999	Manjimup, Beavis Forest Block, Beavis 8	diurnal sighting of 2 quokkas
1999	Manjimup, Lewin Forest Block, Pine Creek Road, 1.3 km from Davidson Road	Carcass
1999	Walpole, Walpole-Nornalup National Park, 100m west of Nornalup Bridge	Roadkill, carcass identified
1999	Manjimup, 220 metres east of Boundary Road on Willow Spring Road	identified from carcass
1999	Manjimup, Andrew Forest Block	diurnal sighting of 2 quokkas
1999	Manjimup, near intersection Penny Road and Willow Spring Road	diurnal sighting of 1 quokka
1999	Stirling Range National Park, Pyungoorup Peak	Carcass forwarded to Western Australian Museum
1999	Two Peoples Bay Nature Reserve, on access track to research quarters	Nocturnal sighting of 1 quokka
1999	Walpole, South West Highway, approximately 400m west of the Jack Rate Lookout and approximately 700m east of Tinglewood Road	Roadkill 1 adult
2000	Waychinicup National Park	carcass
2000	Two Peoples Bay Nature Reserve, Little Beach Road, start of slashed firebreak to south of road	Nocturnal sighting of 1 quokka
2000	Two Peoples Bay Nature Reserve, approximately 2–300 m from start of Little Beach Road	Nocturnal sighting of 2 quokkas
2000	Waychinicup National Park, Waychinicup Road, just north of creek crossing	carcass
2000	Manjimup, Nelsons Location 9466 Jones Rd, Yanmah / Glenoran area	day sighting of 3 individuals, feeding on household scraps
2000	Waychinicup National Park, campsite	Nocturnal sighting of 2 quokkas
2000	Two Peoples Bay Nature Reserve, Little Beach Road, start of slashed firebreak to south of road	carcass
2000	Manjimup, Beavis Forest Block	
2000	Manjimup, Donnelly Mill Road	nocturnal sighting of 1 quokka
2000	Manjimup	
2000	Manjimup, 100m South of Palings Road and Coronation Road	Carcass

Table 5 (cont.)

Date of record	Location	Comment
2000	Manjimup, 1km east along Telephone Road from Coronation Road	Carcass
2000	Manjimup	one individual sighted running from road to scrub
2001	Walpole, 1/2 way between Deep River and Crystal Springs on South Western Highway	carcass
2001	Walpole, Crystal Springs, Coalmine Beach turnoff on South Coast Highway, approximately 3km east of Walpole	Carcass
2001	Stirling Range National Park, Mt. James Road	capture of 1 quokka during Western Shield monitoring
2001	Dwellingup, Del Park Road, south of Alcoa minesite	Roadkill 1 adult

Table 6

Previously unpublished records of occurrence of the quokka, *Setonix brachyurus*, held by the authors. Records are from opportunistic sightings and trapping programs implemented to determine presence. Records are listed chronologically.

Year of record	Location or Site name	Source	Comment
1971	Dwellingup, Lewis (Wild Pig) Swamp	Dillon (1993) see note 1, below	Reported on the 1971 survey of the wetter western creek systems in vicinity of Dwellingup. A total of 52 quokkas caught at 6 sites. Population density estimates of 1 animal per 2 ha in swamps unburnt for 5–10 years. Locations nominally mapped as Lewis and Holyoake swamps
1971	Dwellingup, Holyoake	Dillon (1993) see note 1, below	As above
1988	Dwellingup, Alcoa's Huntly Mine Site envelope	Dillon (1993) see note 1, below	Four of 5 sites inspected in 1988 showed evidence of quokka activity. Nominally mapped as Lewis Swamp, within mine site envelope. No estimates of population size
1992	Dwellingup, Holyoake	Dillon (1993) see note 1, below	15 of 30 swamps surveyed in vicinity of Dwellingup in 1992 showed evidence of quokka activity. Three of these were then trapped unsuccessfully (fence funnel trap), subsequently one quokka only was trapped (wire cage trap) at the Holyoake site only.
1992	Collie/Mornington, Hadfield Forest Block	R. Brazell, note 2 below	Population presumed to be contiguous with population trapped and population size reported by Hayward et al. (2003)
1992	Collie/Mornington, Gervasse Forest Block	R. Brazell, note 2 below	This site known to support a relatively large population. Population estimate reported in this study (see Table 7)
1992	Collie/Mornington, Hamilton Forest Block	R. Brazell, note 2 below	3 quokkas trapped when site trapped to determine presence in 1992. Population presumably contiguous with the population trapped by Hayward et al. (2003)
1992	Collie/Mornington, Victor Road Site, Hamilton Forest Block	R. Brazell, note 2 below	This site known to support a relatively large population. Population presumably contiguous with the population trapped by Hayward et al. (2003)
1992	Collie/Mornington, Hadfield Forest Block	R. Brazell, note 2 below	This site known to support a quokka population – population estimate reported by Hayward et al (2002). Other incidental quokka reportings and opportunistic trapping from Hadfield Forest Block presumed to be contiguous with this population
1995	Pemberton, Chudalup Forest Block	Dillon (1996), note 3 below	Presence indicated, abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant). Abundance considered comparable with survey in 1978–79
1995	Manjimup, Andrew Forest Block (second site)	Dillon (1996), note 3 below	Presence indicated, abundance rated at 2 on scale of 0 (absence) to 3 (relatively abundant). Unknown if abundance has changed since survey in 1978–79
1995	Manjimup, Lindsay Forest Block	Dillon (1996), note 3 below	Presence indicated. Abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant) and considered to be reduced from previous survey in 1978–79. Logging operations close to swamp.
1995	Nannup, Mack Forest Block	Dillon (1996), note 3 below	Presumably contiguous with the Andrew Forest Block (third site) record. Presence indicated, abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant). Abundance considered comparable with survey in 1992–93

Table 6 (cont.)

Year of record	Location or Site name	Source	Comment
1995	Walpole, Weld Forest Block	Dillon (1996), note 3 below	Presence indicated, abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant). Abundance considered comparable with survey in 1978–79
1995	Walpole-Nornalup National Park (Hilltop Road or formerly Hilltop Forest Block)	Dillon (1996), note 3 below	Presence indicated, abundance rated at 2 on scale of 0 (absence) to 3 (relatively abundant). Abundance considered comparable with survey in 1978–79. Was burnt in wildfire in 1987, quokkas seen dispersing at time of fire
1995	Walpole, Crossing Forest Block	Dillon (1996), note 3 below	Presence indicated, abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant). Abundance considered comparable with survey in 1978–79
1995	Walpole, Giants Forest Block	Dillon (1996), note 3 below	Presence indicated, abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant). Abundance considered comparable with survey in 1978–79
1995	Nannup, Gregory Forest Block	Dillon (1996), note 3 below	Presence indicated, abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant). Abundance considered comparable with survey in 1992–93. Site is long unburnt
1995	Nannup, Beaton Forest Block	Dillon (1996), note 3 below	Presence indicated, abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant). Abundance considered comparable with survey in 1992–93
1995	Nannup, Beaton Forest Block (third site)	Dillon (1996), note 3 below	Presence indicated, abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant). Abundance considered comparable with survey in 1992–93
1995	Manjimup, Andrew Forest Block (third site)	Dillon (1996), note 3 below	Presumably contiguous with the Mack Forest Block record. Presence indicated. Abundance rated at 2 on scale of 0 (absence) to 3 (relatively abundant) and considered to be comparable with previous survey in 1978–79. Site disturbed by construction of newly dug water point.
1995	Nannup, Helms Forest Block	Dillon (1996), note 3 below	Presence indicated, abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant). Abundance considered reduced from survey in 1975. swamp patch burnt in 1994 (1 year prior to this assessment)
1995	Nannup, Beaton Forest Block (second site)	Dillon (1996), note 3 below	Presence indicated, abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant). Unable to determine if change in abundance from previous survey
1995	Nannup, Beaton Forest Block (fifth site)	Dillon (1996), note 3 below	Presence indicated, abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant). Unable to determine if abundance has changed since previous survey
1995	Manjimup, Andrew Forest Block	Dillon (1996), note 3 below	Presence indicated, abundance rated at 2 on scale of 0 (absence) to 3 (relatively abundant). Unknown if abundance has changed since survey in 1978–79
1995	Nannup, Beaton Forest Block (fourth site)	Dillon (1996), note 3 below	Presence indicated, abundance rated at 2 on scale of 0 (absence) to 3 (relatively abundant). Unable to determine if abundance changed from previous survey
1995	Nannup, Gregory Forest Block (second site)	Dillon (1996), note 3 below	Presence indicated, abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant). unable to determine if abundance has changed since last survey. runways appear unused, old scat only detected

1995	Dwellingup, Kesners Swamp, Marrinup Forest Block	P. de Tores, M. Dillon, A. Tomkinson and R. Buehrig, note 4 below	Known to support a population in the 1970s, population presence confirmed through trapping in February to March 1995. Population size estimated by Hayward (2003)
1995	Dwellingup, Lewis (Wild Pig) Swamp, Wilson Forest Block	P. de Tores, M. Dillon, A. Tomkinson and R. Buehrig, note 4 below	Showed signs of fresh activity in 1995, presence unable to be confirmed by trapping. Presence also unable to be confirmed in 2000 by Hayward et al. (2003) and this location may no longer supports a population
1995	Dwellingup, Holyoake Forest Block	P. de Tores, M. Dillon, A. Tomkinson and R. Buehrig, note 4 below	Showed evidence of activity in 1995, however, by 2000 considered to no longer support a population
1995	Jarrahdale, Rosella Road, Gordon Forest Block	P. de Tores, M. Dillon, A. Tomkinson and R. Buehrig, note 4 below	Trapped to confirm presence. Seven capture events of 4 quokkas, April 1995
1996	Manjimup, Storry Forest Block	Dillon (1996), note 3 below	Presence indicated, abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant). Unable to determine if abundance has changed since last survey
1996	Nannup, Netic Forest Block	Dillon (1996), note 3 below	Presence indicated, abundance rated at 2 on scale of 0 (absence) to 3 (relatively abundant). Unable to determine if abundance has changed since previous survey. fresh tracks and activity beyond swamp area
1996	Nannup, Nelson Forest Block	Dillon (1996), note 3 below	Presence indicated, abundance rated at 1 on scale of 0 (absence) to 3 (relatively abundant). Unable to determine if abundance has changed since previous survey. appears 6–10 years since last (patchy) burn
1996	Jarrahdale, Chandler Road, Chandler Forest Block	P. de Tores, M. Dillon, A. Tomkinson and R. Buehrig, note 4 below	Known to support a population -population estimate reported by Hayward et al. (2003)
1996	Jarrahdale, Albany Highway Site. (Travellers' Arms site).	P. de Tores, M. Dillon, A. Tomkinson and R. Buehrig, note 4 below	Population reported from a roadkill in 1996 and subsequent follow up trapping (in the same year) confirmed presence. This site presumed to be the Travellers' Arms site referred to in 1956 by R. Aitken, cited by Barker et al. (1957) (Table 3) and trapped by Kent Williams in 1966 (Table 4)
1996	Collie/ Mornington Road, Hamilton Forest Block	R. Brazell, note 2 below	Known from 1 roadkill, source population not confirmed
2000	Collie, Davis Forest Block	M. Hayward, note 5 below	Presence inferred by detection of scats within runways
2000	Dwellingup, Marrinup Forest Block	M. Hayward, note 5 below	Presence inferred by detection of scats within runways
2000	Dwellingup, Federal Forest Block	M. Hayward, note 5 below	Presence inferred by detection of scats within runways
2000	Pemberton, Dickson Road	M. Hayward, note 5 below	Presence inferred by detection of scats within runways
2000	Dwellingup, Finlay Brook, Wilson Forest Block	M. Hayward, note 5 below	Presence inferred by detection of scats within runways. Spoor subsequently observed by de Tores and Dillon
2000	Dwellingup, Clinton Forest Block	M. Hayward, note 5 below	Presence inferred by detection of scats within runways.
2000	Dwellingup, Alcoa Conveyor Belt	M. Hayward, note 5 below	Presence inferred by detection of scats within runways.
2000	Dwellingup, South Dandalup Dam	M. Hayward, note 5 below	Presence inferred by detection of scats within runways. Also known previously from incidental sightings. Population may be contiguous with population at Kesners Swamp and the Conveyor Belt Site

Table 6 (cont.)

Year of record	Location or Site name	Source	Comment
2000	Dwellingup, Keats Forest Block	M. Hayward, note 5 below	Presence inferred by detection of scats within runways.
2000	Dwellingup, Turner Forest Block	P. de Tores, note 4 below	Incidental sighting in May 2000, subsequent additional incidental sighting reported in October 2000 and roadkill (carcass collected by M. Maxwell and C. Trethowan) in December 2000. Also subsequently considered by Hayward to support a quokka population

Notes:

1. Dillon (1993) reported on a 1971 survey of creek systems in the wetter western creek systems in vicinity of Dwellingup, a 1988 survey within Alcoa's Huntly mine site envelope near Dwellingup and 1992 broadscale survey to determine presence in swamps near Dwellingup
2. Unpublished records from incidental sightings and opportunistic trapping by R.I. Brazell, Western Australian Department of Conservation and Land Management.
3. Dillon (1996) report on survey of sites surveyed from 1995 –1996, where presence was confirmed through trapping, or indicated by scats observed within runways and other fresh signs of activity – scats alone not considered sufficient to confirm presence.
4. Unpublished records from incidental sightings, trapping programs initiated to determine presence and opportunistic trapping by P. J. de Tores, M. J. Dillon, A. Tomkinson and R. Buehrig, Western Australian Department of Conservation and Land Management.
5. Results from unpublished field survey conducted by M. W. Hayward between September 1998 and September 2000 where a range of potential locations were examined for evidence of quokka presence. With the exception of the South Dandalup Dam site, the sites listed were previous not known to support quokkas.

Table 7

Previously unpublished trapping records for the quokka, *Setonix brachyurus*, from sites in the northern jarrah forest of south-west Western Australia

Site name	**Year(s) trapped**	**Purpose of trapping program**	**Method of analysis**	**Result**
Gervasse Forest Block, near Collie	1992 to 2000	Long-term monitoring of abundance and survivorship	Abundance estimates derived from the *'deaths and no immigration'* Jolly-Seber model Survivorship estimates derived from the Program MARK Cormack-Jolly-Seber model	Population estimate of 49.21 ±7.85 individuals
Rosella Road, near Jarrahdale	April 1995	Opportunistic trapping to determine presence only Subsequently trapped by Hayward et al. (2003) to derive population estimates	Listing of total number of captured individuals	7 captures of 4 quokkas
Albany Highway, southeast of the Perth metropolitan area. This location is presumed to be the Travelers' Arms site referred to by Barker et al. (1957) (Table 3) and Williams in 1966 (Table 4)	1996	Opportunistic trapping to determine presence only	Listing of total number of captured individuals	1 capture of an adult male
Holyoake, Dwellingup	August 1995	Opportunistic trapping to determine presence only	N/A	No captures, no evidence of recent presence. Old runways and no fresh scats
Lewis (Wild Pig) Swamp, Dwellingup	August 1995	Opportunistic trapping to determine presence only	N/A	No captures, some evidence of recent activity in runways
Kesners Swamp, Dwellingup	February to June 1995	Opportunistic trapping to determine presence only Subsequently trapped by Hayward et al. (2003) to derive population estimates	Listing of total number of captured individuals	22 captures of 10 quokkas

Table 8

Location records for the quokka, *Setonix brachyurus*, excluded from maps used to infer distribution and excluded from estimates of extent of occurrence. Records listed and/or the location described were either unable to be confirmed, or were from captive colonies/sanctuaries

Location	**Year of record**	**Source of record**	**Comment**
North Twin Peak Island	1905	Shortridge (1909)	Shortridge included 'Twin Peak' island as a known site for the quokka. Unclear if this was a reference to North Twin Peak Island or South Twin Peak Island. Quokkas have not been recorded from either island by any other author and the record is considered to be a tammar wallaby, see comments in text
South Twin Peak Island Point Culver	1905	Shortridge (1909) Western Australian Museum records. WAM registration number 024346	Comments for the North Twin Peak Island, above apply. Identification confirmed as a quokka in 1982 by D.J. Kitchener (WA Museum) (Norah Cooper pers. comm. to PJdeT). The record is outside the known historic range and the range as determined by the fossil record and is therefore considered spurious. No additional location details available and no date of collection or any other details. Accuracy of location therefore considered insufficient to include within inferred distribution.
Coorow	1949	Western Australian Museum records. WAM registration number 002781	Validity of record questioned by Nora Cooper (WA Museum). Remains were collected from a cave in 1949, subsequently destroyed and unable to be verified (Norah Cooper pers. comm. to PJdeT).
Breaksea Island	1975	Western Australian Museum records. WAM registration number 002781	See comments in text.
Department of Zoology, University of Western Australia	1958 and 1959	Western Australian Museum records. WAM registration numbers 003365 and 003618	Specimen presumed to be from the captive colony held at the University of Western Australia, ex Rottnest Island
Karakamia Sanctuary, Chidlow, east of Perth	1998	Smitz (1998)	Four quokkas originally sourced from mainland locations and released within a predator proof fenced sanctuary. Three quokkas released in 1996, two of which were originally sourced from the Gervasse population, near Collie and held by the 'Big Swamp Wildlife Park', Bunbury. The third was a captive bred young of the first two. The fourth animal sourced from the Rosella Road site and released in 1997. One death has been recorded and at least 1 young has been produced, population size unknown at May 2002
Harry Waring Marsupial Reserve, Jandakot	1979	Austin (1979)	Population sourced from Rottnest Island and released at the fenced Harry Waring Marsupial Reserve. The colony failed to persist.
Muddy Lake, south of Bunbury	2002	Dell and Hyder-Griffiths (2002)	Unconfirmed record – See listing in Table 4
Water Corporation reserve, Dunsborough	2004	Jim Lane (pers. comm. to PJdeT)	Unconfirmed record

Table 9

Known To Be Alive (KTBA) estimates for the quokka, *Setonix brachyurus*, at the Gervasse Forest Block site, for the period 1992 to 2002.

Month and Year of trapping	**KTBA estimate**
June/July 1992	First trapping session, no KTBA estimate available
March 1993	14
June/July 1993	20
January 1994	22
August 1994	20
April 1995	19
January 1996	15
January 1997	12
February 1998	12
March 1999	11
February 2000	Last trapping session, no KTBA estimate available

Table 10

Locations previously known to support populations of the quokka, *Setonix brachyurus*, re-surveyed in the period 1995–1996 by Dillon (1996) and found to show no evidence of presence or where presence was unable to be confirmed.

Location	**Year of last known record**	**Comment**
Netic Forest Block, Manjimup	1978–79	0 to 2 years since last burnt. Quokkas subsequently reported from other locations within this and neighbouring forest block (see Table 5)
Shannon, Walpole	1978–79	0 to 2 years since last burnt, swamp vegetation completely burnt. Quokkas subsequently reported from other locations within Shannon River area (see Table 5)
Giants Forest Block, Walpole	1978–79	Very heavy litter layer and 11 years or more since last burn. Previously known from a roadkill only at this site. Quokkas subsequently reported from other locations within this forest block (see Tables 5 and 6)
Walpole-Nornalup National Park (Hilltop Road area), Walpole	1978–79	Very heavy litter layer and 11 years or more since last burn. No recent evidence of activity. Quokkas subsequently reported from other locations within this vicinity and may be at high density (see text and Tables 5 and 6)
Sheepwash Forest Block, Denmark	1978–79	6 to 10 years since last burn. No sign of recent activity
Farmland area, Bunbury	1976	No evidence of activity, habitat now water logged. Location determined on basis of incorrect geographic co-ordinates for Muddy Lake listed by Kabay and Start (1976)
Urbrae Forest Block, Dwellingup	1988	11 years or more since last burn. Quokkas subsequently reported from other locations within this forest block (see Table 6)
Holyoake, Dwellingup	1992	3 to 5 years since last burn. Subsequently trapped more intensively (August 1995) (Table 7) with no evidence of quokka activity or presence
Inglehope Forest Block, Dwellingup	1972–73	6 to 10 years since last burn. No sign of activity when surveyed by Dillon (1996) nor when surveyed by Hayward (2002) in 1999–2000.

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A list of macrofungi recorded in burnt and unburnt *Eucalyptus diversicolor* regrowth forest in the southwest of Western Australia: 1998–2002

RICHARD M. ROBINSON[1] AND VERNA L. TUNSELL

Science Division, Department of Conservation and Land Management, Manjimup, WA 6258
[1] Corresponding Author: richard.robinson@dec.wa.gov.au

ABSTRACT

In December 1997, a wildfire in the Pemberton region of southwest Western Australia burnt about 1600 ha of karri (*Eucalyptus diversicolor*) regrowth forest. Immediately following the fire, a network of sites was selected in burnt 17–25-year-old regrowth forest and in similar aged regrowth unburnt since establishment. We present a species list of the macrofungi recorded from 1998–2002, at 5 burnt and 5 unburnt sites. A total of 322 species of macrofungi were recognised, of which 144 were identified to species or designated an affinity species. All but four species are represented by voucher collections, and most by *in situ* photographs, and detailed macro and micro descriptions. Voucher collections were lodged at PERTH, and descriptions are available from the first author (R.R.).

INTRODUCTION

Karri (*Eucalyptus diversicolor* F. Muell.) forest is restricted to the southwest of Western Australia, largely confined within the 1000 mm isohyet where it occurs on a variety of soil types as either pure or mixed forest with jarrah (*E. marginata* Donn. ex Sm.) and/or marri (*Corymbia calophylla* (Lindl.) K.D. Hill and L.A.S. Johnson). Karri achieves its best development as a tree on red-earths in the central region of its range, where it mostly occurs in pure stands and rainfall exceeds 1250 mm per annum (Christensen 1992).

Fungi are important components of all terrestrial ecosystems. They play key roles in decomposition and nutrient cycling, assist nutrient uptake in plants, and species of hypogeous truffle-like fungi form a major component of the diet of many Australian mammals. Fungi are a large and diverse group and form a major component of the biodiversity of forest ecosystems (May and Simpson 1997).

No systematic survey of macrofungi has been undertaken in the southwest forest region of Western Australia, which includes karri, jarrah, tuart (*E. gomphocephala* DC.) and wandoo (*E. wandoo* Blakely) forest and woodlands. In a census of macrofungi of Western Australia, Hilton (1982, 1988) listed 504 named taxa, of which 135 occurred in the southern forest region. The only lists of fungi compiled from local survey in the southwest of WA are for coastal woodland at Two Peoples Bay (Syme 1992) and jarrah forest near Denmark (Bougher *et al.* 1997). Syme (1992) listed 441 taxa of which 76 were identified including 68 that were noted as occurring in Hilton's census. Bougher *et al.* (1997) listed 355 taxa of which 32 were identified.

The total number of Australian fungi is unknown, but estimated to be as high as 250 000 (Pascoe 1990), with the number of macrofungi ranging from 10 000 (May 2003a) to 20 000 (Young 2005). Despite their importance, they are often overlooked or neglected in surveys and conservation initiatives for monitoring and protecting biodiversity. As a result very few species can be considered well known with respect to their distribution, ecology and general biology (May and Wood 1997). Recently, however, improved knowledge of many species in regard to response to fire, fruiting behaviour, and distribution has been gained (Robinson *et al.* submitted).

Most Australian macrofungi appear to be widespread. Although 49% of the vascular plants in the southwest of Western Australia are endemic to the State (Hopper and Gioia 2004), it is estimated that 78% of macrofungal Basidiomycetes recorded in Western Australia are also found in eastern Australia or overseas (May 2002).

Ecological studies of fungal communities in Australia are hindered by the present state of macrofungal taxonomy, which is far less developed than that of vascular plants. The number of Australian Basidiomycete macrofungi that have accepted names is 3 070 (May 2003a), but many of these names are misapplied European names and are now known to be incorrect. Recent re-examination of early voucher material has shown that most species given European species names are in fact unique Australian fungi (May 2003b). There are also many species yet to be formally described. This, coupled with the few professional macromycete taxonomists currently employed in Australia, makes the identification of macrofungi and the verification of names a very time consuming and difficult task

In view of this, we present a list of macrofungi recorded in burnt and unburnt karri regrowth forest from surveys of plots between 1998 and 2002. The list is presented as a contribution to improved knowledge of the fungal flora of karri and southwest Australian forests. The list also provides the full data upon which the analyses of Robinson *et al.* (submitted) are based. Given that the survey was confined to regrowth forest, this list is unlikely to represent the full spectrum of macrofungi found within karri forest.

METHODS

A description of the sites and plot layout is detailed in Robinson *et al.* (submitted). Briefly, the survey was carried out in 17–25 year-old karri regrowth forest that was either burnt by a wildfire in December 1997 or unburnt since the time of regeneration. A total of 10 sites (5 burnt, 5 unburnt) were chosen and a total of 36 plots (each plot 5 x 5 m) were established and monitored on a fortnightly basis during the fungal fruiting season (April–Sept) and monthly for the remainder of the year. Surveys based on epigeous sporocarps were conducted from 1998–2000 and again in 2002. Seven sites were situated in the 900–1100 mm rainfall zone and three within the 1400 mm zone (Fig. 1). Care was taken not to trample the plots and on each sample date the species of macrofungi and the number of sporophores in each plot was recorded at each site. For each recognised species, voucher specimens were photographed *in situ* and collected, and a detailed morphological and microscopic description completed. When possible macrofungi were identified to species, otherwise they were assigned as having affinity to known species or given tentative field identifications *in lieu* of them either not being formally named or the authors having limited access to resources or trained specialists in the taxonomy of Australian fungi. All voucher collections were lodged with the Western Australian Herbarium (PERTH).

Nomenclature of the majority of Basidiomycetes follows May and Wood (1997) and May *et* al. (2003), with updates from the Interactive Catalogue of Australian Fungi (May *et al.* 2004) and additions from the CABI Bioscience Database, Index Fungorum (Index Fungorum Partnership 2004). Because there is no catalogue of Australian Ascomycetes, taxon names were based on those listed from Index Fungorum or in recent literature. Classification is arranged in accordance with the 9th Edition of Ainsworth and Bisby's Dictionary of the Fungi (Kirk *et al.*2001). Species are listed alphabetically under Order and Family. Informal phrase names are accompanied by a voucher specimen identifier (the collector's name and reference number) following the recommendations of Barker (2005).

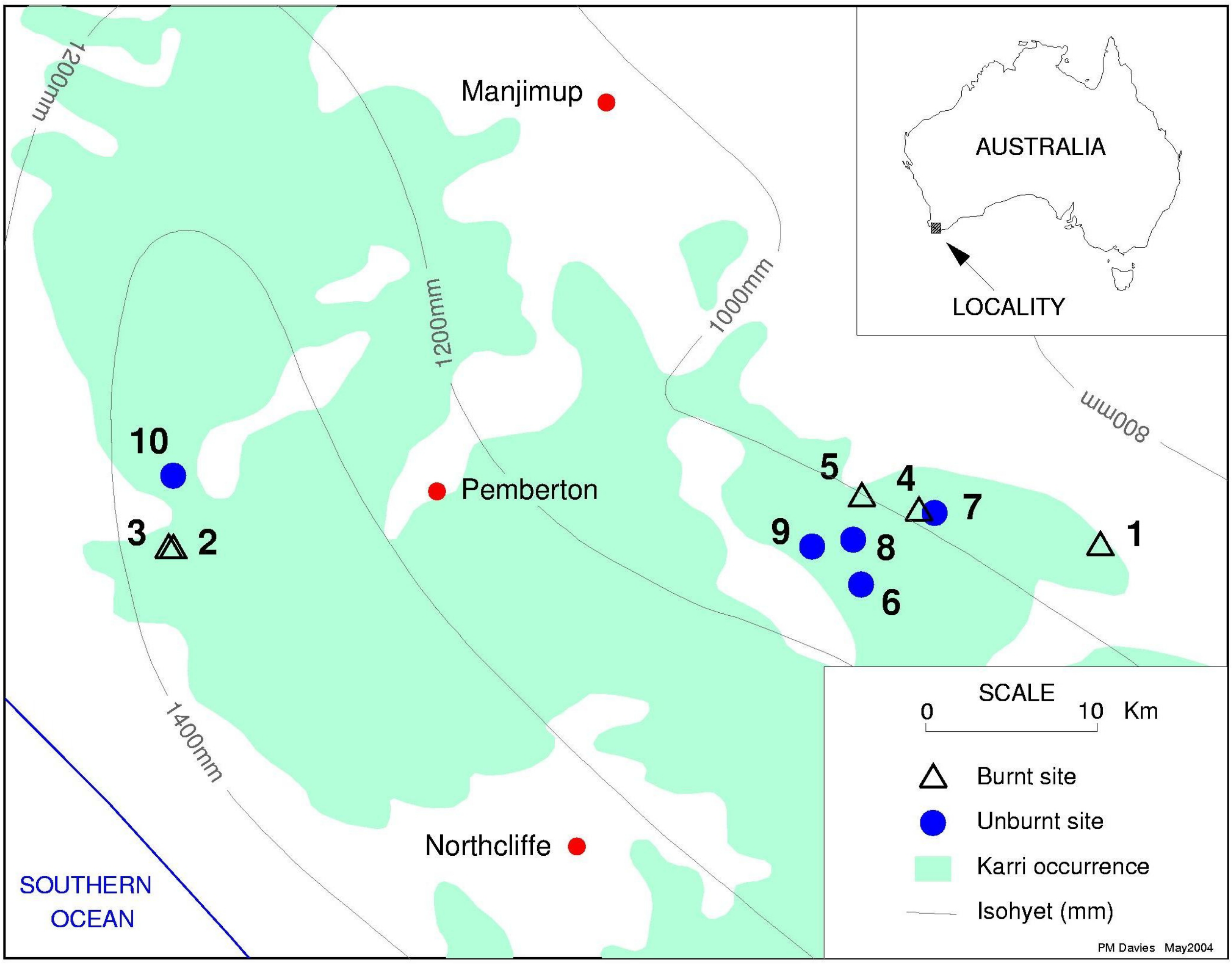

Figure 1. Map showing distribution of karri forest in southwestern Australia and location of monitoring plots in burnt (Δ) and unburnt (●) forest. Two 5 x 5 m plots were established at sites 3 and 8, and 4 plots at each of the other sites.

RESULTS

A total of 322 species of macrofungi were recognised (Table 1), and represented by 1753 voucher collections. Of these, 127 species were identified to species and 17 were allocated as having affinity to known species, but differing in some respects. The remainder were identified with an informal field name. Thirty-six species were not identified to genus, but were included as they are all represented with lodged voucher collections. Two hundred and thirty species were recorded on burnt sites and 204 on unburnt sites. Table 1 includes the yearly abundance of each species and the substrate on which sporophores occurred and Table 2 includes the PERTH herbarium accession numbers and the project collection numbers of the vouchers for determined species.

DISCUSSION

Because of difficulties with identifying and naming Australian macrofungi, it is possible that a single species on the list may represent a group of very similar taxa, or a group of species on the list may represent a single but variable species (although considerable care was taken to minimise such problems). Further taxonomic investigation is needed before all the collections can be identified and named with certainty to species, and the total number of species may change with such investigation. However, the list was compiled from the results of a study designed to investigate the effects of fire on macrofungal species richness and abundance, and to document fungal succession following fire (Robinson *et al.* submitted) and was not intended to be a detailed taxonomic investigation. Therefore we have presented a complete list of the species that we recognised. Photographic and morphological details of selected species can also be requested from the senior author (R.R.).

Karri forest appears to be rich in macrofungal taxa. Over the study period, 322 species were recorded. In wet sclerophyll forests of Tasmania, Packham et al. (2002) and Gates *et* al. (2005) recorded 242 and 307 species respectively. In mountain ash forests in Victoria, and *Eucalyptus obliqua* L'Hérit. dominated gullies and woodlands in South Australia, McMullen-Fisher *et* al. (2002) and Burns and Conran (1997) recorded 116 and 78 species respectively. We were able to name 39% of the taxa we recorded. Other ecological studies recorded similar results. Packham *et al.* (2002), Gates *et al.* (2005) McMullen-Fisher et al. (2002) and Burns and Conran (1997) respectively were able to name 41%, 48%, 51% and 47% of taxa recorded. Being able to identify 40–50% of macrofungal species encountered appears to be reasonable, and agrees with current inventories listing 3 072 accepted Basidiomycete taxa (May and Wood 1997, May *et al.* 2003) and an estimated 10 000 species of macrofungi proposed for Australia (May 2003a).

On the basis of the changing (successional) nature of the burnt sites, no attempt was made to analyse data in order to establish common or rare species. Robinson *et al.* (submitted) analysed the data in terms of species richness and species composition on the burnt and unburnt sites. However, many species were only recorded in one year. This was especially evident on the burnt sites where species were shown to belong to successional fungal communities (Robinson *et al.* submitted) and demonstrates the importance of including habitats disturbed by fire in surveys for fungal diversity. Fifty-five percent of the species recorded on the unburnt plots were recorded every year of the survey. However, 37% of the species were only recorded in one year which highlights the importance of regular monitoring, even on established or stable sites, in order to record the maximum number of species present on a site.

In the Basidiomycetes, *Mycena* and *Cortinarius* were represented with the greatest number of taxa (36 and 16 respectively), and also the highest number of undetermined species, 26 and 11 respectively. Seventy species of *Mycena* and 47 species of *Cortinarius* are listed in May and Wood (1997) and Grgurinovic (2003) provided a detailed taxonomic treatment on 66 species of *Mycena* from south-eastern Australia. In reality, however, both genera are represented in Australia by a large number of yet unnamed species. In our list, at least one taxon (*Mycena* spp., sp. 209) obviously represents a number of species that are very similar or belong to a variable complex. This taxon included 36 voucher collections and 11 separate morphological descriptions. It is likely that this and several other taxa on the list will only be truly defined by the use of molecular techniques.

Mycena has been well monographed for Australia, with a focus on collections from the south-east (Grgurinovic 2003). However, we had difficulty naming many of our collections from south-western Australia. In particular, a number of what apperaed to be distinct species with grey and brown colours could not be matched to both macro and micro characters of named species. Whether such collections represent unnamed species or as yet undocumented variation within named species warrants further investigation. We also had difficulty in identifying a common species with reddish latex which belongs in *Mycena* Section *Galactopoda*. We named this *Mycena sanguinolenta* despite the fact that this name no longer applies to known Australian taxa, because our collections did not correspond exactly to the species of this Section included by Grgurinovic (2003) such as *M. kurkuracea* and *M. toyerlaricola*. Western Australian collections were most similar to *M. kurkuraceae* but differed in having a brown gill edge (rather than red) and stout basidia without basal clamp connections, and fruited singly on soil, most commonly on recently burnt ground.

In the Ascomycetes, species of *Peziza* and *Plicaria* were well represented and both genera are common and abundant on burnt ground, especially in the first year after fire (Robinson *et al.* submitted). Sixteen taxa were recognised, but only five were identified to species level. Rifai's (1968) comprehensive taxonomic treatment of

Australian Pezizales specimens housed at Kew identified 79 species (plus 8 extra-Australian species).

Some species with European connections are listed as well as a number of putative Gondwanan taxa which have *Nothofagus* connections in other regions of the southern hemisphere. For example, *Cotylidia undulata* is a new record for WA (Robinson 2006) and coincides with the first record for Australia, from Tasmania (Ratkowsky and Gates 2005, Gates *et al.* 2005). It is rare in Europe (Breitenbach and Kränzlin 1986), but in Western Australia is common on burnt sites in both jarrah and karri forest fruiting in association with the moss *Funaria hygrometrica* (Robinson 2006). *Nothojafnea cryptotricha* has previously been recorded only in Victoria and South Australia (Rifai 1968), and recently in Tasmania (Gates *et al.* 2005). It appears to be very close to *N. thaxteri*, which is endemic to high rainfall *Nothofagus dombeyi* forests of Patagonia (Gamundi 1999). A second darker species of *Nothojafnea* with smaller spores was also recorded on one of the burnt sites. A common species of *Austropaxillus* matched macro and micro characters of *Austropaxillus macnabbii* (McNabb 1969 [as *Paxillus aurantiacus*]), a species not previously recorded in Australia but common in *Nothofagus* forests of New Zealand. Other known Gondwanan associates, as listed in Horak (1983), included on the list are *Cortinarius rotundisporus*, *Dermocybe splendida*, *Panellus ligulatus*, *Pluteus flammipes*, *Tubaria rufofulva* and *Pholiota multicingulata*.

While it is recognised that the list includes many unnamed and a number of unidentified species, it was considered to be of greater value to represent each species that we were able to distinguish rather than omit or lump the unidentified species together within their specific genera (eg. *Mycena* spp. or *Cortinarius* spp.). The unnamed species were determined to be different on the basis of their morphological and/or microscopic descriptions, but some genera listed (eg. *Clavulinopsis* and *Coprinus*) have recently been reviewed and require more detailed examination in order to assign them to recently erected segregate genera.

We consider it important to publish such lists, especially if they are supported with lodged voucher material, and accompanied by detailed collection notes and descriptions. When lists associated with ecological studies are accompanied with voucher specimens, not only is knowledge regarding biodiversity, substrate preference, fruiting patterns and other ecological information improved, but also identifications can be validated. It is intended that researchers interested in the taxonomic status of a particular species or group of species can access specimens through PERTH for formal identification.

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Table 1

Fungal species (Order and families follow Kirk *et al*. 2001), showing the corresponding species number, substrate on which it was recorded, and the number of sporophores recorded in burnt and unburnt karri forest in each year from 1998-2000 and 2002. Abbreviations for substrates: S = soil, L = litter (includes bark), T = twigs, W = wood, D = dung, M = sporophore, F = fruits/flowers, I = insect.

			BURNT					UNBURNT				
Sp. #		**Substrate**	**1998**	**1999**	**2000**	**2002**	**Total**	**1998**	**1999**	**2000**	**2002**	**Total**
	BASIDIOMYCETES											
	AGARICALES											
	Agaricaceae											
390	*Agaricus austrovinaceus* Grgur. & May	S									1	1
300	*Agaricus sylvaticus* Schaeff.	S				7	7		3		4	7
322	*Agaricus xanthoderma* Genev.	S				1	1			23	2	25
383	*Agaricus* sp. Maroon fibrils (R.Robinson & B.Smith FF1529)	S				2	2					
25	*Lepiota cristata* (Alb. & Schwein. : Fr.) P.Kumm.	S			2	1	3	10	5	27		42
399	*Lepiota* sp. Small brick red (R.Robinson & B.Smith FF1707)	S				3	3				1	1
217	*Lepiota* sp. Creamy tan (R.Robinson FF737)	S							12	19	1	32
329	*Leucoagaricus rubrotinctus* (Peck) Singer	S			1		1			4	1	5
297	*Macrolepiota clelandii* Grg.	S	1	1	11	7	20	2	7	20	4	33
355	*Melanophyllum haematospermum* (Bull. : Fr.) Kreisel	S			4		4					
	Clavariaceae											
114	*Clavaria* aff. *amoena* Zoll. & Moritzi	S		1	11	5	17	72	21	266	226	585
409	*Clavaria* cf. *phoenicea sensu* Peterson 1988	S				4	4					
349	*Clavaria* sp. Small lemon clubs (R.Robinson FF1289)	S			112		112					
384	*Clavulinopsis* sp.* Creamy white (R.Robinson & B.Smith FF1534)	S				22	22					
126	*Clavulinopsis* sp. Grey brown (R.Robinson FF199)	S				45	45	3			3	6
141	*Clavulinopsis* sp. Grey-white (R.Robinson FF269)	S		3			3	2	1			3
113	*Clavulinopsis* sp. Small white clubs (R.Robinson FF202)	S			2	29	31	147	6	191	10	354
145	*Macrotyphula juncea* (Fr. : Fr.) Berthier	L						2	45	9	3	59
	* taxa referred to as *Clavulinopsis* sp. have not been examined in detail sufficient to assign to recently erected segregate genera.											
	Coprinaceae											
306	*Coprinopsis* aff. *lagopus* (Fr.) Redhead, Vilgalys & Moncalvo	S		9	1		10					
72	*Coprinus* aff. *domesticus sensu* Bougher & Syme 1998	W	668	181		60	909					
281	*Coprinus* sp.* Grey scaly cap (R.Robinson FF956)	S		1			1					
311	*Coprinus* sp. Light brown (R.Robinson FF1061)	S		3			3					
158	*Coprinus* sp. Light brown, grooved (R.Robinson FF377)	S	3				3					
182	*Coprinus* sp. Mealy scales (R.Robinson FF475)	S	59	26			85					
73	*Coprinus* sp. Medium (R.Robinson FF170)	S	121	1	6		128					
74	*Coprinus* sp. Large (R.Robinson FF466)	S	24	2			26					
	* taxa referred to as *Coprinus* sp. have not been examined in sufficient detail to assign to recently erected segregate genera.											
	Cortinariaceae											
358	*Cortinarius basirubescens* Cleland & J.R.Harris	S								1		1
162	*Cortinarius kiambriamensis* Grgur.	S						3				3
173	*Cortinarius rotundisporus* Cleland & Cheel	S						1		6	4	11
138	*Cortinarius vinaceo-cinereus* Cleland	S						9		32	6	47

143	*Cortinarius vinaceolamellatus* Cleland	S						3	10	2	12	27
163	*Cortinarius* sp. 7 (R.Robinson FF329)	S						2		1	2	5
179	*Cortinarius* sp. 8 (R.Robinson FF430)	S	1				1					
402	*Cortinarius* sp. Brown (R.Robinson & B.Smith FF1630)	S									7	7
284	*Cortinarius* sp. Brown conical cap (R.Robinson FF979)	S						2	3	2		7
340	*Cortinarius* sp. Brown with lilac tints (R.Robinson FF1247)	S			3	3	6			14		14
249	*Cortinarius* sp. Chestnut (R.Robinson FF1164)	S		1	3		4					
237	*Cortinarius* sp. Large orange-brown viscid cap (R.Robinson & B.Smith FF660)	S		9			9					
140	*Cortinarius* sp. Light brown with red-brown centre (R.Robinson FF268)	S				4	4	4				4
231	*Cortinarius* sp. Mauve-brown hygrophanous cap, purple-brown gills (R.Robinson & B.Smith FF689)	S		14	24	1	39					
175	*Cortinarius* sp. Orange brown viscid cap (R.Robinson FF1290a)	S		1			1	2	1	10	3	16
406	*Cortinarius* sp. Pointy cap (R.Robinson FC134)	S									3	3
122	*Crepidotus* aff. *uber* (Berk. & M.A.Curtis) Sacc.	W		78	507	689	1274	43	91	394	353	881
238	*Crepidotus variabilis* (Pers. : Fr.) P.Kumm.	T							44		30	74
387	*Crepidotus* sp. Brown (R.Robinson & B.Smith FF1547)	W				44	44					
81	*Crepidotus* sp. Light yellow, tomentose (R.Robinson FF130)	W			19	25	44	29	2	7	11	49
184	*Crepidotus* sp. White (R.Robinson FF444)	W			40		40	16	55	62		133
350	*Dermocybe clelandii* (A.H.Smith) Grgur.	S				23	23			1	2	3
408	*Dermocybe* aff. *Kula* Grgur.	S				1	1					
391	*Dermocybe splendida* E.Horak	S				1	1					
242	*Galerina* sp. No ring (R.Robinson FF755)	S		4	2		6					
386	*Galerina* sp. Small with eccentric stipe, on wood (R.Robinson & B.Smith FF1546)	W				10	10					
107	*Galerina* spp. (incl. *G. unicolor*)	L			4	17	21	11	36	42	61	150
298	*Gymnopilus* sp. Slender (R.Robinson FF764)	W		10	33	64	107				17	17
20	*Gymnopilus* sp. Plum (R.Robinson FF1440)	W				1	1	1		2	1	4
248	*Gymnopilus allantopus* (Berk.) Pegler	W		32	41		73					
177	*Inocybe australiensis* Cleland & Cheel	S	1	18	26	25	70	35	106	66	33	240
417	*Inocybe discissa* (Cleland.) Grgur.	S									1	1
416	*Inocybe violaceocaulis* Matheny & Bougher	S				2	2				2	2
188	*Inocybe* sp.	S	4				4					
421	*Inocybe* sp. Shaggy cap (R.Robinson & B.Smith FF1726)	S				2	2				1	1
397	*Inocybe* sp. Dark brown umbonate (R.Robinson & B.Smith FF1596)	S									12	12
120	*Inocybe* sp. Fibrillose umbonate (R.Robinson FF1463)	S	10	5	32	1	48	1				1
159	*Inocybe* sp. Grey-brown with white fibrils (R.Robinson FF384)	S		3	5	1	9	2	3			5
133	*Inocybe* sp. Fibrillose conic cap (R.Robinson FF1395)	S		3	14	66	83	37	30	53	80	200
277	*Inocybe* sp. Scaly cap (R.Robinson FF946)	S		23	10	25	58			1	1	2
103	*Inocybe* sp. Umbonate scaly cap (R.Robinson FF100)	S						6	1	11	2	20
165	*Inocybe* sp. White wooly cap (R.Robinson FF339)	S			1		1	8	11	8		27
420	*Simocybe* sp.	W				16	16					
289	*Tubaria rufofulva* (Cleland) D.A.Reid & E.Horak	W	3	2	14	42	61	18	36	34	56	144
	Entolomataceae											
200	*Entoloma moongum* Grgur.	S			3		3	1	2	2	7	12
310	*Entoloma rubromarginatum* E.Horak	S				3	3		2	5	13	20
335	*Entoloma* sp. Grey brown 1 (R.Robinson FF1225)	S								1	1	2
136	*Entoloma* sp. Grey brown 2 (R.Robinson FF264)	S						9		1	1	11
183	*Entoloma* sp. Grey brown 3 (R.Robinson FF455)	S										
374	*Entoloma* sp. Grey brown cap, blue stem (R.Robinson FF1454)	S								2		2
377	*Entoloma* sp. Silver grey cap, blue stem (R.Robinson FF1471)	S								2		2

Table 1 (cont.)

Sp. #		Substrate	BURNT 1998	1999	2000	2002	Total	UNBURNT 1998	1999	2000	2002	Total
	Hydnangiaceae											
155	*Laccaria lateritia* Malençon	S		6	3	8	17	8	26	3	6	43
	Marasmiaceae											
296	*Anthracophyllum archeri* (Berk.) Pegler	T				28	28	79	766	828	360	2033
302	*Armillaria luteobubalina* Watling & Kile	W						2	1			3
326	*Marasmiellus* sp. Emu bush (R.Robinso FF1162)	W			44	24	68					
212	*Marasmius alveolaris* Cleland	T		29	333	802	1164	470	1113	889	1105	3577
27	*Marasmius crinisequi* F.Muell.	L				209	209	603	243	227	501	1574
28	*Marasmius elegans* (Cleland) Grgur.	S		1		46	47	215	147	366	152	880
210	*Marasmius* sp. Tiny white, hairy (R.Robinson FF626)	L			6		6		10	11		21
328	*Marasmius* sp. Tan with brown centre (R.Robinson FF1172)	L			10	1	11			11	2	13
18	*Marasmius* sp. Orange red (R.Robinson FF812)	T		1		3	4	37	29		17	83
223	*Marasmius* sp. Brown, plane (R.Robinson FF664)	L	3	61	554	527	1145	230	444	455	225	1354
341	*Marasmius* sp. Red brown (R.Robinson FF1251)	L			14	13	27					
243	*Marasmius* sp. Tan (R.Robinson FF770)	S	10	60	95		165					
258	Xerula australis (Dörfelt) R.H.Petersen	S			2		2		1	2	1	4
	Mesophelliaceae											
129	*Malajczukia karrialis* Trappe & Castellano	S	30	5	2		37		3			3
61	*Mesophellia* sp. (R.Robinson FF 54)	S	2				2					
	Nidulariaceae											
148	*Crucibulum laeve* (Huds. : Pers.) Kambly	L	2				2					
	Pleurotaceae											
323	*Hohenbuehelia bingarra* Grgur.	W			95	46	141					
1	*Hohenbuehelia carbonaria* (Cooke & Massee) Pegler	W	7				7					
	Pluteaceae											
424	*Amanita ananiceps* (Berk.) Sacc.	S			4		4					
171	*Amanita brunneibulbosa* O.K.Miller	S		2	1	2	5	4	10	5	3	22
279	*Amanita xanthocephala* (Berk.) D.A.Reid & R.N.Hilton	S	10	47	30	33	120	2	3	3	4	12
265	*Amanita xanthocephala* forma *macalpiniana* (Cleland & Cheel) D.A.Reid	S							3			3
235	*Amanita* sp. White cap, deep rooting stem and volva (R.Robinson FF655)	S		2	3		5					
270	*Pluteus atromarginatus* (Konrad) Kuhner	W		1			1			5	3	8
194	*Pluteus lutescens* (Fr.) Bres.	T				3	3	1	15	5	8	29
194	*Pluteus flammipes* E.Horak	T										
204	*Pluteus nanus* (Pers. : Fr.) P.Kumm.	W	1	29	5	3	38	2		4		6
271	*Pluteus* sp. Olive yellow (R.Robinson FF890)	S		1			1					
	Strophariaceae											
299	*Hypholoma australe* O.K.Miller	S	8	6	79	57	150	33	9	6	26	74
385	*Melanotus hepatochrous* (Berk.) Singer	W				5	5					
94	*Psilocybe coprophila* (Bull. : Fr.) P.Kumm.	D	26	51	37		114	1				1
168	*Pholiota multicingulata* E.Horak and *Pholiota highlandensis* (Peck) Quadr.	W/L	17		3	10	30	8	10	13	32	63
128	*Pholiota sp.* Water soaked gills (R.Robinson FF385)	S	796	370	30	18	1214				1	1

	Tricholomataceae											
185	*Clitocybe* sp. Brown (R.Robinson FF438)	L				5	5	1		1		2
275	*Clitocybe* sp. Small dark grey (R.Robinson FF942)	L							2	1	2	5
283	*Clitocybe* sp. Cream buff (R.Robinson FF962)	L							3			3
339	*Clitocybe* sp. Grey brown (R.Robinson FF1246)	S			4	4	8					
342	*Collybia sp.* Buff funnel (R.Robinson FF1254)	S								19	20	39
244	*Collybia* sp. Wallace (R.Robinson FF797)	L							25		30	55
305	*Gymnopus dryophilus* (Bull. : Fr.) Murrill	S		1			1					
368	*Hygrocybe cantharellus* (Schwein.) Murrill	S								2	9	11
351	*Hygrocybe conica* (Scop.: Fr.) P. Kumm.	S			7	1	8	2		7	2	11
410	*Hygrocybe* sp. Yellow orange (R.Robinson & L.van der Putten FF1656)	S									4	4
64	*Lyophyllum* sp. Creamy buff viscid cap (R.Robinson FF66)	S	40				40					
130	*Lyophyllum* sp. Dark grey brown slimy cap (R.Robinson FF238)	S	1				1					
344	*Melanoleuca fusca* (Cleland.) Grgur.	S								1		1
246	*Melanoleuca* sp. Light brown (R.Robinson FF816)	S		1			1					
234	*Mycena albidocapillaris* Grgur. & T.W.May	L		39	73	42	154				13	13
250	*Mycena carmeliana* Grgur.	W				2	2		25	23	33	81
121	*Mycena fuhreri* Grgur.	L		3	4		7	124	195	241	88	648
118	*Mycena mijoi* Grgur.	L				1	1	85	112	243	596	1036
147	*Mycena mulawaestris* Grgur.	W		7	1		8	20	21	19	23	83
84	*Mycena nargan* Grgur.	W						3			6	9
119	*Mycena nullawarrensis* Grgur.	L				50	50	7	12	18	5	42
229	*Mycena sanguinolenta* (Alb. & Schwein.:Fr.) P.Kumm.	L	1	39	24	1	65	1		12		13
153	*Mycena yirukensis* Grgur.	L/T						97	43	155	133	428
330	*Mycena yuulongicola* Grgur.	W								15	27	42
230	*Mycena* sp. Dark brown with grey gills, no odour (R.Robinson FF680)	L		45	1		46					
170	*Mycena* sp. Brown with pinkish light brown gills (R.Robinson FF321)	S	1				1					
245	*Mycena* sp. Buff with white gills and red brown stem (R.Robinson FF813)	L		14			14					
151	*Mycena* sp. Dark brown smoky grey gills (R.Robinson FF315)	L	2				2					
135	*Mycena* sp. Dark brown with cream buff gills, no odour (R.Robinson FF255)	S						1				1
227	*Mycena* sp. Dark brown with cream gills, weak bleach odour (R.Robinson FF728)	L		3	7		10		3	1	13	17
14	*Mycena* sp. Dark brown with creamy tan gills (R.Robinson FF25)	L						1				1
228	*Mycena* sp. Dark brown with dull white gills, no odour (R.Robinson FF735)	L							3	1		4
4	*Mycena* sp. Dark brown with silver grey gills (R.Robinson FF9)	S	32				32					
30	*Mycena* sp. Dark translucent grey brown (R.Robinson FF171)	S	73				73					
123	*Mycena* sp. Golden orange (R.Robinson FF197)	L/T						22	32	3	1	58
219	*Mycena* sp. Grey brown (R.Robinson FF668)	L		8			8		1	3		4
226	*Mycena* sp. Grey brown, strong bleach odour (R.Robinson FF726)	L		46			46		12	19	13	44
221	*Mycena* sp. Grey-brown with creamy grey gills (R.Robinson FF672)	L		23			23					
13	*Mycena* sp. Light brown grey with light brown gills (R.Robinson FF27)	L						10				10
233	*Mycena* sp. Light grey brown, no odour (R.Robinson FF 694)	L		25	2		27					
352	*Mycena* sp. Slender red brown (R.Robinson FF1317)	L								1		1
24	*Mycena* sp. Small white cap with slimy yellow stem (R.Robinson FF16)	T/L			1		1	85	48	86	164	383
11	*Mycena* sp. Smokey grey-tan with tan-grey gills (R.Robinson FF11)	L						12				12
365	*Mycena* sp. Tiny buff on bark (R.Robinson FF1379)	L								9		9
195	*Mycena* sp. Tiny mealy white (R.Robinson FF526)	L			4	12	16	3		1		4
146	*Mycena* sp. Tiny white scaly cap (R.Robinson FF291)	T/L		34	176	103	313	23	90	63	38	214
232	*Mycena* sp. Tiny white with decurrent gills on soil (R.Robinson FF691)	S		45	71	13	129		1	2		3
334	*Mycena* sp. Tiny white with decurrentgillson litter (R.Robinson FF1194)	L			14	17	31					
331	*Mycena* sp. Grey brown, faint bleach odour (R.Robinson FF1190)	L			2	2	4			2	3	5
209	*Mycena* spp. Small buff (R.Robinson FF623)	L/S	4	33	149	54	240	9	50	23	19	101
290	*Omphalina* sp. Yellow orange (R.Robinson & B.Smith FF1029)	L							1			1

Table 1 (cont.)

Sp. #		Substrate	BURNT 1998	BURNT 1999	BURNT 2000	BURNT 2002	BURNT Total	UNBURNT 1998	UNBURNT 1999	UNBURNT 2000	UNBURNT 2002	UNBURNT Total
99	*Omphalina* sp. Orange (R.Robinson FF125)	L						4	9	5	9	27
156	*Panellus ligulatus* E.Horak	W			6	1	7	14	65	74	23	176
104	*Resupinatus cinerascens* (Cleland.) Grgur.	T			102	723	825	1	25		32	58
216	*Rhodocollybia butyracea* (Bull. : Fr.) Lennox	L			18	1	19		43	18	4	65
346	*Tephrocybe* sp. Powdery grey (R.Robinson FF1274)	S			11		11					
131	*Tricholoma eucalypticum* A.Pearson	S	20	44	42	2	108	36	29	67	10	142
267	*Tricholoma* aff. *virgatum* (Fr.) P.Kumm.	S			4	1	5		1			1
161	*Tricholoma* sp. Salmon buff (R.Robinson FF328)	S						6	2	22		30
	BOLETALES											
	Boletaceae											
319	*Boletellus ananiceps* (Berk.) Singer	S		1			1					
419	*Boletus* sp. Light pinkish brown (R.Robinson & B.Smith FF1730)	S									1	1
241	*Xerocomus multicolor (*Cleland.) Grgur.	S				1	1		4			4
46	*Tylopilus* sp. Purple-black (R.Robinson FF31)	S						6				6
	Coniophoraceae											
269	*Podoserpula pusio* (Berk.) D.A Reid	L							1	6		7
	Gomphaceae											
369	*Ramariopsis* sp. Taxon 5, *sensu* Petersen 1998	S			1	16	17			8	1	9
	Hygrophoropsidaceae											
411	*Tapinella panuoides* (Fr. : Fr.) E.J.Gilbert	L									3	3
	Paxillaceae											
10	*Austropaxillus* aff. *macnabbii* (Singer, J.Garcia & L.D.Gómez) Jarosch [as '*mcnabbii*']	S		51	65	2	118	7		2		9
252	*Austropaxillus infundibuliformis* (Berk.) Bresinsky & M.Jarosch	S		16	2		18					
220	*Austropaxillus* sp. Dark brown (R.Robinson FF671)	S		4			4					
	Sclerodermataceae											
224	*Scleroderma areolatum* Ehrenb.	S		4	4		8					
	CANTHARELLALES											
	Cantharellaceae											
268	*Cantharellus concinnus* Berk.	S						73	4	23	6	106
	Clavulinaceae											
96	*Clavulina amethystina* (Bull. : Fr.) Donk	S			9	6	15	37	8	12		57
266	*Clavulina* sp. White coraloid (R.Robinson FF917)	S							2			2
26	*Clavulina* sp. Creamy tan (R.Robinson FF12)	S						1				1
95	*Clavulina* sp. Pink buff coraloid (R.Robinson FF119)	S						181	125	87	101	494
176	*Clavulina* sp. Slender grey brown (R.Robinson FF 408)	S				15	15	40	10	35	10	95
375	*Clavulina* sp. White (R.Robinson FF1456)	S								4	1	5
361	*Clavulicium* sp. Yellow glue (R.Robinson FF1368)	T								4	8	12

	Hydnaceae											
178	*Hydnum repandum* L. : Fr.	S						1		20	5	26
	DACROMYCETALES											
	Dacromycetaceae											
357	*Calocera* sp. Yellow antlers (R.Robinson FF134)	W						1		1		2
273	*Heterotextus peziziformis* (Berk.) Lloyd	T		2	10	33	45	8	26	37	6	77
	HYMENOCHAETALES											
	Hymenocheataceae											
314	*Coltricia oblectans* (Berk.) G.Cunn.	S		3	8	219	230	9	27	7	87	130
285	*Hymenochaete* sp. Chestnut (R.Robinson FF991)	W		1	2		3					
	PHALLALES											
	Geasteraceae											
378	*Gaestrum javanicum* Lév.	S				1	1			1		1
	Hysterangiaceae											
254	*Hysterangium* sp. Olive gleba (R.Robinson FF871)	S		8	3	4	15				7	7
	Ramariaceae											
43	*Ramaria capitata* (Lloyd) Corner	S	11	3	1	2	17					
225	*Ramaria ochraceosalmonicolor* (Cleland.) Corner	S	2	626	202		830					
169	*Ramaria lorithamnus* (Berk.) R.H.Petersen	S		1			1	3	3	3		9
282	*Ramaria* sp. Lemon-yellow (R.Robinson FF959)	S				1	1		1			1
	POLYPORALES											
	Meruliaceae											
17	*Meruliopsis corium* (Pers. : Fr.) Ginns	W		1	4		5	1				
	Podoscyphaceae											
332	*Cotylidia undulata* (Fr. : Fr.) P. Kast.	S	6		22	3	31					
	Polyporaceae											
321	*Laccocephalum mylittae* (Cooke & Massee) Nunez & Ryvarden	S	3				3				1	1
23	*Laccocephalum sclerotinium* (Rodway) Nunez & Ryvarden	S	71	2			73					
320	*Laccocephalum tumulosum* (Cooke) Nunez & Ryvarden	S	6				6					
7	*Neolentinus dactyloides* (Cleland.) Redhead & Ginns	S	642				642					
415	*Panus fasciatus* (Berk.) Pegler	W				2	2					
15	*Trametes velutina* (Pers. : Fr.) G. Cunn.	W						82	62	51	35	230
203	*Trametes versicolor* (L. : Fr.) Lloyd	W						1				1
412	*Trichaptum byssogenum* (Jungh.) Ryvarden	W				3	3					
	Fomitopsidaceae											
291	*Piptoporus australiensis* (Wakef.) G.Cunn.	W						2	4			6
	Podoscyphaceae											
263	*Podoscypha petalodes* (Berk.) Pat.	W							3			3
	Steccherinaceae											
400	*Antrodiella citrea* (Berk.) Ryvarden	T				1	1				2	2

Table 1 (cont.)

Sp. #		Substrate	BURNT 1998	1999	2000	2002	Total	UNBURNT 1998	1999	2000	2002	Total
222	*Steccherinum* sp. Spined shelves (R.Robinson FF748)	W		1		4	5		9	4	2	15
54	*Steccherinum* sp. White toothed resupinate (R.Robinson FF43)	W	1				1					
	RUSSULALES											
	Auriscalpinaceae											
78	*Clavicorona piperata* (Kauffman) Leathers & A.H.Smith	W						2	33	9	50	94
	Russulaceae											
336	*Lactarius eucalypti* O.K.Miller & R.N.Hilton	S								2		2
75	*Russula adusta* (Pers. : Fr.) Fr.	S				2	2	7	1	11	5	24
82	*Russula clelandii* O.K.Miller & R.N.Hilton	S			1		1	4	7	6	13	30
404	*Russula neerimea* Grgur.	S									4	4
83	*Russula* sp. White (R.Robinson FF138)	S			1	2	3	16	2	2	1	21
392	*Gymnomyces costatosporus* T.Lebel	S				1	1					
	Stereaceae											
295	*Stereum hirsutum* (Willd. : Fr.) Pers.	W				2	2	30	6		8	44
373	*Stereum* sp. Chocolate brown (R.Robinson FF1448)	W			10	20	30					
	THELEPHORALES											
	Bankeraceae											
403	*Phellodon* sp. Brown with white margin (R.Robinson & B.Smith FF1634)	L								1	18	19
247	*Phellodon niger* (Fr. : Fr.) P.Kast.	L		9			9					
	Thelephoraceae											
360	*Thelephora* sp. Chocolate brown (R.Robinson FF1364)	S			3		3					
356	*Thelephora* sp. Dark grey-brown with light grey margin (R.Robinson FF1340)	S			1		1					
	Unknown AGARICS											
139	Agaric. Black with black scales (R.Robinson FF210)	S						1				1
307	Agaric. Bronze with brown gill edges (R.Robinson FF1050)	S							1			1
67	Agaric. Brown with brown scales (R.Robinson FF72)	S	1				1					
180	Agaric. Brown with pinkish-buff forked gills (R.Robinson FF434)	S	2				2					
29	Agaric. Dark brown with inrolled margin (R.Robinson FF87)	S	13				13					
197	Agaric. Golden brown (R.Robinson FF553)	S						4				4
164	Agaric. Olive gills (R.Robinson FF333)	L				1	1	248	217	51	37	553
257	Agaric. Orange brown (R.Robinson FF876)	S							4			4
354	Agaric. Purple brown (R.Robinson FF1322)	S								4		4
108	Agaric. Red with red gills (R.Robinson FF1067)	S						3	6	12	9	30
	Unidentifiable AGARICS		24	15	20	10	69	20	12	33	8	73
	Unknown SEQUESTRATE AGARICS											
359	Truffle. Light yellow brown with sac-like gleba (R.Robinson FF1360)	S			2		2					
276	Truffle. Light yellow (R.Robinson FF935)	S		2	2		4					
262	Truffle. Olive-yellow, white gleba with irregular convoluted locules (R.Robinson FF896)	S		1			1					

	Unknown POLYPORALES											
301	Polypore. Beige resupinate stains brown (R.Robinson FF369)	W						1	1	2	2	6
292	Polypore. Brown toothed resupinate (R.Robinson FF604)	W		1			1					
272	Polypore. Resupinate, hydnoid/ridged (R.Robinson FF799)	W							1			1
274	Polypore. Resupinate, irregular elongated pores (R.Robinson FF532)	W						1	1		1	3
364	Polypore. Small creamy shelf (R.Robinson FF1378)	W								12	2	14
206	Polypore. Small velvet hoof (R.Robinson FF617)	W		30			30					
388	Polypore. Soft yellow brown hoof (R.Robinson FF1553)	W				1	1					
293	Polypore. White resupinate (R.Robinson FF609)	W			1	1	2		2			2
396	Thelephore. White shell (R.Robinson FF1608)	W				20	20					
	TREMELLALES											
	Tremellaceae											
393	*Tremella frondosa* Fr. : Fr.	W				9	9					
3	*Tremella fuciformis* Berk.	W						5		1		6
8	*Tremella mesenterica* Retz. : Fr.	W						5				5
286	*Tremella* sp. Translucent white (R.Robinson FF992)	W		3	17		20					
	UREDINIOMYCETES											
	UREDINIALES											
	Pucciniaceae											
423	*Aecidium eburneum* McAlpine	F									38	38
	ASCOMYCETES											
	PEZIZALES											
	Morchellaceae											
181	*Morchella elata* Fr.	S	152				152					
	Pezizaceae											
370	*Boudiera* sp. Pale red orange (R.Robinson FF1420)	S			40	25	65					
187	*Hydnoplicata convoluta* (McAlpine) Trappe & Claridge	S	2				2		1			1
191	*Peziza echinospora* P.Karst.	L	3				3					
22	*Peziza praetervisa* Brez.	S	923		2		925		3			3
21	*Peziza tenacella* W. Phillips	S	836				836					
280	*Peziza thozetii* Berk.	S		2			2		6		4	10
38	*Peziza* sp. Light brown (R.Robinson FF74)	S	66				66					
401	*Peziza* sp. Dark olive brown (R.Robinson FF1624)	S				4	4					
41	*Peziza* sp. Dark brown (R.Robinson FF82)	S	272				272					
288	*Peziza* sp. Light orange bowls (R.Robinson FF1022b)	W							2			2
90	*Peziza* sp. Burgundy brown (R.Robinson FF178)	S	85				85					
394	*Peziza* sp. Pink-brown (R.Robinson & B.Smith FF1574)	S				31	31					
36	*Plicaria* sp. Brown black cup (R.Robinson FF154)	S	129	4			133					
260	*Plicaria* sp. Dark brown saucer (R.Robinson FF904)	S		10			10					
32	*Plicaria* sp. Dark brown black (R.Robinson FF92)	S	10				10					
160	*Plicaria* sp. Dark brown black on rotten wood (R.Robinson FF387)	W	65				65					
	Pyrenomycetaceae											
112	*Aleuria rhenana* Fuckel	S	9		9	10	28					
304	*Aleurina ferruginea* (W.Phillips) W.Y.Zhuang & Korf	S		11	60	4	75				2	2
149	*Geopyxis carbonaria* (Alb. & Schwein.) Sacc.	S	355				355					
196	*Nothojafnea* sp. Dark brown (R.Robinson FF570)	S	815				815					

Table 1 (cont.)

Sp. #		Substrate	BURNT 1998	BURNT 1999	BURNT 2000	BURNT 2002	BURNT Total	UNBURNT 1998	UNBURNT 1999	UNBURNT 2000	UNBURNT 2002	UNBURNT Total
189	*Nothojafnea cryptotricha* Rifai	S				4	4	146	246	624	280	1296
309	*Scutellinia* aff. *margaritacea sensu* Bougher & Syme 1998	W				24	24		13	4	23	40
66	*Anthracobia muelleri* (Berk.) Rifai	S	209	25			234					
405	*Cheilymenia* sp. Orange (R.Robinson & B.Smith FF1640)	D				14	14				5	5
88	*Pulvinula archeri* (Berk.) Rifai	S	2245	686	69		3000					
414	*Pulvinula tetraspora* (Hansf.) Rifai	S				37	37					
	Sarcosomataceae											
190	*Plectania* aff. *platensis* (Speg.) Rifai	L			9	866	875	362	653	813	807	2635
	HELOTIALES											
	Geoglossaceae											
166	*Trichoglossum hirsutum* (Pers. : Fr.) Boud.	S			2		2	21	2	30	2	55
	Hyaloscyphaceae											
413	*Lachnum* aff. *lachnoderma* (Berk.) G.G.Hahn & Ayers	T				2	2				14	14
	Helotiaceae											
366	*Discinella terrestris* (Berk. & Broome) Dennis	S			11		11					
	Rustromiaceae											
51	*Lanzia lanaripes* (Dennis) Spooner	W	15	57	29	20	121	105	167	183	123	578
	HYPOCREALES											
	Clavicipitaceae											
324	*Beauveria bassiana* (Bals.-Criv.) Vuill.	I			2	2	4					
333	*Cordyceps* aff. *superficialis* (Peck) Sacc.	I			2		2					
347	*Cordyceps* sp. Brown irregular head (R.Robinson FF1286)	I			1		1					
239	*Cordyceps* sp. Case moth cocoon (R.Robinson FF705)	I							2			2
338	*Cordyceps* sp. White drumsticks (R,Robinson FF1241)	I								1		1
256	*Paecilomyces* aff. *tenuipes*. (Peck) Samson	I		1			1					
	Hypocreaceae											
395	*Hypocrea gelatinosa* (Tode) Fr.	W				5	5				1	1
315	*Hypomyces chrysospermus* Tul. & C.Tul.	M						2	1			3
	XYLARIALES											
	Xylariaceae											
192	*Biscogniauxia plana* (Petch) Y.M.Ju & J.D.Rogers	W			2		2	15	9	1	4	29
312	*Biscogniauxia uniapiculata* Penz. & Sacc.) Whalley & Laessøe	W						1				1
255	*Daldinia eschscholzii* (Ehrenb.) Rehm	W	7	58	42	31	138					
316	*Diatrype* sp. Tiny, black erumpent mounds (R.Robinson FF533)	W								4	3	7
379	*Hypoxylon cinnabarinum* (Henn.) Y.M.Ju & J.D.Rogers	W						1				1
318	*Hypoxylon* aff. *diatrypeoides* Rehm.	W							1	4	1	6
253	*Hypoxylon* aff. *subcorticeum* Y.M.Ju & J.D.Rogers	W		1	1	38	40		2		2	4
313	*Hypoxylon* aff. *subrutilum* Starbäck	W				24	24		2	3	7	12

380	*Hypoxylon* sp. Black pimpled tar (R.Robinson FF1494)	W									1	1
317	*Hypoxylon* sp. Red brown with beige margin (R.Robinson FF533)	W								2	1	3
294	*Xylaria hypoxylon* (L.) Grev.	W		22	86	25	133	1	234	233	128	596
371	*Xylaria* aff. *polymorpha* (Pers.) Grev.	W			1		1					
56	*Xylaria* sp. Grey coral (R.Robinson FF47)	S	106				106					
	Unknown - ASCOMYCETES											
303	Discomycete. Yellow stalked disc on *Podocarpus* fruit (Robinson FF1032)	F		66			66					
261	Discomycete. Orange yellow, 1-3mm (R.Robinson FF902)	S		71			71					
251	Discomycete. Cream, 2-3mm (R.Robinson FF860)	T							17	26		43
337	Discomycete. Cream grey (R.Robinson FF1237)	S								30		30
60	Discomycete. Lemon yellow, on bare soil (R.Robinson FF52)	S	109				109					
33	Discomycete. Lemon yellow, on emu dung (R.Robinson FF91)	D	100				100					
48	Discomycete. Lemon yellow, on 'roo dung (R.Robinson FF32)	D						25				25
208	Discomycete. Tiny orange (R.Robinson FF621)	L		6			6					
240	Discomycete. Tiny yellow stalked disc (R.Robinson FF709)	L		11			11		30		23	53
367	Unknown. Black and white horn (R.Robinson FF1400)	S								1		1
327	Unknown. Wooly antlers (R.Robinson FF1167)	L			7		7					
343	Unknown. White tipped black threads on marri fruit (R.Robinson FF1258)	F				5	5			1		1
348	Unknown. Black needle (R.Robinson FF1285)	S			1		1					
	UNKNOWN – Sterile mycelium											
12	Unknown. White spikes (R.Robinson FF15)	L						18		13	15	46
	Total sporophores for each year		9276	3329	3771	5679	22054	4240	6193	7735	6662	24829
322	Total number of species											
	Number of species fruiting in each year		65	94	111	119	230	108	114	129	131	204

Table 2

The collection numbers for voucher specimens representing each species from Table 1. All collections are lodged at PERTH. The 8-digit number denotes the PERTH reference and the FF number denotes the project reference.

Sp #	PERTH Collection Numbers (Project collection numbers)
1	04577264 (FF 4), 04577655 (FF 4804), 4578015 (FF 80)
3	Not Collected
4	04577388 (FF 9)
7	04577272 (FF 3), 04577361 (FF 10), 04577671 (FF 46), 04577833 (FF 64), 04577191 (FF 90), 045777906 (FF 58)
8	Not Collected
10	04577744 (FF 41), 04577736 (FF 42), 04578341 (FF 102), 05355079 (FF 112), 04579313 (FF 192), 05349370 (FF 610), 05349362 (FF 611), 05352258 (FF 669), 05656443 (FF 1089), 056556869 (FF 1109), 05656974 (FF 1115)
11	04577353 (FF 11)
12	04577310 (FF 15), 04577590 (FF 38), 05340144 (FF 440), 05340187 (FF 452), 05352479 (FF 678)
13	04577531 (FF 27)
14	04577566 (FF 25)
15	04577442 (FF 20), 04578694 (FF 136), 04578775 (FF 144), 05354846 (FF 854), 05355494 (FF 925), 05655048 (FF 960)
17	02664720 (FF 229), 05355745 (FF 949), 05656451 (FF 1088), 05659604 (FF 1358)
18	04577396 (FF 24), 04579445 (FF 212), 04580109 (FF 217), 05338468 (FF 289), 05340888 (FF 524), 05354234 (FF 794), 05354390 (FF 812), 05354722 (FF 848), 06646484 (FF 1604), 06647472 (FF 1690), 06647529 (FF 1701)
20	04577450 (FF 19), 0560599 (FF 1440), 06647243 (FF 1679), 06646050 (FF 1563)
21	04577698 (FF 45), 04577892 (FF 59), 04577884 (FF 60), 04578104 (FF 88), 04578244 (FF 96), 04578864 (FF 153), 04578821 (FF 156), 04578961 (FF 159), 04579178 (FF 190)
22	04579151 (FF 97), 04578872 (FF 152), 04578929 (FF 164), 04579135 (FF 177), 191, 056555137 (FF 967), 05658705 (FF 1280), 05660661 (FF 1449)
23	04577760 (FF 55), 04577906 (FF 58), 04577949 (FF 70), 04578139 (FF 85), 04578252 (FF 95), 04578228 (FF 98), 04578910 (FF 165), 04578899 (FF 167), 04579003 (FF 173), 05340705 (FF 508), 05340691 (FF 509)
24	04577302 (FF 16), 04577582 (FF 39), 04578546 (FF 118), 05338840 (FF 334), 05339154 (FF 354), 05340551 (FF 482), 05352657 (FF 719), 05354021 (FF 780), 05659388 (FF 1345)
25	04577280 (FF 2), 04577469 (FF 18), 04577418 (FF 23), 04579461 (FF 210), 04579771 (FF 261), 05338425 (FF 292), 05339715 (FF 414), 05353610 (FF 753), 05355613 (FF 929), 05657628 (FF 1183), 05647954 (FF 1202), 05657318 (FF 1156), 05657261 (FF 1159)
26	04577345 (FF 12)
27	04577337 (FF 13), 04578503 (FF 121), 04578597 (FF 129), 05655145 (FF 982), 05657237 (FF 1138), 05660114 (FF 1405), 06646077 (FF 1561)
28	04577329 (FF 14), 04577647 (FF 33), 05355907 (FF 539), 05341310 (FF 565), 05353637 (FF 751), 05354633 (FF 840), 05656133 (FF 1069), 05658438 (FF 1257), 05658446 (FF 1256), 05658519 (FF 1265), 06645909 (FF 1560), 06646018 (FF 1567)
29	04578112 (FF 87)
30	04578120 (FF 86), 04578554 (FF 131), 04579038 (FF 171), 04579119 (FF 179), 04579615 (FF 244), 04579755 (FF 247), 05339553 (FF 396), 05339901 (FF 429), 05340055 (FF 431)
32	04577175 (FF 92)
33	04577183 (FF 91)
36	04578090 (FF 73), 04578058 (FF 77), 04578260 (FF 94), 04578856 (FF 154), 04579070 (FF 183), 04579224 (FF 185), 05339995 (FF 437), 05354625 (FF 841), 05655293 (FF 985)
38	04578082 (FF 74), 04578074 (FF 75)
41	045778163 (FF 82), 04578279 (FF 93), 04578953 (FF 160)
43	04577957 (FF 69), 04578031 (FF 78), 04578023 (FF 79), 04578155 (FF 83), 04578805 (FF 158), 04579542 (FF 235), 05339391 (FF 379), 05338646 (FF 305), 05339499 (FF 386), 05339464 (FF 389), 05339456 (FF 390), 05339952 (FF 425), 05353734 (FF 759), 05658330 (FF 1250), 06645860 (FF 1550)
46	04577493 (FF 31)
48	04577485 (FF 32)
51	04577612 (FF 36), 04578600 (FF 128), 05339472 (FF 388), 05353831 (FF 765), 05355168 (FF 891), 05658217 (FF 1227), 05659051 (FF 1311), 05659221 (FF 1327), 05659930 (FF 1390), 06645925 (FF 1558b)
54	04577728 (FF 43)
56	04577663 (FF 47), 04577973 (FF 67)
60	04577795 (FF 52), 04577841 (FF 63)
61	04577779 (FF 54)
64	04577868 (FF 62), 04577981 (FF 66), 04577930 (FF 71)
66	04577787 (FF 53), 045477965 (FF 68), 04577205 (FF 89), 04579089 (FF 182), 05655781 (FF 1034)
67	04577922 (FF 72)
72	04579054 (FF 169), 04579631 (FF 242), 053399444 (FF 426), 05340012 (FF 435), 05341159 (FF 548), 05355230 (FF 900), 06646557 (FF 1613), 06647219 (FF 1666)
73	04579046 (FF 170), 04579623 (FF 243), 04579593 (FF 246), 05339308 (FF 371), 05339979 (FF 423), 05340047 (FF 432), 05341639 (FF 584), 05659450 (FF 1339)
74	05339529 (FF 383), 05340373 (FF 466), 05340837 (FF 512), 05341590 (FF 588), 05655242 (FF 989b)
75	04578783 (FF 143), 04579763 (FF 262), 05338794 (FF 323), 05355087 (FF 882), 05657350 (FF 1152), 05657814 (FF 1198), 05658160 (FF 1234), 05658284 FF 1239), 05658926 (FF 1292), 05659922 (FF 1391), 0664298 (FF 1590), 06646824 (FF 1638)
78	04578708 (FF 135), 04578767 (FF 145), 04579577 (FF 232), 05340934 (FF 520), 05352827 (FF 720), 05353998 (FF 783), 05355095 (FF 881), 06645763 (FF 1542)
81	04577620 (FF 35), 04578589 (FF 130), 02664712 (FF 230), 05655129 (FF 968), 05659787 (FF 1374), 05659876 (FF 1380), 06645488 (FF 1520)
82	04578686 (FF 137), 05338913 (FF 327), 05355362 (FF 905), 05355346 (FF 907), 05355621 (FF 928), 05655358 (FF 995),

Sp #	PERTH Collection Numbers (Project collection numbers)
	05659396 (FF 1344), 06646417 (FF 1594), 06646506 (FF 1602), 06446751 (FF 1627)
83	04578422 (FF 111), 04578678 (FF 138), 04579453 (FF 211), 05338808 (FF 322), 05355648 (FF 927), 05655250 (FF 989a), 05659175 (FF 1316), 05659302 (FF 1336), 05659841 (FF 1382), 06646700 (FF 1632), 06447308 (FF 1674)
84	04578643 (FF 140), 06645747 (FF 1544)
88	04579186 (FF 189), 05339596 (FF 393), 05339561 (FF 395), 05340039 (FF 433), 05340810 (FF 514), 05341698 (FF 595), 05353815 (FF 767), 05354870 (FF 868), 05355850 (FF 884), 05355257 (FF 898), 05355281 (FF 895), 05654912 (FF 955), 05655803 (FF 1033), 05655765 (FF 1036), 05659744 (FF 1038), 05656125 (FF 1070), 05656265 (FF 1073), 05657725 (FF 1189), 05659477 (FF 1354)
90	04579062 (FF 168), 04579127 (FF 178)
94	04578007 (FF 65), 04578430 (FF 110), 04578848 (FF 155), 04578988 (FF 175), 04579216 (FF 186), 04579607 (FF 245), 05339405 (FF 378), 05340500 (FF 471), 05341426 (FF 572), 05352061 (FF 654), 05352150 (FF 663), 05353823 (FF 766), 05660017 (FF 1399)
95	04578538 (FF 119), 04579992 (FF 274), 05354005 (FF 782), 05355311 (FF 909), 05658454 (FF 1255)
96	04578376 (FF 117), 04579399 (FF 201), 04580001 (FF 273), 05338867 (FF 332), 05339081 (FF 343), 05339227 (FF 363), 05340209 (FF 450), 05655617 (FF 1019), 05659671 (FF 1367), 05660262 (FF 1424), 06644671 (FF 1591)
99	04578457 (FF 125), 04578619 (FF 127), 05341248 (FF 556), 05352711 (FF 714), 05354013 (FF 781), 05355435 (FF 914), 05355591 (FF 931), 05657407 (FF 1147), 05659086 (FF 1309)
103	04578198 (FF 100), 04579828 (FF 258), 05339146 (FF 355), 05339723 (FF 413), 05658918 (FF 1293), 05659507 (FF 1351), 05659914 (FF 1392)
104	04579038 (FF 103), 05352614 (FF 707), 05656419 (FF 1092), 05656737 (FF 1104), 05657830 (FF 1195), 06645836 (FF 1552), 06645984 (FF 1554)
107	04578317 (FF 105), 04579275 (FF 196), 02664755 (FF 226), 04579844 (FF 256), 04579836 (FF 257), 05338514 (FF 300), 05339030 (FF 348), 05339251 (FF 360), 05339200 (FF 365), 05339693 (FF 400), 05339839 (FF 419), 05347092 (FF 495), 053449591 (FF 636), 05352134 (FF 697), 05352746 (FF 712), 05353688 (FF 747), 05354617 (FF 842), 05354773 (FF 859), 05655447 (FF 1002), 05655978 (FF 1051), 05657393 (FF 1148), 05658098 (FF 1222), 05660637 (FF 1452), 06648835 (FF 1512), 5682 (FF 1534a), 06645801 (FF 1539), 06644591 (FF 1557)
108	04578309 (FF 106), 05338352 (FF 283), 05341337 (FF 563), 05659736 (FF 1067), 05658470 (FF 1253), 05659264 (FF 1324), 06646220 (FF 1580), 06647839 (FF 1736)
112	04578724 (FF 150), 04579534 (FF 236), 04579666 (FF 240), 04579739 (FF 249), 05339448 (FF 375), 05340489 (FF 473), 05658497 (FF 1252), 05658756 (FF 1276)
113	04579380 (FF 202), 05338999 (FF 336), 05338948 (FF 341), 05339022 (FF 349), 05339103 (FF 358), 05339774 (FF 409), 05340233 (FF 447), 05340578 (FF 481), 05655021 (FF 961), 05655420 (FF 1004), 05659361 (FF 1346), 05659779 (FF 1376), 05660157 (FF 1401), 06646328 (FF 1588), 06647294 (FF 1677)
114	04579364 (FF 204), 04579437 (FF 213), 04580117 (FF 216), 04579984 (FF 275), 04579968 (FF 277), 05338360 (FF 282), 05338956 (FF 340), 05339111 (FF 357), 05339758 (FF 411), 05340535 (FF 484), 05355249 (FF 899), 05654971 (FF 965), 05655072 (FF 973), 05658543 (FF 1262), 05659655 (FF 1369), 05658977 (FF 1303), 05659655 (FF 1383), 05660033 (FF 1397),06646859 (FF 1635)
118	04578406 (FF 113), 04579305 (FF 193), 04579259 (FF 198), 04579348 (FF 206), 04579429 (FF 214), 04580060 (FF 222), 05338379 (FF 281), 05338557 (FF 296), 05349621 (FF 633), 05352347 (FF 695), 05352495 (FF 702), 05352605 (FF 708), 05352908 (FF 730), 05353580 (FF 739), 05354161 (FF 800), 05655226 (FF 976), 05657105 (FF 1134), 05657423 (FF 1145), 05657946 (FF 1203), 05657938 (FF 1204)
119	04577604 (FF 37), 04579488 (FF 209), 05339863 (FF 416), 05340675 (FF 487), 05352673 (FF 717), 05352819 (FF 721), 05354153 (FF 801), 05657970 (FF 1216), 05658128 (FF 1219), 05659106 (FF 1307), 06645674 (FF 1535), 06645887 (FF 1548), 06646093 (FF 1576), 06647650 (FF 1706)
120	04577825 (FF 50), 04577752 (FF 56), 04579208 (FF 187), 04579194 (FF 188), 04579720 (FF 250), 04579712 (FF 251), 05339545 (FF 397), 05340799 (FF 516), 05353890 (FF 776), 05655900 (FF 1041), 05659019 (FF 1299), 05660270 (FF 1423), 05660866 (FF 1463), 05660831 (FF 1465), 05660874 (FF 1478)
121	04577639 (FF 34), 04578295 (FF 107), 04578449 (FF 109), 04579291 (FF 194), 04579402 (FF 200), 04580095 (FF 218), 04579321 (FF 207), 05341280 (FF 552), 05352584 (FF 710), 05352762 (FF 727), 05352894 (FF 731), 05353467 (FF 734), 05353521 (FF 744), 05349540 (FF 754), 05354803 (FF 857), 05658004 (FF 1213), 05658195 (FF 1231), 05657296 (FF 1157), 05660645 (FF 1451), 05660815 (FF 1467), 05660793 (FF 1469), 06645631 (FF 1538), 06645585 (FF 1527)
122	04578570 (FF 131), 045800079 (FF 220), 05338387 (FF 280), 05340993 (FF 530), 05352916 (FF 729), 05353459 (FF 736), 05354056 (FF 778), 05657288 (FF 1158), 05657466 (FF 1165), 05658071 (FF 1223), 05659817 (FF 1385), 05660297 (FF 1421), 06648878 (FF 1509)
123	04579267 (FF 197), 02664739 (FF 228), 05338336 (FF 285), 05338972 (FF 338), 05339170 (FF 352), 05340306 (FF 457), 05349613 (FF 634), 05352320 (FF 698), 053523132 (FF 699), 05352509 (FF 701), 05353572 (FF 740), 05353548 (FF 743), 05353440 (FF 746), 05354242 (FF 810), 05655080 (FF 972), 056555560 (FF 1009), 05658934 (FF 1291)
126	04579240 (FF 199), 06646646 (FF 1622), 06645224 (FF 1633), 06647537 (FF 1700)
128	04578996 (FF 174), 04579550 (FF 234), 05338638 (FF 306), 05338573 (FF 310), 05339421 (FF 376), 05339502 (FF 385), 05339928 (FF 428), 05340497 (FF 472), 05347041 (FF 499), 05341078 (FF 540), 05341043 (FF 542), 05341035 (FF 543), 05341175 (FF 546), 05341167 (FF 547), 05341450 (FF 569), 05341434 (FF 571), 05341620 (FF 585), 05341582 (FF 589), 05341566 (FF 591), 05351960 (FF 646), 05354048 (FF 779), 05655846 (FF 1030), 05655919 (FF 1040b), 05656001 (FF 1048), 05656230 (FF 1075), 05660912 (FF 1474), 06647952 (FF 1741)
129	04579011 (FF 172), 04579100 (FF 180), 045792327 (FF 184), 04579526 (FF 237), 05339383 (FF 380), 05339588 (FF 394), 05340349 (FF 469), 05341604 (FF 587), 939, 05656303 (FF 1086), 05656478 (FF 1087)
130	04579518 (FF 238)
131	04578287 (FF 108), 04578473 (FF 123), 04579674 (FF 239), 04579909 (FF 266), 05338409 (FF 294), 05338581 (FF 309), 05338778 (FF 325), 05339375 (FF 381), 05352282 (FF 667), 05352398 (FF 687), 05353718 (FF 761), 05353866 (FF 763), 05353920 (FF 773), 05354110 (FF 788), 05354404 (FF 811), 05354331 (FF 818), 05354587 (FF 829), 05354609 (FF 843), 05354595 (FF 844), 05354730 (FF 847), 05354919 (FF 863), 05355109 (FF 880), 05655269 (FF 988), 05657040 (FF 1124), 05657326 (FF 1155), 05658292 (FF 1238), 06647855 (FF 1734)
133	04578759 (FF 146), (FF 225), 05338522 (FF 299), 05338875 (FF 331), 05339197 (FF 366), 05339847 (FF 418), 05340284 (FF 459), 03540519 (FF 486), 05340616 (FF 493), 05341485 (FF 582), 0355001 (FF 872), 05355826 (FF 943), 05355737 (FF 950), 05655234 (FF 975), 05655218 (FF 977), 05655151 (FF 980), 05655404 (FF 990), 05659124 (FF 1321), 05659272

Table 2 (cont.)

Sp #	PERTH Collection Numbers (Project collection numbers)
	(FF 1323), 05659299 (FF 1337), 05659965 (FF 1387), 05660041 (FF 1395), 05660203 (FF 1412), 05660165 (FF 1416), 05660475 (FF 1435), 05660556 (FF 1445), 05660734 (FF 1459), 05660920 (FF 1473), 05661005 (FF 1482), 06645976 (FF 1555), 06646301 (FF 1589), 06446603 (FF 1609), 06646735 (FF 1629), 06646883 (FF 1648), 06647111 (FF 1659), 06647200 (FF 1667), 06647359 (FF 1685), 06647677 (FF 1720), 06647669 (FF 1720b), 06647820 (FF 1721)
135	04579852 (FF 255)
136	04579801 (FF 259), 04579925 (FF 264), 05339537 (FF 398), 05658896 (FF 1294), 06646743 (FF 1628)
138	04579933 (FF 263), 04579895 (FF 267), 05658861 (FF 1296), 05658888 (FF 1295), 05658993 (FF 1301), 06646425 (FF 1593), 06646379 (FF 1598)
139	04579860 (FF 270)
140	04579887 (FF 268), 06646468 (FF 1606)
141	04579879 (FF 269), 05355141 (FF 892), 05655668 (FF 1016)
143	04580036 (FF 271), 04580028 (FF272), 05338832 (FF 319), 05338824 (FF 320), 05338786 (FF 324), 05354749 (FF 846)
145	05338344 (FF 284), 05354145 (FF 802), 05355605 (FF 930), 05355699 (FF 938), 05659825 (FF 1384), 06646492 (FF 1603)
146	05338476 (FF 288), 05338433 (FF 291), 05340225 (FF 448), 05349354 (FF 613), 05349508 (FF 622), 05349915 (FF 624), 05349648 (FF 632), 05349729 (FF 640), 05352169 (FF 662), 05354080 (FF 791), 05656427 (FF 1090a), 05656753 (FF 1102), 05656915 (FF 1120), 05657512 (FF 1160), 06645518 (FF 1518), 06646697 (FF 1617)
147	04578740 (FF 147), 05338441 (FF 290), 05338506 (FF 301), 05339219 (FF 364), 05349893 (FF 796), 05354315 (FF 803), 05354439 (FF 825), 05349249 (FF 827), 05354927 (FF 862), 05657122 (FF 1144), 05658578 (FF 1260), 05658500 (FF 1266), 06646212 (FF 1581)
148	05338601 (FF 307)
149	05338603 (FF 308), 05338743 (FF 311), 05338719 (FF 314), 05339960 (FF 424), 05340357 (FF 468)
151	05338700 (FF 315)
153	04578325 (FF 104), 04579392 (FF 114), 04578414 (FF 115), 04579283 (FF 195), 04579410 (FF 215), 04579798 (FF 260), 05338484 (FF 287), 05338417 (FF 293), 05338565 (FF 295), 04579410 (FF 297), 05339189 (FF 351), 05340292 (FF 458), 05352789 (FF 724), 05354978 (FF 875), 05657792 (FF 1200), 05657903 (FF 1206), 05659256 (FF 1325)
155	05338530 (FF 298), 05339820 (FF 420), 05341108 (FF 536), 05354226 (FF 795), 05354528 (FF 835), 05354714 (FF 849), 05354811 (FF 856), 05354900 (FF 864), 05355729 (FF 935), 05655153 (FF 981), 05660025 (FF 1398), 06647936 (FF 1743)
156	04125320 (FF 221), 05338654 (FF 304), 05340152 (FF 439), 05340179 (FF 453), 05340624 (FF 492), 05341477 (FF 583), 05354692 (FF 851), 05655412 (FF 1005), 05658233 (FF 1243)
158	05339413 (FF 377)
159	05339510 (FF 384), 05655862 (FF 1045), 05656109 (FF 1055), 05659620 (FF 1356)
160	04578937 (FF 163), 04579658 (FF 241), 05339480 (FF 387), 05339618 (FF 392), 05340438 (FF478)
161	04579917 (FF 265), 04579976 (FF 276), 05338697 (FF 316), 05338689 (FF 317), 05338670 (FF 318), 05338816 (FF 321), 05338905 (FF 328), 05657040 (FF 1124)
162	05338751 (FF 326)
163	05338891 (FF 329), 05338883 (FF 330), 06646980 (FF 1655), 06647081 (FF 1661)
164	05338859 (FF 333), 05338980 (FF 337), 05339073 (FF 344), 05339162 (FF 353), 05339278 (FF 359), 05339243 (FF 361), 05339685 (FF 401), 05339642 (FF 405), 05340144 (FF 451), 05340527 (FF 485), 05340861 (FF 525), 05354102 (FF 789), 05355443 (FF 913), 05355818 (FF 944), 05655544 (FF 1011)
165	05338964 (FF 339)
166	05339049 (FF 347), 05339634 (FF 406), 05655730 (FF 1023), 05660009 (FF 1347), 05659647 (FF 1370), 05659809 (FF 1372), 05660130 (FF 1403), 05660327 (FF 1418), 05660440 (FF 1438), 06647227 (FF 1681), 06647413 (FF 1695)
168	05339065 (FF 345), 05339235 (FF 362), 05339650 (FF 404), 05355419 (FF 916), 912,05355575 (FF 933), 05655455 (FF 1001), 05658942 (FF 1306), 05660696 (FF 1462), 06646581 (FF 1610), 06646654 (FF 1621)
169	05339138 (FF 356), 05339731 (FF 412), 05352096 (FF 650), 05655064 (FF 974), 05659906 (FF 1393)
170	05339626 (FF 391)
171	04577515 (FF 29), 05339324 (FF 370), 05341086 (FF 538), 05341124 (FF 551), 05354269 (FF 808), 05354935 (FF 861), 05354986 (FF 874), 05355192 (FF 888), 05655633 (FF 1017), 05656435 (FF 1090), 05656435 (FF 1090), 05658276 (FF 1240), 05658632 (FF 1271) , 05658594 (FF 1275), 05659027 (FF 1314), 05659183 (FF 1315), 05659957 (FF 1388), 05660564 (FF 1444), 06645712 (FF 1531), 06646026 (FF 1566)
173	05339804 (FF 422), 05659213 (FF 1328), 05659434 (FF 1341), 06647103 (FF 1660), 06646875 (FF 1649)
175	05339669 (FF 403), 05353793 (FF 769), 05354064 (FF 793), 05658772 (FF 1290a), 05658969 (FF 1304), 06646778 (FF 1626),
176	05339782 (FF 408), 05340217 (FF 449), 05340586 (FF 480), 05340659 (FF 489), 05655609 (FF 1020), 05659698 (FF 1366), 05660092 (FF 1407), 06647316 (FF 1689), 06647448 (FF 1693)
177	05339790 (FF 407), 05339766 (FF 410), 05340128 (FF 442), 05340101 (FF 443), 05340071 (FF 445), 05340063 (FF 446), 05340772 (FF 518), 05340896 (FF 523), 05341140 (FF 549), 05341469 (FF 568), 05354447 (FF 824), 05354854 (FF 853), 05355559 (FF 919), 05355524 (FF 922), 05355508 (FF 924), 05355664 (FF 941), 05655110 (FF 969), 05655102 (FF 970), 05655366 (FF 994), 05655439 (FF 1003), 05655587 (FF 1006), 05655579 (FF 1007), 05655676 (FF 1015), 05655714 (FF 1025), 05655773 (FF 1035), 05656095 (FF 1056), 05656273 (FF 1072), 05656222 (FF 1076), 05658802 (FF 1287), 05659000 (FF 1300), 05658985 (FF 1302), 05659043 (FF 1312), 05659280 (FF1338), 05659569 (FF 1355), 05659612 (FF 1357), 05659868 (FF 1381), 05661048 (FF 1479), 06646069 (FF 1562), 06646956 (FF 1642), 06647014 (FF 1652), 06647286 (FF 1676)
178	05339871 (FF 415), 05659035 (FF 1313), 05659035 (FF 1350), 05660424 (FF 1425), 05660416 (FF 1427), 05660394 (FF 1428)
179	05339898 (FF 430)
180	05340020 (FF 434), 05340446 (FF 477)
181	05340268 (FF 461), 05340411 (FF 463), 05340403 (FF 464), 05340381 (FF 465), 05340330 (FF 470), 05340470 (FF 474), 05340594 (FF 479), 05347076 (FF 497), 05347068 (FF 498), 05347033 (FF 500), 05347025 (FF 501), 05340683 (FF 510), 05340845 (FF 511), 05340829 (FF 513), 05340802 (FF 515), 05341051 (FF 541), 05341191 (FF 544), 05341299 (FF 567), 05341558 (FF 576)

Sp #	PERTH Collection Numbers (Project collection numbers)
182	04578880 (FF 151), 05340241 (FF 462), 05340462 (FF 475), 05351979 (FF 645), 05354560 (FF 831), 05655528 (FF 1013), 05655838 (FF 1031)
183	05340322 (FF 455)
184	04577523 (FF 28), 05340098 (FF 444), 05340993 (FF 490), 05657881 (FF 1207)
185	05339987 (FF 438), 05658764 (FF 1290b), 06646158 (FF 1570), 06647464 (FF 1691)
187	05347017 (FF 502), 05355354 (FF 906)
188	05340748 (FF 505)
189	05340608 (FF 494), 05340780 (FF 517), 05341116 (FF 535), 05341329 (FF 564), 05341019 (FF 528), 05655625 (FF 1018), 05655692 (FF 1027), 05656192 (FF 1063), 05656184 (FF 1064), 05656176 (FF 1065), 05656168 (FF 1066), 05660181 (FF 1414), 06647170 (FF 1670), 06647782 (FF 1725),
190	05340543 (FF 483), 05340667 (FF 488), 05340942 (FF 519), 05340918 (FF 522), 05340950 (FF 534), 05341272 (FF 554), 05341221 (FF 557), 05341205 (FF 559), 05341345 (FF 562), 05341388 (FF 575), 05341531 (FF 577), 05655471 (FF 999), 05655757 (FF 1022a), 05655951 (FF 1052), 05656079 (FF 1058), 05656206 (FF 1062), 05656389 (FF 1078), 05660343 (FF 1431a), 05660580 (FF 1441), 05660548 (FF 1446), 05660629 (FF 1453), 05660602 (FF 1455), 05660742 (FF 1458A), 05660823 (FF 1466), 05660785 (FF 1470), 05661013 (FF 1481), 06647421 (FF 1694), 06647499 (FF 1704), 06647626 (FF 1709), 06647790 (FF 1724), 06647928 (FF 1729), 06647847 (FF 1735), 06648185 (FF 1752)
191	05341183 (FF 545)
192	05341736 (FF 592), 05341701 (FF 594), 05341671 (FF 596), 06640249 (FF 602), 04577299 (FF 1), 05656818 (FF 1098), 05661099 (FF 1486)
194	05341027 (FF 527), 05352886 (FF 732), 05354838 (FF 855), 05354781 (FF 858), 05655005 (FF 963), 05655099 (FF971), 05655463 (FF 1000), 05655641 (FF 1008), 05656117 (FF 1054), 05659493 (FF 1352), 05660386 (FF 1429)
195	05340853 (FF 526)
196	05341302 (FF 566), 05341442 (FF 570), 05341612 (FF 586), 05341574 (FF 590)
197	05341264 (FF 553), 05341361 (FF 560), 05341523 (FF 578)
200	05341213 (FF 558), 05654998 (FF 964), 05655943 (FF 1053), 05659558 (FF 1363), 05659639 (FF 1371), 05661021 (FF 1480), 06647383 (FF 1682), 06647731 (FF 1714), 06647898 (FF 1731)
203	05341515 (FF 579)
204	05339057 (FF 346), 0539294 (FF 373), 05349389 (FF 612), 05352045 (FF 656), 05355184 (FF 889), 05655277 (FF 987), 05658039 (FF 1210), 05657989 (FF 1215), 05659523 (FF 1349), 06645690 (FF 1533), 06647510 (FF 1702)
206	05349435 (FF 617)
208	05349516 (FF 621)
209	04578511 (FF 120), 04578481 (FF 122), 04578791 (FF 142), 04579372 (FF 203), 05338735 (FF 312), 05340160 (FF 454), 05349346 (FF 614), 05349494 (FF 623), 05349885 (FF 627), 05349869 (FF 628), 05349850 (FF 629), 05349605 (FF 635), 05349699 (FF 643), 05349680 (FF 644), 05352649 (FF 704), 05352681 (FF 716), 05353769 (FF 756), 05353750 (FF 757), 05353726 (FF 760), 05354897 (FF 866), 05656788 (FF 1101), 05656931 (FF 1118), 05657024 (FF 1126), 05657016 (FF 1127), 05657229 (FF 1139), 05657210 (FF 1140), 05657504 (FF 1161), 05657695 (FF 1176), 05657776 (FF 1185), 05657857 (FF 1193), 05658187 (FF 1232), 05658748 (FF 1277), 05659140 (FF 1319), 06645534 (FF 1516), 06645666 (FF 1536), 06646239 (FF 1579)
210	05349907 (FF 626), 05349842 (FF 630), 05657636 (FF 1182), 05657997 (FF 1214)
212	04578627 (FF 126), 04578562 (FF 132), 04578651 (FF 139), 04579585 (FF 231), 05349486 (FF 615), 05355983 (FF 625), 05349656 (FF 631), 05349583 (FF 637), 05349575 (FF 638), 05349737 (FF 639), 05349710 (FF 641), 05354099 (FF 790), 05355842 (FF 885), 05655315 (FF 983), 05355125 (FF 894), 05654890 (FF 957), 05656907 (FF 1105), 05656893 (FF 1106), 05656990 (FF 1113), 05657075 (FF 1121), 05657121 (FF 1132), 05657113 (FF 1133), 05658144 (FF 1217), 06645461 (FF 1521)
216	05353564 (FF 741), 05352487 (FF 703), 05352703 (FF 715), 05355800 (FF 722), 05353564 (FF 741), 05354137 (FF 786), 05354250 (FF 809), 05656052 (FF 1060), 05656141 (FF 1068), 15657148 (FF 1131), 05657245 (FF 1137), 05657199 (FF 1142), 05657385 (FF 1149), 05657768 (FF 1186), 05657806 (FF 1199), 05660378 (FF 1430), 06645917 (FF 1559)
217	05353602 (FF 737), 05353696 (FF 745), 05353645 (FF 750), 05657415 (FF 1146), 05657369 (FF 1151)
219	05352266 (FF 668), 05353556 (FF 742)
220	05349877 (FF 671)
221	05352223 (FF 672), 05352231 (FF 670)
222	05353661 (FF 748), 05353661 (FF 748), 05355117 (FF 878), 05355206 (FF 887), 05355710 (FF 936), 05355672 (FF 940), 05655331 (FF 996), 05657377 (FF 1150)
223	04577434 (FF 21), 04577558 (FF 26), 04577507 (FF 30), 04578384 (FF 116), 04578635 (FF 141), 04579097 (FF 181), 04580087 (FF 219), 04580052 (FF 223), 04580044 (FF 224), 02664747 (FF 227), 05338395 (FF 279), 05339359 (FF 367), 05340314 (FF 456), 05347084 (FF 496), 05340985 (FF 531), 05341256 (FF 555), 05341353 (FF 561), 05341396 (FF 573), 05349419 (FF 619), 00535212 (FF 664) , 05352444 (FF 683), 05353475 (FF 733), 05353599 (FF 738), 05354307 (FF 804), 05354579 (FF 830), 0354501 (FF 836), 05354757 (FF 845), 05355001 (FF 873), 05355478 (FF 911), 05655498 (FF 998), 05655994 (FF 1049), 05656400 (FF 1093), 05657059 (FF 1123), 05657091 (FF 1135), 05657342 (FF 1153), 05657334 (FF 1154)
224	05352290 (FF 665), 05354498 (FF 820), 05355877 (FF 883), 05658314 (FF 1236), 05660238 (FF 1411)
225	05352274 (FF 666), 05341952 (FF 647), 05352126 (FF 648), 05352215 (FF 673), 05352452 (FF 682), 05655307 (FF 984), 05655196 (FF 978), 05658403 (FF 1244)
226	05349230 (FF 726), 05352088 (FF 652), 05352428 (FF 685), 05347734 (FF 692), 05352738 (FF 713), 05352770 (FF 725), 05657083 (FF 1136), 05657180 (FF 1143), 05349559 (FF 1220), 06645542 (FF 1515)
227	05352754 (FF 728), 05657539 (FF 1174), 06648819 (FF 1514)
228	05353785 (FF 735), 05658209 (FF 1230)
229	04579143 (FF 651), 04578368 (FF 101), 05352460 (FF 681), 05352568 (FF 688), 05347750 (FF 819), 05656877 (FF 1108), 05657598 (FF 1169), 05658225 (FF 1226)
230	05349257 (FF 680), 05347742 (FF 653), 05352207 (FF 658), 05349532 (FF 679), 05352401 (FF 686), 05352320 (FF 693), 05353904 (FF 775), 05354420 (FF 826), 05656834 (FF 1112)
231	05352037 (FF 657), 05352541 (FF 689), 05354412 (FF 828), 05657156 (FF 1130), 05657601 (FF 1168), 05657679 (FF 1178), 05657660 (FF 1179), 05657652 (FF 1180), 05657865 (FF 1192)
232	05352525 (FF 691), 05352177 (FF 661), 05354552 (FF 832), 05656958 (FF 1117), 05657563 (FF 1171), 06647251 (FF 1678)

Table 2 (cont.)

Sp #	PERTH Collection Numbers (Project collection numbers)
233	05352355 (FF 694), 05353947 (FF 771), 05657784 (FF 1184)
234	05352118 (FF 649), 05657482 (FF 1163), 05657520 (FF 1175), 05667733 (FF 1188), 05660076 (FF 1394)
235	05352053 (FF 655), 05656850 (FF 1110)
237	05352185 (FF 660), 05354196 (FF 798)
238	05352517 (FF 700), 05352576 (FF 711), 05352797 (FF 723), 06645615 (FF 1524)
239	05352630 (FF 705), 05355486 (FF 926)
240	05352592 (FF 709), 05655285 (FF 986), 06645798 (FF 1540)
241	05352339 (FF 696), 05352665 (FF 718), 05656486 (FF 1096), 06648886 (FF 1508)
242	05353777 (FF 755), 05660319 (FF 1419)
243	05341418 (FF 574), 05353742 (FF 758), 05353955 (FF 770), 05353939 (FF 772), 05353912 (FF 774), 05353882 (FF 777), 05354544 (FF 833), 05355265 (FF 897), 05655870 (FF 1044), 05656842 (FF 1111), 05657067 (FF 1122), 05657032 (FF 1125), 05657687 (FF 1177)
244	05354218 (FF 797), 05354471 (FF 821), 05354706 (FF 850), 06646514 (FF 1601)
245	05354382 (FF 813), 05354323 (FF 817)
246	05354358 (FF 816)
247	05354536 (FF 834)
248	04579747 (FF 248), 05354676 (FF 837), 05354641 (FF 839), 05355222 (FF 901), 05656966 (FF 1116), 05657741 (FF 1187)
249	05354668 (FF 838), 05657474 (FF 1164)
250	05354684 (FF 852), 05355532 (FF 921), 05659760 (FF 1377)
251	05354765 (FF 860), 05658047 (FF 1209), 05658551 (FF 1261)
252	05354455 (FF 823), 05353874 (FF 762), 05353807 (FF 768), 05659310 (FF 1335)
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254	05354889 (FF 867), 05355028 (FF 871), 05659574 (FF 1361), 06646522 (FF 1616), 06647073 (FF 1662), 06647405 (FF 1696)
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The flora and fauna of Legendre Island

J. RICHARDSON [1,2], F.J. STANLEY [1,3], P.G. KENDRICK [1] AND G. KREGOR [1]

[1]Department of Environment and Conservation, PO Box 835, Karratha, 6714,
[2] Current address: Science Division, Department of Environment and Conservation, Locked Bag 104, Bentley Delivery Centre WA 6983.
[3] Current address: Marine Policy and Planning Branch, Department of Environment and Conservation, 47 Henry Street, Fremantle, 6160.

ABSTRACT

This paper presents the current knowledge of the vertebrate fauna and vascular flora of Legendre Island off the Pilbara coast of Western Australia. It reports on a biological survey performed by the Department of Environment and Conservation (DEC; formerly the Department of Conservation and Land Management, CALM) in July 2000 and collates historical biological data from the island. The survey added 21 new species of vascular flora to the island's species list. One-hundred and seventy plant species, including six weed species, are now known from the island. None of the native taxa are declared rare flora or priority species. The survey added one new species of vertebrate (the python, *Liasis stimsoni*) to the island's records. The confirmed terrestrial vertebrate fauna of Legendre Island consists of one species of mammal (*Rattus tunneyi*), 20 species of reptiles and 50 species of birds.

We suggest that differences between the species identified in 2000 and in previous surveys are the result of seasonality and patchiness of distribution. We believe that more plant and animal species remain unrecorded from the island and recommend a survey program that allows for sampling seasonal variation and variation between wet and dry summers. Such a strategy may also detect those fauna not recently recorded.

We argue that because Legendre Island is the only large limestone island in the Dampier Archipelago and is an important breeding location for three species of marine turtle, it should be included in the conservation estate as part of the proposed Dampier Archipelago National Park.

Introduction

The Dampier Archipelago comprises 42 islands, islets and rocks, lying close to the town of Dampier on the north west coast of Western Australia (Figure 1). The islands are variously composed of Precambrian volcanic and granitic rocks, Pleistocene limestones, and Holocene sand deposits (Kriewaldt, 1964). Twenty-seven of the islands are currently reserved for conservation or for conservation and recreation (CALM, 1990). The other islands are either unallocated Crown land or are under temporary reservation for industrial purposes.

The Dampier Archipelago attained its present form between 7000 and 8000 years ago, following inundation of surrounding lands by the sea (Semeniuk *et al.*, 1982). Legendre Island is the most northerly island of the archipelago and, at approximately 1300 hectares, is the fifth largest. It is not, however, one of the nature reserves of the Dampier Archipelago despite being the only large limestone island found there.

The biological values of Legendre Island have not been previously assessed with any rigour. The known fauna and flora of the island were presented in the Dampier Archipelago Nature Reserves Management Plan (CALM, 1990) which summarised all observations and biological collections known from the island at that time. However, to our knowledge, no pitfall trapping had ever been undertaken. Considering the size of the island and its limestone substrate, a more detailed assessment of the biological values of the island was warranted.

This paper presents the results from a biological survey undertaken on Legendre Island in July 2000, as well as all historical fauna and flora records for the island. We include notes on the history and vesting of the island.

Background

Legendre Island lies between latitudes of 20°21'8"S to 20°25'18"S, and longitudes of 116°49'39"E to 116°57'3"E. It covers an area of 1344 hectares above high water mark, and is approximately 15.5 km long and 1.5 km wide at the widest point. The highest point is 33 m above sea level. On the southern side there are extensive shallow sandy flats, extending as far as adjacent islands. To the north, the water depth descends rapidly to 20 metres and more. A working lighthouse is present on its western end.

The island is composed of Pleistocene dune limestone, with areas of fringing Holocene sands. Extensive areas of sandplain, containing pink-brown limestone-derived sands, have a well-developed hard pan at about 0.3 metres depth. Adjacent Hauy and Keast Islands, and the slightly more distant Delambre Island also contain some limestone areas, but are largely composed of Holocene sand deposits (Kriewaldt, 1964, Ryan, 1966, Biggs, 1976a, 1976b). Legendre Island is the largest limestone island in the Dampier Archipelago. The only limestone island off the Pilbara coast to exceed Legendre in size is Barrow Island.

The island was visited by the French Expedition under the command of Nicholas Baudin on 29 March 1803. It is believed to have been named in honour of the French mathematician Adrien Marie Legendre (pers. comm., WA Department of Land Information).

Climate

The climate of the Dampier Archipelago is semi-arid tropical with two seasons, a hot summer extending from October to April and a mild winter between May and September. Mean summer temperature ranges from 24°C (minimum) to 35°C (maximum), while mean winter temperatures range from 17°C to 29°C (CALM, 1990). Rainfall is seasonal but unreliable, with an annual average of 276 mm. Evaporation is approximately 2500 mm per year, exceeding rainfall by a factor of 9 (CALM, 1990). The islands may receive more rainfall than the mainland and early morning dews can occur in both summer and winter.

Land status

The majority (1137.5 ha) of Legendre Island is vested in the Minister for State Development, for Future Industrial Purposes. Legendre Island was once part of a proposal to develop a deepwater port to support the iron ore industry, in which it was planned to run a service corridor along the Burrup Peninsula and Dolphin Island to a proposed port area at Legendre Island. This plan was deleted from the Burrup Land Use Plan and Management Strategy in 1996. However, the vesting of the island remains with the Minister for State Development.

Limestone resources have been identified on numerous islands in the Dampier Archipelago, with Legendre assessed to hold 264 million tonnes of limestone at a mean grade of 83.51% (Landvision, 2001). Lime is an important resource for use in cement making and steel production. While Hamersley Iron operated an iron ore pelletising plant at Dampier between 1968 and 1980, no extraction of lime resources was undertaken from Legendre. There are no current leases over Legendre Island, and previously issued exploration licences were surrendered in 2001 (pers. comm., Department of Industry and Resources, September 2004).

In its report to the Environmental Protection Authority (EPA, 1974), the Conservation Through Reserves Committee recommended that part of Legendre Island be left in its natural state, although some of the island was being investigated for deep water port infrastructure. Based on these recommendations and public submissions, the EPA (1975) recommended that the entire Dampier Archipelago be declared a Class A reserve for conservation of flora and fauna. This was later amended, with Legendre and Dolphin Islands proposed to be Class B reserves. However, since this recommendation and following amendments to the Land Administration Act 1997, Class B reserves no longer exist. Thus Legendre Island was never incorporated into the conservation estate.

Previous surveys

Prior to the establishment of the Dampier Archipelago conservation reserves between 1977 and 1987, there were three significant visits by naturalists to the Archipelago. The earliest of these, a WA Museum (WAM) expedition by D. Bathgate, G. W. Kendrick and B. Wilson in 1961, did not visit Legendre Island. However, in the following year (1962), a larger WAM expedition visited many islands of the archipelago, including Legendre, and made extensive collections of vertebrates and flora. Lastly, a joint WAM and WA Department of Fisheries and Wildlife expedition to the archipelago in July 1970 (Burbidge and Prince, 1972), visited islands that were most likely to be affected by proposed industrial developments in the area. Legendre Island was included, but while this expedition surveyed vertebrate fauna and flora, no pitfall trapping was undertaken.

Various other data have been collected since the establishment of the reserves. In 1978, Ian Abbott surveyed birds on Legendre and the surrounding islands (Abbott 1979, 1982) and Ron Johnstone (WA Museum) included mangrove stands on Legendre Island in his 1973–1982 survey of mangrove birds of Western Australia (Johnstone, 1990). Keith Morris (DEC, Woodvale) collated his personal bird records for the island in the Dampier Archipelago Nature Reserves Management Plan (CALM, 1990). Long (1996) performed a flora survey of the southern part of the island for Woodside Petroleum in June 1996 and also made some incidental records of fauna.

No widespread pitfall trapping was undertaken in the archipelago until Connell (1983) studied biogeography and community structure of the reptiles on selected small islands in 1983. Legendre Island was not included here, and no pitfall trapping was done there until a CALM survey in 1998 (unpublished data).

In 1998, it was decided that a fauna survey using pitfall traps should be undertaken, because of the possibility that small, cryptic mammals and reptiles may have been missed during the earlier surveys. In particular, it was thought possible that *Ningaui*, *Planigale* and some small rodents (eg *Pseudomys delicatulus*) might be present on the island, but undetected. That survey established pitfall traps in three different vegetation communities on the western end of the island (see below) and opened these traps from 21 to 23 April 1998.

The island vegetation was classified by Beard (1971a) as t_1Hi: Grass Steppe Spinifex (*Triodia pungens*) no trees or shrubs. The vegetation was classified from an aerial traverse north of the island (Beard, 1971b).

Flora records for Legendre Island come from several sources. Herbarium vouchers were lodged at Perth by the WAM survey in 1962 (99 vouchers of 76 species) and by BG Thomson (2 vouchers of 2 species), while species lists were compiled on two separate occasions: Burbidge and Prince (1972) listed 72 species and Long (1996), surveying a proposed southern corridor, recorded 75 species.

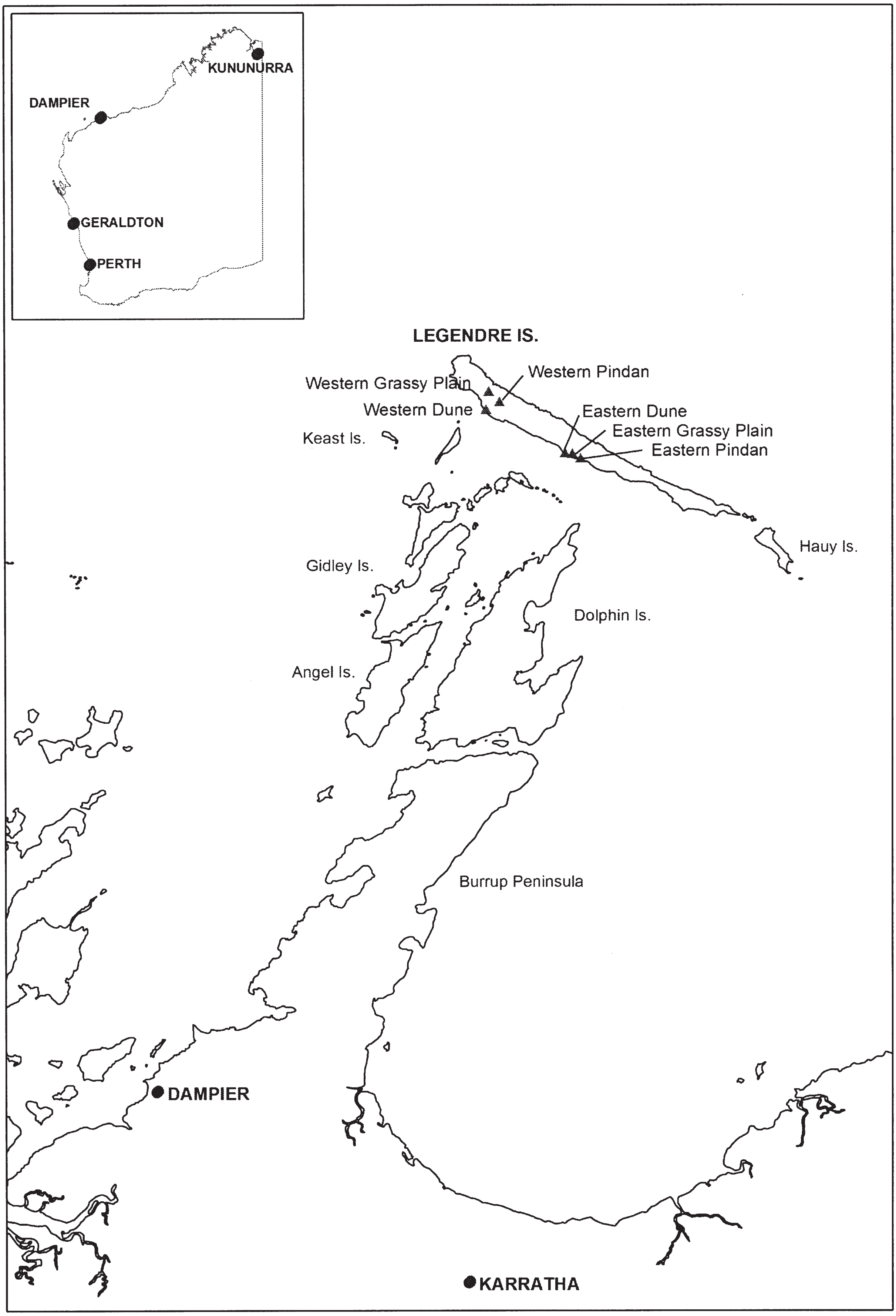

Figure 1. *The Dampier Archipelago showing Legendre Island and the location of the study sites.*

METHODS

Sampling Sites

In the 1998 CALM survey, pitfall trap lines were established in a sand dune, a grassy-plain and a pindan community on the western side of the island. These were again used in the 2000 survey and are designated as Units 1, 2 and 3 respectively. Also in 2000, pitfalls were established in analogous vegetation communities on the eastern end of the island (Units 4, 5 and 6). These sites are termed western and eastern respectively (Figure 1). Only the western sites were sampled in 1998; these data are also presented in the results.

As limestone hills are the dominant feature of the island several units were located here. Unit 7 was established on a limestone hill site about 200 metres north of the eastern dune unit (Unit 4). Unit 8 is an ecotonal region between a limestone hill (Unit 7) and the pindan (Unit 6). Unit 9 is a coastal limestone shelf. Unit 10 is a limestone hill above the campsite (south-east of the eastern units). Unit 11 is an unspecified limestone hill on the western end of the island.

Flora

Vegetation was sampled within 50 x 50 m quadrats within Units 1–10. Unit 11 was not sampled using a quadrat but was sampled by fortuitous collections across a limestone hill.

At least one specimen of each plant species was collected for identification in Karratha.

Fauna

Fauna was sampled by varying techniques depending on location. Vegetation Units 1 to 6 were each sampled the same way: 20 Elliott traps (baited with oats and peanut paste) and pitfall traps. In each unit, Elliott traps were opened for the same period as the pitfall traps. The pit lines consisted of two 20-litre buckets with approximately five metres of fence between them and two metres of fence either side. Units 1, 2 and 3 (the western sites) had four pit lines that were open from the 11th to the 15th of July 2000. The eastern sites (Units 4, 5 and 6) had three pit lines and were open from the 11th to the 17th of July.

The other areas sampled for fauna were on limestone hills where pitfall traps could not be installed. Unit 7 was one of these sites. Unit 7 was sampled by 20 Elliot traps (using the same bait as above) opened from the 11th and 17th of July.

Two other areas were also trapped for mammals. On the northern side of the island a distinctive rocky outcrop was located and 25 Elliot traps, using the same bait as above, were set for four consecutive nights. The mangrove community on the southern side of the island was trapped for Water Rats (*Hydromys chrysogaster*). Four cage traps were set behind the mangroves (two baited with oats and peanut paste, the other two with sardines) for four consecutive nights from the 11th to 14th April.

Each of the designated units was also actively searched for reptiles. Where appropriate this involved digging up rat burrows, tearing off bark, spotlighting, rolling rocks and logs, as well as the more passive sit-and-watch technique, used amongst trees and rocks. All captures were identified in the field or camp as appropriate and released on-site. At least one specimen of each species (except for the Stimson's python) was lodged with the WA Museum. For purposes of comparison, numbers of animals caught in each vegetation unit are presented, but, as there was no marking of animals, these may include recaptures.

Bird records were taken *ad hoc* from sightings around the island. Consequently, these data are not related to any vegetation unit.

Results and Discussion

Vegetation communities

Five main vegetation units can be identified on Legendre Island:

Mangal

Mangals on Legendre Island are found on the southern side of the island and are dominated by the white mangrove, *Avicennia marina*, interspersed with occasional specimens of *Bruguiera exaristata*, *Ceriops tagal* and *Aegialitis annulata*. There were many *A. marina* seedlings particularly on the landward side of the mangal in both 1998 and 2000.

Sand Dune

Sand (white Holocene) dunes are present behind the beaches on the western end and southern side of the island. This habitat is dominated by the low shrub *Acacia bivenosa*, with an herbaceous understorey including *Swainsona formosus*, *Ptilotis exaltatus*, *Tephrosia eriocarpa*, and *Canavalia rosea*.

Grassy Plains

This habitat type is dominated by grasses, including *Enneapogon polyphyllus*, *Themeda triandra*, *Triraphis mollis*, *Eragrostis setifolia*, and *Panicum decompositum*, interspersed with herbaceous annuals, such as *Ptilotus exaltatus*, and the creeper *Rhynchosia minima*. The soil is generally orange sand.

Pindan

This habitat type is somewhat similar to the grassy plain in both vegetation structure and soil colour however, the substrate is much harder and the vegetation community noticeably different. The vegetation is dominated by grass species including *Enneapogon polyphyllus* and *Triodia* sp., with numerous herbaceous annuals such as *Amaranthus pallidiflorus*, *Ptilotus* *exaltatus*, *Euphorbia australis* and *Flaveria australasica* and other small plants such as *Boerhavia schomburgkiana*, *Alysicarpus rugosus*, *Indigofera linnaei* and *Melhania oblongifolia*, together with the creeper, *Rhynchosia minima*.

Limestone Hill

Outcroppings of limestone exist in a number of locations on Legendre Island. These range from low areas to hillocks to steep hills. The vegetation on these limestone areas was dominated by grasses and herbaceous plants such as *Sorghum plumosum*, *Triodia wiseana*, *Abutilon lepidum* and *Trichodesma zeylanicum*, with creepers such as *Mukia maderaspatana* and *Rhynchosia minima*. There were also scattered clumps of *Ficus brachypoda* and *Pittosporum phylliraeoides.*

Flora

One-hundred and seventy vascular plant species from 42 families and 105 genera are known from the island; none are declared rare flora (DRF) or priority listed (Appendix 1). Eighty-three species were collected in the 2000 survey, 21 of which new records for the island. Significantly, eighty-seven species previously recorded from the island were not collected in the 2000. This is assumed to be due to seasonal and sampling effects, as the uncollected taxa include both perennial and annual species. Changes in vegetation structure in some vegetation units were noted between the 1998 and 2000 surveys and these could be responsible for some of these differences. In the two years between CALM surveys, there was considerable change in the vegetation structure with substantial grass growth in Pindan and Grassy Plain units on both the eastern and western ends of the island. During the 1998 survey these units were largely bare of grass however in 2000, there was thick growth to one metre high in the eastern Grassy Plain, and spinifex growing through and over the pit fences in the western Pindan. Furthermore, the 1998 survey was done at the end of summer all vegetation was very dry and there were no plants in flower. In stark contrast, during the 2000 winter survey there were a large number of plants in flower and the vegetation was generally green and lush. This followed very high summer rains earlier that same year.

Six island plant species are introduced or naturalised (*Aerva javanica*, *Malvastrum americanum*, *Passiflora foetida*, *Setaria verticillata*, *Amaranthus viridis*, and *Salsola tragus*). Keighery and Longman (2004) consider the first four species environmental weeds, i.e. those that reproduce in reasonably intact bushland. *Aerva javanica* (kapok) was introduced to Australia as a fodder plant. It readily invades disturbed areas and is now widespread on the Pilbara mainland and is recorded from a number of other Pilbara coastal islands, including many islands of the Montebello group (pers. obs., Jeff Richardson). It has not been recorded on the island previously. *Malvastrum americanum* is a native of America and a common weed of arid zone and other habitats, from the Nullarbor to the Pilbara and Kimberley (Hussey *et al.*, 1997). It was not recorded on the island prior to 2000 and then only in the grassy plain on the western end of the island. *Passiflora foetida* (stinking passion flower), native to South America (Hussey *et al.*, 1997), is a common weed of disturbed areas on creek and river banks from Carnarvon to the Kimberley. It also was not collected before 2000 and was only found in the western pindan. *Setaria verticillata* (whorled pigeon grass) is a common and widespread weed of disturbed land and shrublands in the Pilbara and Kimberley (Hussey *et al.*, 1997). Although it was not collected in 2000 it was recorded by Burbidge and Prince (1972). *Amaranthus viridis* is an annual herb that is native to tropical America (Hussey *et al.*, 1997). It was not found in 2000, or recorded by Burbidge and Prince (1972), but was vouchered at the Perth herbarium in 1962. *Salsola tragus* is widespread in WA and also on Legendre Island.

Mammals

Five species of mammal have been recorded on Legendre Island. These records are from vouchered specimens, oral records and evidence such as skeletal remains and scats. The 2000 survey attempted to resolve as many unsubstantiated records as possible.

Vouchers of *Rattus tunneyi* were lodged in the Western Australian museum in 1962 (the WAM visit) and 1970 (Burbidge and Prince, 1972). We found this species in all vegetation units and in high numbers (367 captures for all sites combined; Table 1). *Rattus tunneyi* is not listed on the Western Australian or Commonwealth threatened species lists and is considered secure in the Rodent Action Plan (Lee, 1995). However, it has suffered a significant decline since European settlement (Braithwaite and Baverstock, 1995). It formerly occurred along the west coast and throughout the Pilbara, Gascoyne and Kimberley regions of Western Australia, but has now disappeared from more than 50% of its original area of occupancy in this State and the Northern Territory, and is extinct in South Australia (Morris, 2000). Morris (2000) recommends it should be regarded as lower risk (near threatened) under the IUCN categories of threat (IUCN, 2004), and that it should be monitored and could be added to the CALM Priority Fauna list.

Foxes have been recorded on the island from as early as 1962 (WAM), and Burbidge and Prince (1972) found evidence (scats and tracks) of their presence in 1970. A

baiting program was subsequently initiated in 1996 (pers. comm., K. Morris, DEC, Woodvale). There has been no recent evidence of foxes (in this and the 1998 survey) implying that the baiting program has been effective in eradicating this introduced species.

The presence of two other island mammal species has been inferred from skeletal material. Burbidge and Prince (1972) found the skull of a Rock Rat (*Zyzomys argurus*) and a skull of *Pseudomys hermannsburgensis* was found in an owl pellet by P. Kendrick (DEC, Karratha) during the 1998 survey. Neither of these species were found on Legendre during the 2000 CALM

Table 1

Terrestrial vertebrate species recorded from Legendre Island, their distribution across the vegetation units surveyed in 2000 (numbers represent total captures in each unit) and the provenance of previous records. See text for unit descriptions and comments on these species. W=record from the museum collected 1962; B= Burbidge and Prince (1972); C1998=CALM survey (unpublished) in 1998; D= Dampier Archipelago Nature Reserves Management Plan, (CALM, 1990).

GROUP	SPECIES	Vegetation Unit Number							Other	Previous
		1	2	3	4	5	6	7	Units	Collectors
MAMMALS	*Rattus tunneyi*	47	43	43	68	67	42	46	11	W, B, C1998
	Vulpes vulpes[1]									W, B
	Tachyglossus aculeatus[2]									L
AGAMIDS	*Ctenophorus caudicinctus*								2	B, L
	Ctenophorus isolepis	1			1				1	W, B, C1998
	Lophognathus gilberti gilberti									W, L
GECKOS	*Gehyra pilbara*[3]							4		B
	Gehyra punctata[4]							11	1	A
	Gehyra variegata							4	1	W, C1998
	Diplodactylus conspicillatus									B
	Diplodactylus elderi[5]									D
	Diplodactylus stenodactylus									B
	Heteronotia binoei							1	2	W, B, C1998
SKINKS	*Ctenotus saxatilis*	16	4	2	4	3	5		1	W, B, C1998
	Ctenotus serventyi	1								W, C1998
	Glaphyromorphus isolepis	5	2		2	1	2	3	2	W, B, C1998
	Lerista bipes	6	3						2	C1998
	Lerista muelleri	3	1	4	1		2	1		W
	Morethia ruficauda	2		1		2	1	3		W
VARANIDS	*Varanus acanthurus*							3[6]		W, B, C1998
	Varanus panoptes					1				C1998
TYPHLOPIDAE	*Ramphotyphlops diversus ammodytes*									B
SNAKES	*Liasis stimsoni*							2		
Total number of species per Unit		8	5	4	5	4	6	9	9	

[1] No foxes seen on the island since the 1996 baiting program initiated.
[2] Scats consistent with the echidna recorded by Long (1996).
[3] Recorded as *G. australis* in Burbidge and Prince (1970), re-identified since (pers. com. L. Smith WA Museum)
[4] Ian Abbott collected 2 species (R60443-44) while on the island surveying for birds in 1978.
[5] The provenance of the record for this species is unknown, it was reported in CALM (1990)
[6] These records come from 3 tails found in a tree. It is assumed that they were dropped there by a raptor, these have not been included in the species count for the unit.

survey despite substantial effort being put into trapping around rock piles to find *Z. argurus.* Both these species live on nearby islands (CALM, 1990) and it is assumed from the results of this survey that the skulls came from animals predated elsewhere, probably by a Barn Owl.

Long (1996) found scats consistent with Echidnas in her southern study sites. There have been no records of this species from previous or the 2000 survey. Although this species is cryptic, it's feeding sign is conspicuous, indicating that Echidna are probably uncommon on Legendre.

Water Rats (*Hydromys chrysogaster*) are thought to live on nearby Dolphin Island, where their tracks are regularly seen near mangroves (pers. obs., Geoff Kregor, Peter Kendrick). We found no tracks, nor evidence of feeding sites, nor did we catch any individuals in the cage traps set behind the mangroves.

Reptiles

Twenty species of reptile are known from museum records from Legendre Island (Table 1). Some have not been recorded since the surveys of 1962 and 1970. For instance, no Diplodactyline geckos were found during this or the CALM 1998 survey, although three species of this group (*Diplodactylus conspicillatus*, *D. stenodactylus* and *D. elderi*) are recorded in CALM (1990) and Burbidge and Prince (1972) vouchered the two former species in the WAM. It is assumed the *D. elderi* record in CALM (1990) comes from an unpublished source.

All gecko species recorded in the current survey were found on the limestone hill (Unit 7) amongst a small area of split and movable rocks (Table 1). In this same rock pile a pair of Stimson's pythons (*Liasis stimsoni*) were found. These constitute a new record for the island.

Three species of agamids (dragons) are known from the island, but only two species were recorded in the 2000 survey. The Ring-tailed Dragon (*Ctenophorus caudicinctus*) was observed on rocky areas near the shore on both the northern and southern sides of the island. Neither of these was within a sampled vegetation unit. This species was collected in 1970 but no specimens were lodged during the WAM survey in 1962 nor was the species recorded in 1998. Long (1996) observed the species frequently. The second agamid found in the 2000 survey (*C. isolepis*) was recorded from areas with a sandy substrate: one in each of the Dune units (both in pitfalls) and one was seen near the campsite. *Lophognathus gilberti* was lodged in the WA museum in 1962 and was recorded as frequent on the southern part of the island by Long (1996), however it has not been recorded during any other surveys on the island.

All the skink species previously recorded on Legendre were recorded during the 2000 survey. *Ctenotus saxatilis* (*C. leseurii* in Burbidge and Prince, 1972) was the most common, being found in all units except the Limestone Hill. Our record of *Ctenotus serventyi* was a single capture in a sand dune unit (Unit 1) the same site where an individual was caught in 1998. This species was not recorded in CALM (1990), but is on WAM records (1962). This similarity of this species and *C. saxatilis* can lead to *C. serventyi* being reported as the more common *C. saxatilis.* The one record here of *C. serventyi* implies that this species is uncommon on Legendre Island and probably elsewhere: Connell (1983), for instance, found none of this species on the 10 nearby islands he studied, although it is known from the nearby Burrup Peninsula.

No blind snakes (Family Typhlopidae) were recorded in this survey. Two specimens of *Ramphotyphlops diversus ammodytes* were collected in 1970 (Burbidge and Prince, 1972) but this species has not been recorded before then or since.

Two varanids have been recorded from Legendre Island. A single *Varanus panoptes* was found on the grassy plain (Site 5) in 2000 and the same location in 1998 (the first record for the species on Legendre). The other varanid recorded in 2000 (*V. acanthurus*) was from traces of the species: three tails were found in trees on the Limestone Hill, presumably dropped there by a raptor. The WA Museum has a record of this species from 1962, Burbidge and Prince (1972) mention its presence and an individual was caught in an Elliott trap on Unit 1 during the 1998 CALM survey.

Large numbers of turtle tracks observed on beaches suggest that Legendre Island is one of the most important turtle nesting islands in the Dampier Archipelago (pers. comm., Keith Morris, DEC, Woodvale). Green turtles (*Chelonia mydas*) have been recorded nesting on the beaches on the northern side of the island (pers. comm., Keith Morris), and it is likely that Hawksbill turtles (*Eretmochelys imbricata*) and Flatback turtles (*Natator depressus*), which commonly nest on other islands of the archipelago, would also nest here. Green turtles have also been observed aggregating in the waters just off the eastern end of Legendre Island (pers. obs., Fran Stanley). More research needs to be conducted into the species of marine turtle that use the beaches and waters surrounding Legendre Island to determine its overall significance for these species.

Birds

Fifty-three bird species from twenty-eight families have been recorded on Legendre Island (Table 2). Over half of these are terrestrial species, the rest are waders or waterbirds. Five species have been recorded breeding on the island: Wedge-tailed Shearwater, Osprey, White-bellied Sea-Eagle, Bar-shouldered Dove and the Barn Owl. There are at least two resident groups of Barn Owls on the island. One group, consisting of five individuals, was seen on the cliffs to the east of the mangroves on the southern side of the island. A pair (probably not included in the above count) was seen in a cave behind the mangroves, where a nest was found with a single egg. Nesting Barn Owls were also recorded in the 1998 CALM survey. Other breeding records from 2000 were two Osprey nests, each with three eggs in them. The earliest known Osprey breeding record is from 1978 (from the CALM Seabird Breeding Island Database; Abbott, 1982).

General Discussion

The present survey has added substantially to our knowledge of the vascular plant and vertebrate species of Legendre Island, which remains, nevertheless, far from complete. Comparing our survey results with previous surveys highlights some glaring knowledge inadequacies. For instance, the recording of 21 new plant species from the island, but the failure to recollect 87 previously recorded species underlie this. Similarly, Long's (1996) record of *L. g. gilberti* was the first since 1962.

Part of the reason for this disparity would be seasonality and also variation between high rainfall and low rainfall years. Other variations may be explained by sampling location: our 2000 record of Stimson's python and all four gecko species are from a single small rock pile that could have easily been overlooked. Likewise, sampling method is also important. There are no bat records from the island, though Microchiropterans were seen feeding on insects in the camp lights.

We recommend a comprehensive survey program that incorporates all the above considerations. Furthermore, to contextualise the biodiversity values of Legendre Island we also recommend that a similar program of biological survey be performed amongst all islands in the group. As a basis for stratifying future sampling we have identified five vegetation communities on the island.

Legendre Island is the only large limestone island in the Dampier Archipelago, and one of only a few large limestone islands off the Pilbara coast, and efforts should be made to include it in the conservation estate. This is

Table 2

Bird species recorded from Legendre Island. Order and nomenclature from draft working list of birds of Australia and Australian Territories, June 2003 (Birds Australia Website). The seabird and wader records of Abbott (1979, 1982) and Burbidge and Prince (1972) not specified as being on Legendre Island are not included. A^1=Abbott (1979); A^2=Abbott (1982); B= Burbidge and Prince (1972); J= Johnstone (1990); C1998 and C2000 CALM officers (unpublished) during the 1998 or 2000 surveys respectively; D=CALM (1990); W1962=record from the museum collected 1962; (b)=breeding record.

FAMILY	COMMON NAME	SOURCE
Phasianidae	Brown Quail[1]	B, C2000
Procellariidae	Wedge-tailed Shearwater	D (b)
Phalacrocoracidae	Pied Cormorant	D
Fregatidae	Lesser Frigatebird	C1998
Ardeidae	White-faced Heron	C1998
Ardeidae	Eastern Reef Egret	D, C1998 (white and dark morphs)
Ardeidae	Great Egret	C2000
Accipitridae	Osprey	A^2 (b), D (b), B, C1998 (b), C2000 (b)
Accipitridae	Black-shouldered Kite	D, B, C1998, C2000
Accipitridae	Whistling Kite	D, B
Accipitridae	Brahminy Kite	D, A^2,C1998, C2000
Accipitridae	White-bellied Sea-Eagle	D (b), B, C1998, C2000
Accipitridae	Spotted Harrier	D, A^2,B, C1998, C2000
Falconidae	Nankeen Kestrel	D, B, C1998, C2000
Scolopacidae	Godwit[2]	C1998
Scolopacidae	Whimbrel	D, C1998
Scolopacidae	Common Greenshank	C1998
Scolopacidae	Grey-tailed Tattler	D, C1998
Scolopacidae	Ruddy Turnstone	C1998
Scolopacidae	Sanderling	C1998
Burhinidae	Beach Stone-curlew[3]	C1998, C2000
Haematopodidae	Pied Oystercatcher	D, A^2,C1998, C2000
Haematopodidae	Sooty Oystercatcher	D, C1998, C2000
Charadriidae	Red-capped Plover	C1998
Charadriidae	Lesser Sand Plover	C1998
Laridae	Silver Gull	D, C1998, C2000
Laridae	Caspian Tern	C1998, C2000
Laridae	Crested Tern	D, A^1
Laridae	Roseate Tern	C1998
Laridae	Bridled Tern	C1998
Columbidae	Bar-shouldered Dove	D (b), C1998, C2000, J
Cacatuidae	Little Corella	D, B, C2000
Psittacidae	Budgerigar	D, A^2
Tytonidae	Barn Owl	C1998, C2000 (b)
Halcyonidae	Sacred Kingfisher	D, W1962, B, C1998
Pardalotidae	Dusky Gerygone[4]	D, J
Pardalotidae	Large-billed Gerygone[5]	B
Meliphagidae	Yellow-throated Miner	C2000
Meliphagidae	Singing Honeyeater	D, A^2,B, C1998
Petroicidae	Mangrove Robin	D, W1962, B, J
Pachycephalidae	White-breasted Whistler	D, W1962, B, J
Dicruridae	Grey Fantail	B, C1998
Dicruridae	Mangrove Grey Fantail	D, J
Dicruridae	Willie Wagtail	D, B, C1998, C2000
Campephagidae	Black-faced Cuckoo-Shrike	D, B, C1998, C2000
Campephagidae	White-winged Triller	D
Artamidae	White-breasted Woodswallow	D, A^2,B, C1998,C2000,J
Artamidae	Pied Butcherbird	C2000
Corvidae	Corvid sp. [6]	B, C1998, C2000, D
Motacilidae	Richard's Pipit	D, A^2,B, C2000
Hirundinidae	Welcome Swallow	D, A^2,B, C1998, C2000
Hirundinidae	Tree Martin	C2000
Zosteropidae	Yellow White-eye[7]	D, B, J

1 Called Quail (?brown) in Burbidge and Prince (1972);
2 Species not identified;
3 Bush Stone Curlew reported in CALM (1990) assumed incorrect;
4 Called Dusky Flycatcher in Johnstone (1990);
5 Called Large-billed Warbler in Burbidge and Prince (1972) this record appears to be out of its known distribution;
6 Identified as Torresian Crow in CALM (1990);
7 Called Yellow Silvereye in Burbidge and Prince (1972).

in line with the EPA's 1975 recommendation that Legendre be included in a Class A reserve. While the island contains relatively large deposits of limestone, the Wittenoom dolomites are a more suitable and more accessible source for lime (Landvision, 2001). In addition, the proposal to construct a deep water port at Legendre Island was dismissed by the EPA and not included in the Burrup Land Use Management Strategy (1996). Inclusion of Legendre Island would ensure the addition of large areas of limestone island habitat in the Pilbara near shore island conservation reserves.

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Appendix 1

The vascular plants of Legendre Island, their occurrence in sampling units and previous collections made from the island. Order and nomenclature follows Paczkowska and Chapman (2000). Vegetation Unit locations and descriptions are outlined in the text. OTHER are those species recorded or collected from the island by: * lodged in the State Herbarium in 1962; # recorded in Burbidge & Prince, (1972); L recorded in Long (1996).

		Vegetation Unit Number											
FAMILY	**SPECIES**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**OTHER**
Poaceae	*Aristida contorta*												#
Poaceae	*Chloris pumilio*												#
Poaceae	*Chrysopogon fallax*												*
Poaceae	*Cymbopogon ambiguus*												*,#,L
Poaceae	*Cymbopogon bombycinus*								+				
Poaceae	*Dactyloctenium radulans*												#
Poaceae	*Digitaria ctenantha*												L
Poaceae	*Enneapogon caerulescens*						+	+	+				L
Poaceae	*Enneapogon oblongus*												*
Poaceae	*Enneapogon pallidus*												#
Poaceae	*Enneapogon polyphyllus*		+	+		+			+				*,L
Poaceae	*Eragrostis dielsii*												L
Poaceae	*Eragrostis eriopoda*												#,L
Poaceae	*Eragrostis falcata*												*
Poaceae	*Eragrostis setifolia*				+	+							
Poaceae	*Eragrostis xerophila*												*
Poaceae	*Eriachne mucronata*									+			
Poaceae	*Eriachne obtusa*												#,L
Poaceae	*Eulalia aurea*	+			+					+			*,#,L
Poaceae	*Panicum decompositum*				+	+	+		+		+		*,L
Poaceae	*Paspalidium sp.*	+											
Poaceae	*Paspalidium tabulatum*												#,L
Poaceae	*Setaria dielsii*			+							+		
Poaceae	*Setaria verticillata*[1]												#
Poaceae	*Sorghum plumosum*							+	+				#,L
Poaceae	*Sorghum timorense*												*
Poaceae	*Spinifex longifolius*	+			+					+			#,L
Poaceae	*Sporobolus virginicus*												*,#,L
Poaceae	*Themeda triandra*		+	+					+				*,#,L
Poaceae	*Triodia angusta*												*
Poaceae	*Triodia epactia*	+											
Poaceae	*Triodia longiceps*												L
Poaceae	*Triodia pungens*												*,#,L
Poaceae	*Triodia sp.*			+									
Poaceae	*Triodia wiseana*					+	+	+	+		+		
Poaceae	*Triraphis mollis*		+										L
Poaceae	*Whiteochloa cymbiformis*												#
Cyperaceae	*Cyperus cunninghamii subsp. cunninghamii*												*
Cyperaceae	*Fimbristylis schultzii*												#
Moraceae	*Ficus brachypoda*							+	+			+	*,#,L
Moraceae	*Ficus opposita var. aculeata*											+	*
Moraceae	*Ficus virens var. virens*												*
Chenopodiaceae	*Atriplex isatidea*												*,#
Chenopodiaceae	*Enchylaena tomentosa*												*,#
Chenopodiaceae	*Neobassia astrocarpa*												*
Chenopodiaceae	*Rhagodia eremaea*			+				+					*,L
Chenopodiaceae	*Rhagodia preissii subsp. obovata*	+			+								*,#
Chenopodiaceae	*Salsola tragus*[1]	+	+	+	+		+	+	+		+		#,L
Chenopodiaceae	*Sclerolaena diacantha*		+	+						+			L
Chenopodiaceae	*Sclerolaena uniflora*												*
Chenopodiaceae	*Threlkeldia diffusa*	+			+					+			#,L
Amaranthaceae	*Achyranthes aspera*							+				+	*,L
Amaranthaceae	*Aerva javanica*[1]							+	+				
Amaranthaceae	*Amaranthus interruptus*												*
Amaranthaceae	*Amaranthus pallidiflorus*	+		+	+	+				+	+		#,L
Amaranthaceae	*Amaranthus viridis*[1]												*
Amaranthaceae	*Gomphrena canescens*											+	#
Amaranthaceae	*Gomphrena sordida*												L
Amaranthaceae	*Gomphrena tenella*												#
Amaranthaceae	*Ptilotus exaltatus var. exaltatus*		+	+	+	+	+		+	+	+		*,#,L
Amaranthaceae	*Ptilotus fusiformis*												#
Amaranthaceae	*Ptilotus obovatus var. obovatus*				+		+	+	+				*,L
Amaranthaceae	*Ptilotus villosiflorus*	+			+								L
Nyctaginaceae	*Boerhavia burbidgeana*	+					+						*
Nyctaginaceae	*Boerhavia schomburgkiana*			+	+				+				#,L
Nyctaginaceae	*Commicarpus australis*												L

FAMILY	SPECIES	Vegetation Unit Number 1	2	3	4	5	6	7	8	9	10	11	OTHER
Aizoaceae	*Sesuvium portulacastrum*									+			*
Aizoaceae	*Trianthema triquetra*												*
Aizoaceae	*Trianthema turgidifolia*		+			+	+			+	+		#,L
Molluginaceae	*Mollugo molluginis*												#
Portulacaceae	*Portulaca intraterranea*												L
Portulacaceae	*Portulaca oleracea*								+				
Portulacaceae	*Portulaca pilosa*												#,L
Menispermaceae	*Tinospora smilacina*												*
Capparaceae	*Capparis spinosa var. nummularia*								+				*,#,L
Capparaceae	*Cleome viscosa*												*,#,L
Pittosporaceae	*Pittosporum phylliraeoides*							+					*,#
Surianaceae	*Stylobasium spathulatum*												#,L
Mimosaceae	*Acacia arida*												*
Mimosaceae	*Acacia bivenosa*	+			+	+				+			*,L
Mimosaceae	*Acacia coriacea*												#
Mimosaceae	*Acacia inaequilatera*												*
Mimosaceae	*Acacia orthocarpa*								+			+	*
Mimosaceae	*Neptunia dimorphantha*												#
Caesalpiniaceae	*Senna glutinosa subsp. x luerssenii*												*
Papilionaceae	*Alysicarpus rugosus*		+	+		+	+		+				L
Papilionaceae	*Canavalia rosea*				+			+	+				*,#,L
Papilionaceae	*Crotalaria novae-hollandiae subsp. novae-hollandiae*												*,#
Papilionaceae	*Cullen badocanum*												*
Papilionaceae	*Indigofera colutea*												#
Papilionaceae	*Indigofera linifolia*			+		+	+		+	+	+		L
Papilionaceae	*Indigofera linnaei*		+	+		+	+		+		+		#
Papilionaceae	*Indigofera monophylla*				+				+	+	+		*,#,L
Papilionaceae	*Indigofera trita*								+				L
Papilionaceae	*Rhynchosia minima*		+	+	+	+	+	+	+	+	+		*,#,L
Papilionaceae	*Swainsona formosa*		+		+					+			*,#
Papilionaceae	*Swainsona pterostylis*	+				+	+			+			#,L
Papilionaceae	*Tephrosia bidwillii*												#
Papilionaceae	*Tephrosia rosea*												L
Papilionaceae	*Tephrosia sp.*			+					+				#
Zygophyllaceae	*Tribulus occidentalis*												*,#,L
Euphorbiaceae	*Adriana tomentosa*											+	
Euphorbiaceae	*Euphorbia alsiniflora*												*
Euphorbiaceae	*Euphorbia australis*	+	+	+	+	+	+			+			L
Euphorbiaceae	*Euphorbia boophthona*	+	+	+	+					+	+		
Euphorbiaceae	*Euphorbia coghlanii*	+				+	+						L
Euphorbiaceae	*Euphorbia drummondii*			+			+						*,L
Euphorbiaceae	*Euphorbia myrtoides*				+				+	+			*
Euphorbiaceae	*Euphorbia tannensis subsp. eremophila*												*,#,L
Euphorbiaceae	*Phyllanthus maderaspatensis*												L
Euphorbiaceae	*Phyllanthus reticulatus*												#
Sapindaceae	*Alectryon oleifolius*		+										#
Sapindaceae	*Diplopeltis eriocarpa*												L
Tiliaceae	*Corchorus parviflorus*												L
Tiliaceae	*Corchorus sp.Burrup(G.Craig 235)*							+	+				
Tiliaceae	*Corchorus walcottii*												#
Malvaceae	*Abutilon cunninghamii*												#
Malvaceae	*Abutilon indicum var. australiense*							+	+				L
Malvaceae	*Abutilon lepidum*							+			+	+	
Malvaceae	*Abutilon sp.*												#
Malvaceae	*Gossypium australe*		+			+	+						
Malvaceae	*Malvastrum americanum*[1]		+										
Malvaceae	*Sida fibulifera*					+	+	+					L
Malvaceae	*Sida sp.*					+	+			+	+		
Sterculiaceae	*Melhania oblongifolia*		+	+		+	+			+			*,L
Violaceae	*Hybanthus aurantiacus*												*
Violaceae	*Hybanthus enneaspermus*												#
Passifloraceae	*Passiflora foetida*[1]			+									
Rhizophoraceae	*Bruguiera exaristata*												#
Rhizophoraceae	*Ceriops tagal*												#
Apiaceae	*Trachymene oleracea subsp. oleracea*												#
Plumbaginaceae	*Aegialitis annulata*												*
Plumbaginaceae	*Plumbago zeylanica*												*
Oleaceae	*Jasminum didymum subsp. lineare*												*,L
Asclepiadaceae	*Cynanchum floribundum*		+						+	+			*,#,L
Asclepiadaceae	*Sarcostemma viminale subsp. australe*	+		+	+		+	+	+				*,#,L
Convolvulaceae	*Convolvulus clementii*												*

FAMILY	SPECIES	1	2	3	4	5	6	7	8	9	10	11	OTHER
						Vegetation Unit Number							
Convolvulaceae	*Evolvulus alsinoides*					+							*,#,L
Convolvulaceae	*Ipomoea lonchophylla*		+	+							+		
Convolvulaceae	*Ipomoea pes-caprae*												#
Convolvulaceae	*Operculina ?aequisepala*												L
Cuscutaceae	*Cuscuta victoriana*												L
Boraginaceae	*Heliotropium cunninghamii*												*
Boraginaceae	*Heliotropium pachyphyllum*												*
Boraginaceae	*Heliotropium tenuifolium*												L
Boraginaceae	*Trichodesma zeylanicum*				+			+					#,L
Verbenaceae	*Clerodendrum tomentosum*												#
Avicenniaceae	*Avicennia marina*												*,#
Solanaceae	*Nicotiana benthamiana*												#
Solanaceae	*Solanum cleistogamum*												*
Solanaceae	*Solanum diversiflorum*												*
Solanaceae	*Solanum ellipticum*												#
Solanaceae	*Solanum esuriale*												L
Solanaceae	*Solanum phlomoides*												L
Solanaceae	*Solanum sp.Boomerang Bay (K.F.Kenneally 10021)*			+									
Scrophulariaceae	*Stemodia grossa*									+			#,L
Scrophulariaceae	*Striga curviflora*							+					*,#
Myoporaceae	*Eremophila longifolia*		+										
Rubiaceae	*Oldenlandia crouchiana*												*
Rubiaceae	*Synaptantha tillaeacea*	+			+								*,L
Cucurbitaceae	*Mukia maderaspatana*							+	+				*,#,L
Cucurbitaceae	*Trichosanthes cucumerina*												#
Goodeniaceae	*Goodenia forrestii*												#
Goodeniaceae	*Goodenia microptera*				+		+					+	*,L
Goodeniaceae	*Scaevola crassifolia*		+			+	+						#,L
Goodeniaceae	*Scaevola cunninghamii*	+								+			*,L
Goodeniaceae	*Scaevola spinescens*									+		+	*,L
Stylidiaceae	*Stylidium spathulatum*											+	
Asteraceae	*Flaveria australasica*		+	+		+	+	+	+	+	+		L
Asteraceae	*Pentalepis trichodesmoides*							+				+	*
Asteraceae	*Pluchea rubelliflora*												*
Asteraceae	*Pterocaulon sphacelatum*				+	+		+	+	+			L
Asteraceae	*Pterocaulon sphaeranthoides*						+		+				*
Asteraceae	*Streptoglossa adscendens*			+			+					+	
Asteraceae	*Streptoglossa liatroides*												*

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Influence of bait type, weather and prey abundance on bait uptake by feral cats (*Felis catus*) on Peron Peninsula, Western Australia

D. ALGAR[1], G.J. ANGUS[1], M.R. WILLIAMS[2] AND A.E MELLICAN[2]

[1] Department of Environment and Conservation, Science Division, P.O. Box 51, Wanneroo, Western Australia 6946.

[2] Department of Environment and Conservation, Science Division, Locked Bag 104, Bentley Delivery Centre, Western Australia 6983.

ABSTRACT

Bait uptake by feral cats has shown variability both on a temporal and spatial scale. This study examined whether bait uptake is influenced by short-term weather parameters and/or the time of year and if so, when bait uptake is at its peak. We aimed to determine the optimum timing of baiting programs to maximize efficiency. The result was that bait uptake by feral cats displayed a high degree of short-term variability but clearly became more frequent and consistent into late summer/early autumn. A number of temperature factors were significantly related to bait uptake over the entire sampling period (long-term weather conditions) but insignificant when bait uptake was a regular occurrence. The exception was fluctuations in minimum temperature, which was of significance in both the long and short-term. Of the other environmental factors, rabbit abundance had a significant relationship with bait uptake. As rabbit abundance decreased from late spring through to early autumn, there was an increase in bait uptake. The two most important environmental factors that affected bait uptake in the short-term were wind speed and fluctuations in minimum temperature.

There was a significant preference for the kangaroo meat sausage bait over a chicken meat sausage bait and day-old cockerel and this could be potentially enhanced by the use of visual lures. Baiting efficacy was also significantly affected by non-target species, particularly Varanids and Corvids, consuming baits, reducing bait availability to feral cats.

INTRODUCTION

Baiting campaigns to control feral cats (*Felis catus*) have been conducted on Peron Peninsula, the site of 'Project Eden', since 1996. 'Project Eden', part of the broader 'Western Shield' program, aims to control introduced predators and return native wildlife to an area from which many mammal species have become extinct (Thomson and Shepherd 1995; Algar and Smith, 1998; Morris *et al.* 2004). The baiting programs have used both on-track deployment from a vehicle and delivery from an aircraft. Bait uptake trials conducted in conjunction with the baiting programs and baiting efficacy achieved during the baiting programs have indicated variability in bait consumption both on a temporal and spatial scale (Algar and Angus 2000a; Morris *et al.* 2004; Algar and Burrows 2004). Knowledge of predictable patterns in this variability (if any) and the possible causal factors, could lead to increased efficacy and cost efficiency of control measures undertaken. Management efforts could be focused on seasons or events where bait acceptance is likely to be greatest and less variable. It may also be possible to undertake complementary management actions that maximize bait acceptance by feral cats.

Behaviour and activity are in part a response to environmental stimuli, as animals have a limited ability to modify their immediate environment to maintain physiological function. Feeding patterns and thus bait uptake by feral cats are therefore potentially influenced by short-term (day-to-day) and/or long-term (seasonal) weather conditions.

The amount of time cats spend seeking food varies between individuals, sexes and seasons, but it accounts for less than 50 % of total activity (Turner and Meister 1988). Cats, despite being opportunistic predators, will only consume a food item if they are hungry (Bradshaw 1992). Cats have the ability to regulate calorific intake to maintain body weight (MacDonald *et al.* 1984; Baker and Czarneki-Maulden 1991; Legrand-Defretin 1994; Bradshaw *et al.* 1996). Cats will generally not exceed dietary requirements when provided food *ad libitum.* Thus for cats to consume baits they must encounter them when they are hungry. If a cat encounters a bait when not hungry it may not be consumed regardless of the acceptability of the bait.

The relationship between bait consumption and hunger can be extended to prey abundance, which is also a function of long-term weather conditions (season/rainfall). The likelihood of cats encountering baits when hungry is potentially diminished in the presence of an abundant prey population. Therefore bait uptake is invariably low when prey availability is high. Rabbits (*Oryctolagus cuniculus*), when present, can form a substantial proportion of feral cat diet (e.g. Jones and Coman 1981; Martin *et al.* 1996; Risbey *et al.* 1999). This is also the case at Peron Peninsula (Project Eden unpub. data). The presence of such a food source was seen as potentially impacting upon bait acceptance by feral cats as was found in an earlier study (Short *et al.* 1997) on the adjoining Heirisson Prong.

A research program was conducted with the aim of improving baiting efficacy on Peron Peninsula. The first objective was to assess whether bait uptake by cats is influenced by measurable and predictable environmental factors and, if so, can bait uptake be enhanced by baiting at specific times. The second objective was to compare the efficacy of the current standard bait against other bait types. Finally, a number of lures that may invoke a feeding response and thus potentially improve bait uptake were assessed.

METHODOLOGY

Study Site

Peron Peninsula was formerly a pastoral station. The peninsula was purchased by the State Government in 1990 to establish Francois Peron National Park on the northern end of the peninsula. The peninsula, an area of 1,050 km^2, lies within the Shark Bay World Heritage Area (see Fig. 1) and is joined to the mainland by a narrow neck (the 3.4 km Taillefer Isthmus). To prevent reinvasion by foxes (*Vulpes vulpes*) and cats from the mainland onto the peninsula a barrier fence was built across the isthmus in 1995. An electronic recording of a barking dog activated by movement sensors, and a cattle grid have been installed in the gap in the fence where the Denham road passes. These devices have provided an effective deterrent to fox and cat movement across this gap (Morris *et al.* 2004). The fence and prevention of movement across the grid has effectively created an island of the peninsula for introduced predator management.

Feral cat control on Peron Peninsula consists of a trapping program and ground and aerial baiting campaigns; these are described in detail in Morris *et al.* (2004). In summary, the Peninsula has been arbitrarily divided into four zones (see Fig. 1) and these zones are trapped on a rotational basis for feral cat control, by district staff. The trapping technique utilizes padded leg-hold traps, Victor 'Soft Catch'® traps No. 3 (Woodstream Corp., Lititz, Pa.; U.S.A.), an audio lure (Felid Attracting Phonic) that produces a sound of a cat call, and a blended mixture of faeces and urine (Pongo). Prior to this study, ground and aerial baiting campaigns were conducted annually in late summer/early autumn. During the course of this study, no baiting campaigns were conducted by district staff. Neither previous baiting exercises nor the ongoing trapping program were likely to compromise the bait uptake trials, however it was necessary to conduct the trials in zones distant from where the operational trapping programs were being conducted during any given period. The availability of track access and zone selection was therefore governed by the location of district operational activities. As toxic baits were used in this study, further track and area restrictions were imposed because of 1080 poison bait regulations. The bait uptake trials were conducted along tracks in Zones 2, 3 and 4 (see track locations on Figs. 2–4). The whole of Zone 1, and parts of others, was omitted from the study site due to the high level of tourist traffic on the majority of track access.

Climate

The climate of Peron Peninsula is described as 'semi-desert Mediterranean' (Beard 1976; Payne *et al.* 1987) Prevailing summer winds are southerly to south-westerly, relatively dry, warm and moderately strong. Prevailing winter winds are lighter, more humid and cool. There is a prevailing south-easterly morning tendency and a south-westerly afternoon tendency. Mean maximum daily temperatures are as high as 38° C for summer months and as low as 21° C for winter months. January and February are the hottest months while June and July are the coolest winter months. Rainfall averages 220 mm per year, most of it falling between April and September.

Vegetation

Beard (1976) and Payne *et al.* (1987) describe the vegetation of the peninsula. Five broad vegetation units occur across the study area – *Acacia ramulosa* scrub, *Acacia* thicket, *Acacia ligulata/Triodia plurinervata* shrub steppe, *Acacia/Lamarchea* thicket and the steppe of the birridas. A minor association occurs in small, near-coastal strips. This is variously a *Spinifex longifolius* grassland or myrtaceous heath. The *Acacia* scrub occurs on undulating sand dunes and is dominated by *Acacia ramulosa* which grows to ~3 m. The *Acacia* thickets occur on the exposed western side of the peninsula and are dominated by dense, low *A. ligulata*. The shrub steppe is dominated by *Triodia plurinervata* grassland. A large disturbed area, to the south of the Eagle Bluff shearing shed, is dominated by *Cenchrus ciliaris* grassland, generally to the exclusion of native species. The *Acacia/Lamarchea* thicket occurs on dunes in the exposed northwest portion of the study site. It exists as a low dense scrub to 1.5 m, dominated by *A. ligulata* and *Lamarchea hakeifolia*. The birridas are variously vegetated with steppe, many with large areas of bare, saline and alkaline clay.

Most of Zone 2 supports *Acacia* scrub. The western-most portion of the zone supports *Acacia/Lamarchea* thicket. A small number of birridas occur in Zone 2, they are seldom more than 600 m in extent. Most of Zone 3 supports *Acacia* scrub. The eastern portion, in particular, is dissected by numerous birridas, many of which are several kilometres in extent. The north-west portion of the zone (west of New Bore) is vegetated by *Acacia* thicket. Transects in Zone 4 are almost exclusively through shrub steppe, including the modified grasslands in the vicinity of the Eagle Bluff Shearing Shed. The southernmost sections traverse a series of birridas, generally flanked by *Acacia* scrub. The western-most transect is over *Spinifex longifolius* grassland.

Bait Types, Lures and Uptake Trials

Bait types

The acceptability of the standard sausage cat bait was assessed against two other bait types at cafeteria stations. Bait type (1) was the standard sausage cat bait approximately 20 g wet-weight, blanched and then dried to 15 g. This bait was composed of 70 % kangaroo meat mince, 20 % chicken fat and 10 % digest and flavour enhancers. Each bait was injected with 4.5 mg 1080. Bait type (2) was a chicken sausage bait produced in the same manner and to the same specifications as the standard cat bait but chicken mince replacing the kangaroo mince. This bait was used because of its relative ease of manufacture but different composition from the standard bait. This bait was also injected with 4.5 mg 1080. Bait type (3) was a dead day-old cockerel which provided a readily available and relatively inexpensive 'natural bait' alternative to the other two and has been used successfully in controlling feral cats elsewhere (Brothers 1982; Twyford *et al.* 2000; Bester *et al.* 2002). The cockerel bait medium was not included on the Australian Pesticides and Veterinary Medicines Authority experimental bait permit and therefore these baits were non-toxic.

Ant attack on baits rapidly degrades the bait medium, reducing palatability. Persistence of ants on the bait deters uptake by feral cats. All three bait types were treated with an ant deterrent compound (Coopex®) at a concentration of 12.5 g l^{-1} Coopex as per the manufacturer's instructions. Previous trials with this product have demonstrated that its use can greatly enhance bait uptake by feral cats (Algar unpub. data).

Bait lures

Initially, five different lures were employed to compare relative frequency of bait uptake in their presence. The lures comprised three visual (tinsel, rodent and reptile) and two audio lures (rabbit and bird sounds). The tinsel lure was constructed from a sheath of tinsel attached to a chaining arrow (40 cm rigid 12 gauge wire), such that the tinsel fluttered in the breeze. The rodent lure comprised a fluffy toy rat/mouse that was attached to a spring on a chaining arrow to allow it to move in the wind. The reptile lure consisted of a modified soft plastic fishing lure resembling a lizard, presented in the same manner as the rodent. The rabbit and bird audios consisted of a 36 x 25 mm printed circuit boards with microprocessor data driven voice ROMs that imitated sounds of 'rabbit' or 'bird' vocalizations.

One lure type was used per day over the four-five day period. At the end of the first month the rodent lure was abandoned as avoidance behaviour by cats was noted on several occasions as lures were approached.

Bait laying procedures

Bait uptake trials were conducted at weekly intervals across lunar phases and weather conditions. The trial periods were mid November – mid December 1999, mid January – mid February and mid March – mid April 2000. The second period was extended into March because of the onset of continuous bait uptake from late January and the need to maximize sampling periods prior to the onset of rainfall.

Bait uptake trials were conducted along discrete sections (transects) of existing track network. A pilot study conducted during the first four days over transect lengths of up to 40 km in length indicated that a reduction in transect length was warranted because of the time required to complete observations. All subsequent observations were conducted over transect lengths of up to 20 km of track per night. Transects were chain-dragged as the baits were laid to clear sign of previous activity. Bait laying commenced two hours before sunset. Baits (bait stations) were laid at 100 m intervals in the centre of the track. Baits were positioned only on sandy substrate where it was possible to observe track activity (eg. baits were not located on birridas).

Each transect comprised a single, standard cat bait laid at 100 m intervals; a cafeteria where the three bait types were offered at 500 m intervals and a lure with cafeteria at the 1000 m intervals. Thus in a 20 km bait uptake transect there was a 20 x 1 km replicates containing standard baits at 100, 200, 300, 400, 600, 700, 800 and 900 m; a set of the three different bait media at 500 and 1000 m and a lure at the 1000 m cafeteria. The lure type used changed daily through the series of lures trialed. A 20 km bait uptake transect presented 160 standard bait stations; 20 cafeteria stations and 20 cafeteria stations with lures. A total of 42 bait uptake trials was conducted during the study period.

Assessment of bait uptake

Baits were examined the morning following bait placement, commencing one hour after dawn. Transect assessment was conducted from a 4-WD vehicle, driven at a speed of less than 10 km/h. The observer was seated in an elevated position on a chair bolted to the front of the vehicle. Each bait station was inspected and the response of individual cats at the bait stations was recorded as no tracks present, a bait pass, visit or uptake. These bait responses are described by: –

- No track — There were no cat tracks within 3 m of the bait;
- Pass — Cat tracks were located within 3 m of the bait but the cat did not deviate from its path to inspect the bait;
- Visit — Cat tracks were within 0.5 m of the bait and indicated that the animal had deviated from its path to inspect the bait, but the bait had not been eaten;
- Uptake — Bait removed. Cat prints approaching the bait, pes and/or tail imprints present, indicating the cat had assumed a sitting position. No non-target prints within reasonable reach of the bait position.

It was necessary to add a further response category of "probable uptake". This response displayed the characteristics of an "uptake" because the bait had been removed, but wind erosion or the presence of non-target species' activity prevented assigning a species to removal of the bait with absolute certainty. This category was classified as a "visit" in the uptake summaries rather than "uptake", as it could potentially overestimate bait consumption by cats. In the analyses "potential uptake" was the sum of actual uptake and probable uptake.

The spacing of baits on the transects often enabled individual cats to encounter more than one bait. The response of individual cats was recorded for each bait station; however the highest ranking bait response for the individual animals was used in bait uptake summaries and statistical analyses. Thus, if an individual cat was recorded as "passing" a bait and then later "visiting" another bait, the individual cat's bait response was categorized as a visit, and so on.

Cat Activity

The location of individual cats along transects was recorded and their on-track distances logged. Imprints of individual animals were differentiated on the basis of location on the road transect. An imprint was assigned to an individual animal if no other imprint was present on at least the previous 1 km of transect. Subsequent imprints were also assigned to that individual unless at least 1 km was traversed with no new imprints present, or the imprint could be clearly differentiated on the basis of size or the direction of travel or the direction of entry/exit to and from the transect. Feral cat use of vehicular tracks, as a measure of activity, was based upon the actual distances travelled on the track, rather than the total span of interaction with the track. The total on-track activity of all individuals present was recorded, including those that did not encounter baits.

Measuring exact on-track distances travelled by individuals was impractical. For the purposes of this exercise, the only objective measures of distance available to observers were the 100 m intervals (initially measured with the vehicle odometer) at which baits were placed. Therefore recording of distance travelled was effectively coded for distances of <100 m, ^{3}100 m or multiples thereof. Distances of <100 m were nominally coded as 10 m, or multiples thereof. The total on-track distance travelled was the sum of all <100 m and ^{3}100 m intervals assigned to the particular individual.

Non-target Bait Uptake

Consumption of baits by non-target animals was recorded. Consumption was assigned to a particular non-target animal when no evidence of other species was within reasonable reach of the bait position.

Assessment of Rabbit Abundance

The presence or absence of rabbit tracks, over a 10 m plot, was recorded at each 100 m bait station. An index of rabbit abundance along the transect was calculated as the percentage of plots where rabbits were present.

Weather Data and Lunar Phase

Weather data for measured and derived variables were obtained from the Australian Bureau of Meteorology weather station in Denham. The data collected comprised: – temperature (°C), wet bulb temperature (°C), dew point (°C), relative humidity (%), barometric pressure (hPa), wind speed and direction (km/h & deg), rainfall (mm) and cloud cover (scale 1–8). Night-time weather data were for available for 1800, 0000, 0300 and 0600 h. Analyses were conducted on data averaged over these time periods and the maximum and minimum values of certain parameters (see Table 1).

The lunar cycle was described by luminosity, which was calculated by the time difference between moon rise to moon set and the time of sunrise/sunset, multiplied by the lunar stage as a percentage. The Perth Observatory supplied this data.

Statistical Analyses

Bait uptake

The proportion of contacting cats taking baits ("uptake") was related to a set of 21 potential predictor variables (see Table 1) using logistic regression analysis. Data were appropriately transformed in order to achieve homoscedasticity and approximate normality of residuals. Appropriate transformations were determined by diagnostic tests of residuals: stem-and-leaf plots, normal-normal plots and plots of studentized residuals against fitted values.

Logistic regression analysis provides a method of determining those variables that are related to bait uptake, and the direction and extent of that relationship. The logistic regression model was applied using the SAS software package (procedure LOGISTIC, SAS Institute Inc., 1989).

To estimate the relationships between categorical variables such as lure type and the bait uptake, each categorical variable was coded as a design (or 'dummy') variable (see for example Hosmer and Lemeshow, 1989). Each categorical attribute consisting of (n) categories was replaced with (n-1) binary design variables. For example, in the case of lure 3, the four design variables would be coded as lure 2 = 0, lure 3 = 1, lure 4 = 0, lure 5 = 0 (see Table 1). The names of these design variables were created by concatenating the parent variable name and the category number. This method of coding means that the estimated regression coefficient for each design variable represents the deviation of that category from the first category. For example, a significant, positive regression coefficient associated with the design variable lure 3, would indicate a higher incidence of bait uptake at bait stations where lure type 3 was used, when compared with stations using lure type 1. Similarly, binary categorical variables such as a rise or fall in daily temperature, were coded 1 (fall) or 0 (rise). For these variables, a significant, positive regression coefficient indicates a higher incidence of bait uptake associated with a fall in temperature.

The final multiple regression model was estimated using the stepwise model-building strategy of Hosmer and Lemeshow (1989). This strategy uses backward elimination of variables deemed non-significant at α = 0.25. A value of 0.25 ensures that in building an initial model, no potentially important variable is excluded. As the transect data were the result of a limited number of surveys, we sought to identify all possible environmental variables that may be useful as predictors of bait uptake. Thus lure type was excluded because it was an imposed manipulation, independent of prevailing environmental conditions. In all other statistical tests, the conventional level of α = 0.05 was used to identify statistical effects.

Bait preference

In order to determine if cats expressed a preference amongst the three alternative baits and if this preference was affected by the alternative lures, the consumption of baits was analysed using the method proposed by Roa (1992). This method uses multivariate analysis of variance (MANOVA) of bait consumption, with lure type treated as an applied treatment. The MANOVA method is preferred to simpler methods, such as chi-squared analysis of bait consumption, because the amounts of different baits taken are likely to be related. This correlation biases techniques such as chi-squared analysis that treat bait consumption as independent. As the number of baits of a particular type in the cafeteria was not always equal, the proportion of baits consumed to those laid was used in the analysis. Bait consumption data were transformed as necessary.

Cat activity

The total distance of cat tracks recorded per transect per day, and the average distance covered per cat, was regressed on the same set of potential predictor variables (see Table 1) using ordinary regression analysis. In contrast to bait uptake, these measures gauged cat activity, as opposed to their propensity to take baits. Residual diagnostic tests (stem and leaf plots and plots of residuals versus fitted values) were inspected for normality, and distance data subsequently square root transformed to achieve normality of residuals. The regression model was applied using the SAS software package (procedures REG and GLM, SAS Institute Inc., 1989).

RESULTS

Bait Uptake

Combined bait uptake for standard and cafeteria trials

Bait station response by all cats is summarized in Table 2. Figures 5 (probable uptakes categorized as visits) and 6 (includes potential uptakes, where probable uptakes categorized as uptakes) illustrate the frequencies and proportions of the various bait responses over the study period. The proportion of individuals recorded on transects that contacted bait stations (see Fig. 7) was relatively consistent throughout the study period at 62 % $\pm$ 3 % ($\mu \pm$ s.e.). Figure 7 illustrates a degree of daily fluctuation, but little in terms of any discernible trends. The proportion of contacting individuals on any given day was generally more than 50 % but rarely 100 %, and zero only once. The various categories of bait response as a percentage of individual cats contacting the bait stations, over the study period, are presented in Figs. 8 to 11. The responses by cats to the bait stations exhibit marked short-term variation. Figures 7 – 11 illustrate several examples of a particular response by 100 % of individuals that contacted a bait station on one day and 0 % of contacting individuals on the previous or subsequent day. Longer-term trends include the relative decrease in the pass response (see Fig. 8), over the study period. Conversely, the proportion of the visit response (see Fig. 9), and in turn the uptake response (see Figs. 10 and 11) increased over the study. Figures 10 and 11 also illustrate that in addition to occurring with greater frequency, the uptake response occurred with greater consistency during the later sampling periods. Bait uptake occurred on 25 % of sampling days prior to 25 January 2000 and 76 % of sampling days post this date. Baits were accepted by 6.2 % of contacting individuals prior to this date and 28.1 % of contacting individuals post this date. Therefore results from the 25 January 2000 have been isolated in subsequent analyses in an attempt to clarify potential influences on short-term variability in bait uptake.

Bait media and lure trials

Bait responses for various segments of the study period, when the bait uptake transect was separated into standard, cafeteria and cafeteria plus lure bait stations, are presented in Tables 3a and 3b. The results show that the bait responses by individual cats to the standard bait stations and cafeteria plus lure bait stations follow the same general trends over the sampling periods. However, the bait response to cafeteria stations where no lure was present did not display any increase in bait uptake over the sampling period.

Cat Activity

The cumulative and average on-track distances travelled by cats during the study period are presented in Figs. 12 and 13. On-track distances, travelled by individual cats, exhibited daily variation. The figures illustrate several examples of on-track activity that is inordinately greater or smaller than on the previous or subsequent days. The only obvious pattern in activity was that distances travelled during the January-February sampling period were consistently greater than for the other periods.

Uptake, On-track Distance and Contact Rate

A significant linear relationship exists between on-track activity and the rate of bait contact (Figs. 14 and 15, Tables 4 a and b). Days on which distances travelled were greater were those days on which a greater proportion of individuals encountered baits. Although not presented here, this trend was consistent when individual response was considered, as opposed to the proportion of individuals on a given day. That is, individuals travelling greater distances on the transect more consistently encountered baits.

No significant linear relationship exists between the rate of bait contact and the rate of bait uptake (Fig. 16, Table 4 c). Days of relatively high bait contact were not necessarily days of high bait uptake. Bait uptake was most consistent between 60 and 90 % contact, but this condition did not preclude poor bait uptake days. Bait uptake was generally poor at the extremes of contact rate and no bait uptake occurred when the contact rate was less than 40 % of individuals. Although not presented here, these trends were consistent when individual response and potential bait uptake were considered.

Non-target Bait Uptake

The mean daily bait uptake ($\mu \pm$ s.e.) by non-target species was 22 % ± 3 %. The relative frequency of uptake by the various species is illustrated in Figure 17. Corvids and Varanids were most frequently responsible for non-target bait uptake. The Torresian Crow (*Corvus orru*) and Little Crow (*C. bennetti*) were frequently sighted during the exercise and are both likely to be responsible for uptake by this family. The Sand Monitor (*Varanus gouldii*) was the most frequently observed Varanid during sampling. All tracks associated with bait uptake by this family were consistent with the numerous sub-adult *V. gouldii* sighted. However, it is possible that a small percentage of baits were taken by the Black-tailed Monitor (*V. tristis*).

Corvids more frequently took baits at the beginning of the sampling period while varanids more frequently removed baits towards the end of the sampling period. Uptake by Emus (*Dromaius novaehollandiae*) was almost always multiple takes by an individual or small group. Therefore, a relatively large proportion of uptake assigned to Emus, on any given day, did not indicate a widespread occurrence.

Tracks consistent with Spinifex Hopping Mouse (*Notomys alexis*) were noted in association with sausage baits throughout the study period. Early in the study, rodent activity was dense around baits, with some baits rolled short distances. As summer progressed, baits were moved by rodents greater distances and more frequently. By late February, some baits were moved as far as 10 m. Complete removal of baits (presumably to burrows) by *N. alexis* was first observed on 5 March. The extreme expression of this behaviour was on 6 March when 85 % of the baits presented were taken by *N. alexis.*

Rabbit Abundance

A summary of rabbit presence/absence over the study period is presented in Figure 18. The data ($\mu \pm$ s.e.) indicate that the rabbit abundance index declined markedly between the November/December (70 % ± 2 % presence) and January/February (33 % ± 3 % presence) sampling periods. The abundance index continued to decline during the latter period to <20 % presence in mid February. The abundance index increased slightly during the February/March sampling period to 28 % ± 2 % presence for the last five days of the sampling period.

Weather and Lunar Phase

Prevailing weather conditions are summarized below; "raw" weather data are available through the authors if required. Night-time weather conditions were generally warm (minimum temperatures generally >20 ^{0}C in November and >25 ^{0}C from early January onwards), humid (generally >80 %) and windy (average night-time wind speed commonly in excess of 30 km/h). Longer-term trends over the study period were for rising temperatures and falling barometric pressure. Other parameters exhibited greater short-term fluctuations, but little in terms of consistent trends. Wind direction exhibited a strong SSW tendency with very few days where the tendency was from the other seven octants. Rainfall was restricted to 7 February, when 0.4 mm was recorded and the 3–4 March when 19.1 mm was recorded. The study was terminated after 6 March 2000 because of the onset of Tropical Cyclone Steve that delivered 150.6 mm over five days. The heavy rainfall associated with the cyclone severely restricted access to the study site, as most roads became impassable.

Lunar cycles for the November/December and January/February sampling periods approximated the first gibbous-first crescent. The February/March sampling period approximated the last gibbous-new moon.

Statistical Analyses

Bait uptake

A range of weather parameters, as well as lure type and rabbit activity, potentially impacted on bait uptake during the sampling period. As indicated in Figures 10 and 11, bait uptake and potential uptake was most consistent from 25 January onwards. For this reason, results from this period were isolated in an attempt to clarify potential influences on short-term variability in bait uptake. Results for analyses performed for both actual and potential bait uptake over the entire study period and post 25 January are presented in Tables 5 – 8. The significant variables to regression model building are presented in flow diagrams (see Figs. 19 – 22). A number of temperature factors were significantly related to bait uptake over the entire sampling period (long-term weather conditions) but insignificant post 25 January, when bait uptake was a regular occurrence. The exception was fluctuations in minimum temperature, which was of significance in both the long and short-term. Of the other environmental factors, rabbit abundance had a significant relationship with bait uptake. As rabbit abundance decreased from late spring through to early autumn, there was an increase in bait uptake. Results indicate that the two most important environmental factors that affected both actual and potential bait uptake in the short-term were wind speed and fluctuations in minimum temperature. Actual and potential bait uptake tended to decrease with an increase in average wind speed, while increasing with a rise in overnight minimum temperature, from the previous day.

Bait Media and Lure Preference

Multivariate analysis of variance indicated that there was a significant preference in the cafeteria bait trial for the standard cat bait (Wilk's $\lambda = 0.80$, $p = 0.04$). Uptake of the standard bait was 64 % greater than the chicken bait and 170 % higher than the cockerel. Significance of relative uptake at stations with all the various lures was tested in the regression analysis of standard bait uptake (see Tables 7a, 8a, 9a and 10a). Note that Table 1 describes the coded variables. Uptake of standard baits was significantly more frequent in the presence of the visual lures used, as opposed to the audio lures.

Cat Activity and Bait Contact

Although not presented in Tables and Figures, results of the multivariate analyses for cat activity and contact rate indicated a temperature dependence. These measures of behaviour were respondent to the measured temperature and to changes in temperature.

DISCUSSION

Bait uptake by feral cats on Peron Peninsula displayed a high degree of short-term variability but became more frequent and consistent through late summer/early autumn. Uptake occurred on 25 % of days prior to 25 January and on 76 % of days after this date. Bait uptake was largely independent of bait contact (encounter). The percentage of individual cats encountering a bait remained relatively constant over the study period at 62 % of animals on any given night, which suggests that the current on-track baiting regime of bait placement at 100 m intervals provides an adequate baiting intensity. There was no linear relationship between bait uptake and either distance travelled or bait contact along tracks; however the distance a cat travelled influenced bait contact. Therefore, increasing on-track baiting density will increase contact rate but not necessarily bait uptake. The average daily on-track distance, travelled by individual cats, was approximately 340 m. This distance would be covered in a relatively short period of time and would represent a small proportion of a cat's daily activity cycle. Therefore the baits would not necessarily be encountered when individual cats were hungry. When the primary prey, in this case rabbits (see below) became less abundant, the chances of encountering a bait when hungry, increased. Animals that travelled relatively long distances (greater than 1,200 m), in the context of this study were, in general, not receptive to baits and their behaviour appeared focused on activity unrelated to hunger and seeking food. Zezulak and Schwab (1980) found that long-distance movements by bobcats (*Lynx rufus*) were associated with conspecific interactions, while shorter movements were associated with foraging behaviour.

Increasing the frequency of baiting is more likely to achieve a higher baiting efficacy, as fresh baits will be present at different times and thus increase the chances that cats are hungry when the baits are encountered. Increasing baiting frequency will also reduce the one-dimensional nature of on-track baiting. Road alignments at Peron are only likely to be accessed by a small proportion of the cat population at any given time. Those cats accessing roads do so for a relatively small proportion of their daily activity. This condition dictates that a very small proportion of the population will encounter baits at any one time by a track-based control measure. Increasing baiting frequency will also reduce the affect of short-term weather variables on bait uptake.

Short-term weather conditions influenced the daily variability associated with bait uptake by feral cats on Peron Peninsula. During the latter period of study when bait uptake was a regular occurrence, yet still displayed daily variability, the two most important environmental factors that affected both actual and potential bait uptake were wind speed and fluctuations in minimum temperature. The relationship between wind speed and bait uptake may be explained by bait recognition. Cat activity and rate of contact exhibited no significant relationship to wind speed. Cats were active and encountering bait stations on windy nights, but bait uptake diminished. If bait odour is important to inducing bait uptake, windy conditions will disperse this odour, reducing bait recognition and uptake. The importance of changes in minimum temperature cannot be explained but it is possible that this environmental variable is involved with a range of other factors that could not be measured or deduced to influence bait uptake.

Luminosity was only of importance to potential uptake post 25 January. However, very few bait uptake trials were conducted when luminosity was greater than two. Data collected during the first period straddled the full moon and indicated peaks in bait uptake either side of the full moon. It is therefore suggested that the influence of lunar phase on bait uptake requires further investigation.

A number of temperature factors were significantly related to bait uptake over the entire sampling period (long-term weather conditions) but insignificant post 25 January, when bait uptake was a regular occurrence. The exception to this was fluctuations in minimum temperature, which was of significance in both the short and long-term. The importance of temperature factors significant only in the long-term may reflect their relative stability over the short-term and their clear seasonal trend. The importance of the temperature variables may be an artifact of seasonal progression. However, it may be that baits were more acceptable at higher temperatures. It was noted that oils within the bait penetrated the sausage skin during warmer more humid weather. The oil itself may have increased acceptability. However, a number of the essential flavour enhancers that are added to the bait are lipid soluble. The exuding oil will have brought these substances to the surface, while they are normally encased within the skin.

Of the other environmental factors, rabbit abundance had a significant relationship with bait uptake. There was an increase in bait uptake with the decrease in rabbit abundance observed from late spring through to early autumn.

Cats throughout history have been relied on as meteorological almanacs as they display behaviour responses to short-term weather patterns (De Wire 1992). A number of authors have studied the correlation between short-term physical parameters and behaviour of smaller felids (Langham 1992 cats; Zezulak and Schwab 1980 bobcats; Beltran and Delibes 1994 Iberian lynx, *Lynx pardinus*, Schmidt 1999 Eurasian lynx, *Lynx lynx*; Avenant and Nel 1998 caracals, *Felis caracal* and Daniels *et al.* 2001 wildcats, *Felis silvestris*). A cause and effect relationship is difficult to establish, however felid activity has been found to be correlated with a number of biotic and abiotic environmental factors. Authors variously attribute the response as a combination of maintaining homeostasis (avoidance of extreme conditions) and response to patterns in prey behaviour and apparent availability.

Avenant and Nel (1998) found ambient temperature the most significant correlate with caracal behaviour. Caracals avoided temperatures greater than 20° C, probably to assist with water conservation. Beltran and Delibes (1994) found a range of short-term weather parameters to influence lynx behaviour and the most important factor varied with seasons. Lynx avoided extreme temperatures and juveniles appeared to be more strongly influenced by weather than adults. Lynx activity was synchronized to that of their primary prey (rabbits). Lynx were active for longer during strong moonlight but did not necessarily move further. Schmidt (1999) found little response by lynx except that they avoided heavy rain and strong wind. Activity was more closely related to the success of procuring primary prey with activity being greater when foraging was less successful. Daniels *et al.* (2001) found little evidence of short-term weather influence on wildcat activity except that they avoided strong wind and were significantly less active during low moonlight. Zezulak and Schwab (1980) found bobcats to avoid extremes of temperature and that peak activity was synchronized with that of their primary prey. Langham (1992) indicated that cat foraging activity was an important component of overall behaviour. When and where cats foraged was related to the relative activity/abundance of various prey species. In canids, Molsher *et al.* (2000) found foxes to predate less mammals during moonlit nights and related this to 'behavioural resource depression'. Prey species modify behaviour in an attempt to balance successful foraging and the risk of predation (Leaver and Daly 2003; Brown and Kotler 2004). In Molsher's *et al.* study, foxes predated alternative food sources during full moon in response to an apparent decline in the availability of their primary prey.

Analysis of stomach contents from cats captured on the peninsula has indicated that rabbits are the main dietary item, however the importance of rabbits as prey varies seasonally (Project Eden unpub. data). This is consistent with studies elsewhere (e.g. Coman and Brunner 1972; Bayly 1976, 1978; Jones 1977; Fitzgerald and Karl 1979; Jones and Coman 1981; Catling, 1988; Jones and Coman, 1981; Martin *et al.* 1996; Molsher *et al.* 1999; Risbey *et al*, 1999; Read and Bowen 2001; Pontier *et al.* 2002; Malo *et al.* 2004). Optimizing predatory cats prefer rabbits to small rodents, when both are equally available. This is because it is more efficient to hunt and obtain a single young rabbit than pursue a number of rodents to achieve the same food intake (Kitchener 1991; Carbone *et al.* 1999). However in the absence or extreme low abundance of such a significant primary prey source, cats exhibit a considerable dietary breadth as they are able to capitalize on a variety of prey sources (Martin *et al.* 1996; Catling 1998; Molsher *et al.* 1999; Risbey *et al.* 1999; Read and Bowen 2001; Paltridge 2002). This functional shift to predating secondary prey sources only occurs after a significant decline in primary prey (Norbury *et al.* 1998).

The seasonal decline in this primary prey species for cats on Peron was consistent with the increase in bait uptake from mid-January onwards. Baiting efficacy for feral cats is therefore strongly linked to the seasonal availability of primary prey species, particularly the rabbit as was found by Short *et al.* (1997). The natural, seasonal rabbit population cycle was sufficient to elicit a functional shift to include consumption of baits as an alternative prey. Rabbit abundance, especially the incidence of predator vulnerable young rabbits in the prey population, is a function of season. Rabbit breeding in this environment occurs immediately following the onset of significant rainfall and will also occur following summer rains (King *et al.* 1983). The gestation period of a rabbit is approximately 30 days and thus prey availability can increase rapidly following rain. Young rabbits and emergent rabbit kittens are present in the population until late spring/early summer. The abundance of rabbits tends to decline through summer and autumn and this may be significantly affected by summer epizootics of mosquito-vectored myxomatosis. Baiting efforts should be maximized during seasonal declines in rabbit abundance, the "baiting window". Control of rabbit populations, most likely through assisting the development and transmission of myxomatosis epizootics and introduction of a virulent strain of RHD, is likely to both increase the magnitude of bait response and broaden the 'baiting window'.

Timing of baiting for feral cats is fundamental. Consistent uptake is more important than any individual result. Routine and regular bait uptake exercises should be conducted when the onset of uptake is expected. Consistent bait uptake can be expected as rabbit abundance declines. On Peron Peninsula, this period, the "baiting window", will usually occur from December through to May, depending on the significance of summer rainfall events and timing of rabbit breeding. Resources should be focused on capitalizing on this period of most efficacious baiting. This study suggests that baiting is not likely to be effective outside this period. In the arid zone where rainfall is unreliable, the time and intensity of rainfall events such as cyclones and thunderstorms will determine the abundance of live prey (eg. King *et al.* 1983; Morton 1990). A difference in bait uptake across geographic areas, when conducted at the same time of year, may reflect differences in prey availability.

The standard cat bait was the most preferred bait medium in the cafeteria trials, with the dead day old cockerel being least preferred. The preference for the standard cat bait in this study follows that demonstrated in exhaustive laboratory and field trials where the standard bait has been compared against a variety of bait media (Algar unpub. data). These cafeteria trials, where the acceptability of various individual constituents was assessed, have been instrumental in the development of the standard cat bait.

Only two individual cats consumed a dead day-old cockerel, and both also consumed the standard cat bait. Interestingly, both these occurrences took place on the coastal transect. Control programs conducted elsewhere using this medium have been on islands where breeding colonies of birds have been present (Brothers 1982; Twyford *et al.* 2000; Bester *et al.* 2002). These sites may have presented the situation where chickens closely resembled prey items to which they had previously been exposed. A period of free feeding prior to toxic presentation by Twyford *et al.* (2000) may also have improved bait acceptance as familiarity with food items is known to increase their acceptance (Bradshaw 1986). Use of laboratory mice by Short *et al.* (1997) may have better approximated "familiar naturally occurring prey" for Peron Peninsula, but their availability as a bait medium for large-scale operational baiting programs and cost precluded their use here.

The percentage of contacting cats that consumed a bait at standard bait stations was significantly greater than for those that contacted cafeteria stations. Presentation of baits in cafeteria stations is unlikely to have deterred cats from bait uptake, as this has not been noted previously in cafeteria trials (Algar unpub. data). It is suggested that the presence of the dead chicken may have discouraged bait consumption as this is the only obvious difference (at least to human senses) between the two bait station types. This effect appeared to be negated in the presence of visual lures.

The use of lures significantly improved bait uptake in the cafeteria trials. The contact rate did not differ between audio and visual lures, however a higher bait uptake was observed at sites with a visual lure. Observations of domestic cat behaviour suggest that certain stimuli will attract at a distance but act as a deterrent at close proximity (Algar unpub. data). The types of audios used may have brought about this reaction and thus not provided a suitable situation for bait recognition and consumption.

Deployment of visual lures at bait stations has been shown to improve bait uptake in other studies (Friend and Algar 1995; Algar and Sinagra 1995). The constant and inanimate nature of visual lures may leave cats more comfortable for close examination and better recognition of baits and the confidence to sit and eat. The exception in this study was the rodent lure; this relatively large object may have been considered threatening. The range of visual lures tested to date is not exhaustive and there is potential for considerable improvement in their design and function.

Activity by non-target species complicates the accurate assessment of bait uptake by feral cats and can sometimes preclude the assigning of uptake to a particular species. Bait uptake by non-target species during this study was almost exclusively by those of diurnal habit. Thus the rate of recorded non-target uptake was principally limited by the length of time baits were available during daylight hours. That is, the time between bait placement and sunset and the time between sunrise and transect inspection. As bait placement was completed close to sunset, the morning hours were the period of greatest non-target uptake. This is supported by the fact that the uptake recorded was significantly greater towards the end of each transect and that any delays experienced during inspection magnified this effect. Therefore the level of recorded non-target uptake does not necessarily reflect any real trends in non-target response.

Rainfall on the 3 and 4 March delayed transect assessment until 1300 h. This sample has been excluded from the study of uptake by feral cats but serves as a useful indication of non-target uptake. Just 19 hours after bait placement, non-targets (principally Varanids in this case) had consumed more than 80 % of baits.

The level of non-target uptake may have been exacerbated by the sampling methods and/or prevailing seasonal conditions. However, non-target species potentially impact greatly on baiting efficacy. It is possible that the impact of non-target uptake during the study was amplified by a certain level of learnt behaviour. That is, bait placement on the various transects allowed association between transect alignment and/or vehicular activity and the presence of a highly palatable food source. Vehicular activity, in itself, often creates a focus of activity for carrion-eaters as (particularly when drags are used) it regularly results in the death of invertebrates, slower-moving Agamids and Skinks, as well as fossorial reptiles. Uptake by varanids may have been unusually high due to a particularly successful breeding event by *Varanus gouldii*. The numerous individuals observed daily were generally of a common cohort, less than one year old. Sightings and tracks of mature adults were relatively uncommon. Interest in the bait medium by rodents (most particularly *Notomys alexis*), has been noted previously at Peron, as well as at other study sites. The complete removal and presumed consumption of baits has not been noted previously. Although purely circumstantial, indications are that this behaviour may have been in response to the approach of Tropical Cyclone Steve.

Non-target activity may impact significantly upon baiting efficacy. Sufficient baiting density and frequency will allow for the removal of baits by non-targets. Increasing baiting density may not result in a greater number of baits available to cats. Replacing baits taken by more frequent baiting may be the only answer. Placing baits slightly off road alignments and laying bait as late as possible in the afternoon may reduce non-target uptake. There is little scope for altering the timing of baiting programs to reduce non-target uptake. The principal determinant to the timing of baiting programs is when baits are most likely to be accepted by cats.

In summary, bait uptake by feral cats on Peron Peninsula in the long-term is driven by the abundance of primary prey (rabbits). Subsequent baiting exercises (Algar and Angus 2000b; Algar and Burrows 2004) comparing campaigns on Peron with sites where rabbits were absent or in low numbers, have confirmed the significance of rabbit abundance in determining bait uptake. Reduction of rabbit abundance on the peninsula will improve bait acceptance and extend the period of effective baiting. In the short term, conducting baiting programs around the full moon may provide potential peaks in bait uptake, while baiting under conditions of strong wind should be avoided. Operationally, the efficacy of on-track baiting during the "baiting window" will be improved by employing visual lures and increasing baiting frequency rather than density.

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Table 1
Potential predictor variables

no	Variable	Description
1	Temp	average temperature
2	Wetb	average wetbulb temperature
3	Dwpt	average dew point
4	RH	average relative humidity
5	Msl	average pressure
6	DIR	average wind direction
7	Kmh	average wind speed
8	CldCode	average cloud cover coded into one of two categories : 0 = greater than 0 inclusive and less than 1 1 = greater than 1 inclusive
9	Luminosity	average luminosity
10	MslRF	rise/fall of average pressure 0 = average pressure is greater/steady from the previous day 1 = average pressure is less than the previous day
11	TempMax	max temperature
12	WetbMax	max wetbulb temperature
13	TempMin	min temperature
14	WetbMin	min wetbulb temperature
15	TMaxRF	rise/fall of max temperature 0 = max temperature is greater/steady from the previous day 1 = max temperature is less than the previous day
16	TMinRF	rise/fall of min temperature 0 = min temperature is greater/steady from the previous day 1 = min temperature is less than the previous day
17	WMaxRF	rise/fall of max wetbulb temperature 0 = max wetbulb temperature is greater/steady from the previous day 1 = max wetbulb temperature is less than the previous day
18	WMinRF	rise/fall of min wetbulb temperature 0 = min wetbulb temperature is greater/steady from the previous day 1 = min wetbulb temperature is less than the previous day
19	Lure Type	coded into one of six categories : 1 = bird 2 = rabbit 3 = reptile 4 = rodent 5 = tinsel 6 = other (excluded from the study)
20	audio/visual	coded into one of three categories : 0 = audio (bird, rabbit) 1 = visual (reptile, rodent, tinsel) 2 = other (excluded from the study)
21	Rabbit activity	coded into one of four categories : 0 = between 0 and 25 percentage presence inclusive 1 = greater than 25 and less than 50 percentage presence inclusive 2 = greater than 50 and less than 75 percentage presence inclusive 3 = greater than 75 percentage presence

Table 2

Summary of bait station responses.

DATE	Transect length (km)	Total No. cats	Cats/ 100 km	Bait contacts	Pass	Visit	Uptake
19/11/1999	38.5	9	23.4	7	4	3	
20/11/1999	33.6	8	23.8	6	6		
21/11/1999	37.5	11	29.3	7		3	4
24/11/1999	40	10	25.0	5	4	1	
25/11/1999	20	9	45.0	4	2	2	
26/11/1999	16.5	11	66.7	9	3	5	1
27/11/1999	19	6	31.6	4	1	3	
28/11/1999	20	7	35.0	5	3	2	
30/11/1999	20	4	20.0	0			
12/01/1999	19	6	31.6	1	1		
12/02/1999	16.1	7	43.5	5	4	1	
12/04/1999	10	5	50.0	3		2	1
12/05/1999	18.8	11	58.5	10	5	4	1
12/06/1999	16	8	50.0	3	2	1	
12/07/1999	16	11	68.8	6	3	2	1
12/10/1999	19.5	9	46.2	6	1	5	
12/11/1999	17	8	47.1	6	1	5	
12/12/1999	18	8	44.4	6	2	4	
13/12/1999	20	9	45.0	5		4	1
18/1/2000	19.2	8	41.7	5	1	4	
19/1/2000	20	11	55.0	6	4	2	
20/1/2000	15.7	5	31.8	2		2	
21/1/2000	10	3	30.0	1	1		
25/1/2000	19.7	9	45.7	9	3	5	1
26/1/2000	16.8	12	71.4	8	1	6	1
27/1/2000	18	10	55.6	8		3	5
28/1/2000	19.5	9	46.2	8	2	5	1
2/01/2000	19	7	36.8	5	1	1	3
2/02/2000	12.3	5	40.7	3		1	2
2/03/2000	15.6	9	57.7	2	2		
2/04/2000	16	8	50.0	7		4	3
2/07/2000	20	9	45.0	6		3	3
2/08/2000	16.8	6	35.7	4	1	3	
2/09/2000	17.5	10	57.1	10	1	7	2
2/10/2000	18.9	11	58.2	7	1	5	1
23/2/2000	15.9	7	44.0	2		2	
24/2/2000	15.5	10	64.5	5	1	1	3
25/2/2000	14.6	10	68.5	6	2	3	1
26/2/2000	15.6	10	64.1	5		4	1
29/2/2000	10	4	40.0	3		1	2
3/01/2000	10	4	40.0	4		2	2
3/02/2000	10	6	60.0	4		4	
3/05/2000	18	8	44.4	6	1	5	
3/06/2000	15.4	9	58.4	4	2	1	1

Table 3a

Summary of responses by contacting individuals to bait station type; potential uptake categorised as visit.

SAMPLING PERIOD	PASS			VISIT			UPTAKE		
	S	C	C/L	S	C	C/L	S	C	C/L
Pre 25.01.2000	51%	67%	33%	43%	25%	59%	5%	8%	7%
Post 25.01.2000	15%	42%	14%	58%	49%	57%	26%	9%	29%
Entire sampling period	33%	53%	23%	51%	38%	58%	16%	9%	19%

Table 3b

Summary of responses by contacting individuals to bait station type; potential uptake categorised as uptake.

SAMPLING PERIOD	PASS			VISIT			UPTAKE		
	S	C	C/L	S	C	C/L	S	C	C/L
Pre 25.01.2000	51%	67%	33%	40%	22%	52%	9%	11%	15%
Post 25.01.2000	15%	42%	14%	48%	44%	46%	36%	14%	40%
Entire sampling period	33%	53%	23%	44%	34%	48%	22%	13%	29%

S= standard bait station
C= cafeteria station
C/L= cafeteria station with lure

Table 4a

ANOVA summary, contact v cumulative distance travelled.

Regression Statistics	
Multiple R	0.52403546
R Square	0.27461317
Adjusted R Square	0.25734205
Standard Error	18.7997655
Observations	44

ANOVA

	df	SS	MS	F	Significance F
Regression	1	5619.605699	5619.606	15.90014	0.000261355
Residual	42	14844.10975	353.4312		
Total	43	20463.71545			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	48.4877724	4.504696599	10.76383	1.19E-13	39.39692375	57.57862	39.39692375	57.57862107
Tot distance	0.00741126	0.001858624	3.987498	0.000261	0.003660404	0.011162	0.003660404	0.011162117

Table 4b

ANOVA summary, contact v mean distance travelled.

Regression Statistics	
Multiple R	0.53545526
R Square	0.28671234
Adjusted R Square	0.2697293
Standard Error	18.6423199
Observations	44

ANOVA

	df	SS	MS	F	Significance F
Regression	1	5867.199685	5867.2	16.88227	0.000180167
Residual	42	14596.51576	347.5361		
Total	43	20463.71545			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	47.7658261	4.546436099	10.50621	2.52E-13	38.59074369	56.94091	38.59074369	56.94090851
Ave distance	0.06397377	0.015569922	4.108805	0.00018	0.032552382	0.095395	0.032552382	0.095395152

Table 4c

ANOVA summary, rate of bait uptake v rate of contact.

Regression Statistics	
Multiple R	0.27163556
R Square	0.07378588
Adjusted R Square	0.05173316
Standard Error	22.0464748
Observations	44

ANOVA

	df	SS	MS	F	Significance F
Regression	1	1626.257978	1626.258	3.3458859	0.074478894
Residual	42	20413.9761	486.0471		
Total	43	22040.23408			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-0.80920079	10.18217911	-0.07947	0.9370345	-21.35767664	19.739275	-21.3576766	19.7392751
%Contacts	0.2819048	0.15411571	1.829176	0.0744789	-0.02911339	0.592923	-0.02911339	0.592923

Table 5a

Estimated coefficients and standard errors for univariate logistic regressions of bait uptake (entire sampling period).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Temp	0.1970	0.0679	8.4228	0.0037
TempMax	0.0736	0.0448	2.6940	0.1007
TempMin	0.1783	0.0608	8.5904	0.0034
TMaxRF	-0.2094	0.3540	0.3500	0.5541
TMinRF	0.4660	0.3545	1.7275	0.1887
Wetb	0.2507	0.0803	9.7546	0.0018
WetbMax	0.1688	0.0772	4.7787	0.0288
WetbMin	0.2417	0.0752	10.3306	0.0013
WMaxRF	0.3961	0.3579	1.2247	0.2684
WMinRF	-0.0040	0.3532	0.0001	0.9910
RH	0.0218	0.0312	0.4895	0.4841
Msl	-0.0225	0.0554	0.1647	0.6848
MslRF	-0.1361	0.3556	0.1465	0.7019
DIR	-0.0053	0.0050	1.1489	0.2838
Kmh	-0.0078	0.0167	0.2157	0.6423
CldCode	0.4566	0.3552	1.6521	0.1987
Luminosity	-0.0672	0.0745	0.8142	0.3669
Dwpt	0.2427	0.0776	9.7839	0.0018
Lure type				
Rabbit	0.5596	0.5674	0.9726	0.3240
Reptile	0.8091	0.5504	2.1605	0.1416
Rodent	1.2246	0.6859	3.1879	0.0742
Tinsel	0.5419	0.5817	0.8679	0.3515
Audio/Visual	0.4811	0.3612	1.7742	0.1829
Rabbit activity				
Rabbit-25-50	0.3883	0.4433	0.7674	0.3810
Rabbit-50-75	-2.1748	0.6817	10.1772	0.0014
Rabbit-75+	-0.0953	0.5777	0.0272	0.8690

Table 5b

Estimated coefficients and standard errors for 1st multivariate logistic regression of bait uptake (entire sampling period).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Intercept	5.3408	7.1412	0.5593	0.4545
Temp	0.1970	0.0679	8.4228	0.0037
Temp	2.4359	1.8045	1.8223	0.1770
TempMax	0.0807	0.1435	0.3163	0.5739
TempMin	0.0229	0.4392	0.0027	0.9584
TMinRF	1.1195	0.5416	4.2722	0.0387
Wetb	-7.3351	4.8434	2.2935	0.1299
WetbMax	-0.4092	0.3086	1.7575	0.1849
WetbMin	0.1349	0.4126	0.1069	0.7437
CldCode	-0.3394	0.5279	0.4134	0.5202
Dwpt	4.7386	3.0353	2.4372	0.1185
Audio/Visual	1.0527	0.5108	4.2473	0.0393
Rabbit activity				
Rabbit-25-50	1.2285	0.6205	3.9195	0.0477
Rabbit-50-75	-1.6147	0.9528	2.8718	0.0901
Rabbit-75+	0.9578	0.9999	0.9175	0.3381

Table 5c

Estimated coefficients and standard errors for 2nd multivariate logistic regression of bait uptake (entire sampling period).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Intercept	4.2874	6.3999	0.4488	0.5029
Temp	2.4605	1.5501	2.5195	0.1124
TMinRF	0.9695	0.4633	4.3789	0.0364
Wetb	-7.2067	4.5402	2.5195	0.1124
WetbMax	-0.2360	0.2237	1.1130	0.2914
Dwpt	4.6908	2.7777	2.8518	0.0913
Audio/Visual	1.0250	0.4653	4.8523	0.0276
Rabbit activity				
Rabbit-25-50	1.1958	0.5670	4.4477	0.0349
Rabbit-50-75	-1.5756	0.8543	3.4012	0.0652
Rabbit-75+	1.0821	0.8265	1.7144	0.1904

Table 5d

Estimated coefficients and standard errors for 3rd multivariate logistic regression of bait uptake (entire sampling period).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Intercept	3.3872	6.3629	0.2834	0.5945
Temp	2.1673	1.5420	1.9755	0.1599
TMinRF	0.9394	0.4561	4.2426	0.0394
Wetb	-6.9871	4.6246	2.2827	0.1308
Dwpt	4.5808	2.8405	2.6007	0.1068
Audio/Visual	0.9177	0.4480	4.1958	0.0405
Rabbit activity				
Rabbit-25-50	0.9879	0.5296	3.4794	0.0621
Rabbit-50-75	-1.8427	0.8149	5.1132	0.0237
Rabbit-75+	0.8372	0.7881	1.1283	0.2881

Table 6a

Estimated coefficients and standard errors for univariate logistic regressions of bait uptake (post 25.1.2000).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Temp	0.0153	0.1072	0.0205	0.8863
TempMax	-0.0316	0.0574	0.3035	0.5817
TempMin	0.0027	0.1024	0.0007	0.9791
TMaxRF	0.2578	0.4307	0.3584	0.5494
TMinRF	0.8481	0.4376	3.7566	0.0526
Wetb	0.0913	0.1255	0.5290	0.4670
WetbMax	-0.0789	0.1192	0.4385	0.5078
WetbMin	0.0703	0.1105	0.4050	0.5245
WMaxRF	0.9510	0.4496	4.4739	0.0344
WMinRF	0.0104	0.4335	0.0006	0.9808
RH	0.0611	0.0441	1.9232	0.1655
Msl	0.1289	0.0801	2.5887	0.1076
MslRF	-0.5081	0.4362	1.3567	0.2441
DIR	0.0013	0.0070	0.0346	0.8524
Kmh	-0.0228	0.0196	1.3445	0.2462
CldCode	0.6035	0.4337	1.9366	0.1640
Luminosity	-0.0592	0.1209	0.6243	0.6243
Dwpt	0.1212	0.1174	1.0665	0.3017
DwptTemp	-0.2449	0.1944	1.5859	0.2079
Lure type				
Rabbit	0.7684	0.6680	1.3230	0.2501
Reptile	1.2186	0.6725	3.2830	0.0700
Rodent	0.0000			
Tinsel	1.0561	0.7126	2.1964	0.1383
Audio/Visual	0.6844	0.4351	2.4748	0.1157
Rabbit activity				
Rabbit-25-50	0.4925	0.4512	1.1912	0.2751
Rabbit-50-75	-0.9220	1.1156	0.6831	0.4085
Rabbit-75+	0.0000			

Table 6b

Estimated coefficients and standard errors for 1st multivariate logistic regression of bait uptake (post 25.1.2000).

n = 19

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Intercept	-2.2222	118.5	0.0004	0.985
TMinRF	1.1595	0.7473	2.4073	0.1208
WMaxRF	0.2409	0.4997	0.2324	0.6298
RH	0.4356	0.4335	1.0095	0.315
Msl	-0.0366	0.1134	0.1041	0.747
MslRF	0.2621	0.5531	0.2246	0.6355
Kmh	-0.0682	0.0311	4.8161	0.0282
CldCode	-0.0963	0.5757	0.028	0.8672
DwptTemp	1.4649	1.9083	0.5893	0.4427

Table 6c

Estimated coefficients and standard errors for 2nd multivariate logistic regression of bait uptake (post 25.1.2000).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Intercept	0.7759	0.6188	1.5725	0.2099
TMinRF	1.2860	0.5215	6.0807	0.0137
Kmh	-0.0571	0.0237	5.7977	0.0160

Table 7a

Estimated coefficients and standard errors for univariate logistic regressions of potential bait uptake (entire sampling period).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Temp	0.2339	0.0603	15.0412	0.0001
TempMax	0.1330	0.0399	11.1175	0.0009
TempMin	0.1884	0.0527	12.7888	0.0003
TMaxRF	-0.3863	0.3017	1.6391	0.2005
TMinRF	0.0987	0.3029	0.1062	0.7445
Wetb	0.2802	0.0701	15.9824	0.0001
WetbMax	0.2626	0.0697	14.1744	0.0002
WetbMin	0.2492	0.0645	14.9392	0.0001
WMaxRF	0.2195	0.3007	0.5326	0.4655
WMinRF	0.2848	0.3015	0.8922	0.3449
RH	0.0092	0.0261	0.1230	0.7258
Msl	-0.0467	0.0472	0.9806	0.3220
MslRF	0.3837	0.3009	1.6269	0.2021
DIR	-0.0069	0.0042	2.6296	0.1049
Kmh	0.0005	0.0141	0.0011	0.9731
CldCode	0.2311	0.3041	0.5776	0.4473
Luminosity	-0.0691	0.0625	1.2195	0.2695
Dwpt	0.2590	0.0670	14.9428	0.0001
Lure type				
Rabbit	0.2877	0.4241	0.4600	0.4976
Reptile	-0.0918	0.4415	0.0432	0.8353
Rodent	0.3747	0.5910	0.4020	0.5261
Tinsel	-0.1766	0.4595	0.1477	0.7007
Audio/Visual	-0.1913	0.3000	0.4066	0.5237
Rabbit activity				
Rabbit-25-50	0.1976	0.4023	0.2412	0.6233
Rabbit-50-75	-1.1173	0.4224	6.9965	0.0082
Rabbit-75+	-0.7187	0.5546	1.6792	0.1950

Table 7b

Estimated coefficients and standard errors for 1st multivariate logistic regression of potential bait uptake (entire sampling period).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Intercept	4.1011	5.9497	0.4751	0.4906
Temp	2.0395	1.5544	1.7217	0.1895
TempMax	-0.0231	0.1291	0.0319	0.8582
TempMin	-0.5925	0.3303	3.2175	0.0729
TMaxRF	-0.4439	0.5730	0.6002	0.4385
Wetb	-4.9975	3.9018	1.6405	0.2003
WetbMax	-0.0558	0.2486	0.0505	0.8223
WetbMin	-0.1727	0.3250	0.2824	0.5952
MslRF	0.3541	0.4551	0.6054	0.4365
DIR	-0.0189	0.0086	4.8756	0.0272
Dwpt	3.7738	2.4628	2.3479	0.1254
Rabbit-25-50	0.3431	0.6284	0.2981	0.5851
Rabbit-50-75	-0.7667	0.7135	1.1546	0.2826
Rabbit-75+	0.3245	0.9236	0.1234	0.7253

Table 7c

Estimated coefficients and standard errors for 2nd multivariate logistic regression of potential bait uptake (entire sampling perid).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Intercept	-3.4911	4.6711	0.5586	0.4548
Temp	0.5079	1.2554	0.1637	0.6858
TempMin	-0.4000	0.2656	2.2682	0.1321
Wetb	-0.7923	3.4047	0.0542	0.8160
DIR	-0.0159	0.0066	5.7479	0.0165
Dwpt	0.9553	2.0851	0.2099	0.6468

Table 7d

Estimated coefficients and standard errors for 3rd multivariate logistic regression of potential bait uptake (entire sampling period).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Intercept	-4.4556	1.7349	6.5959	0.0102
TempMin	0.1776	0.0541	10.7584	0.0010
DIR	-0.0033	0.0045	0.5489	0.4588

Table 7e

Estimated coefficients and standard errors for 4th multivariate logistic regression of potential bait uptake (entire sampling period).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Intercept	-5.3608	1.2653	17.9519	0.0001
TempMin	0.1884	0.0527	12.7888	0.0003

Table 8a

Estimated coefficients and standard errors for univariate logistic regressions of potential bait uptake (post 25.1.2000).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Temp	0.1143	0.0988	1.3377	0.2474
TempMax	0.0471	0.0515	0.8379	0.3600
TempMin	0.0458	0.0935	0.2394	0.6246
TMaxRF	0.0057	0.3933	0.0002	0.9884
TMinRF	0.5781	0.3985	2.1047	0.1469
Wetb	0.2456	0.1182	4.3188	0.0377
WetbMax	0.1146	0.1075	1.1379	0.2861
WetbMin	0.1860	0.1036	3.2238	0.0726
WMaxRF	0.6190	0.3969	2.4329	0.1188
WMinRF	0.1797	0.3963	0.2055	0.6503
RH	0.0868	0.0407	4.5543	0.0328
Msl	0.0654	0.0738	0.7848	0.3757
MslRF	0.0625	0.3918	0.0255	0.8732
DIR	0.0059	0.0064	0.8540	0.3554
Kmh	-0.0251	0.0178	1.9939	0.1579
Cldcode	0.6690	0.3987	2.8159	0.0933
Luminosity	-0.1567	0.1124	1.9459	0.1630
Dwpt	0.2708	0.1114	5.9035	0.0151
DwptTemp	-0.3064	0.1758	3.0382	0.0813
Lure type				
Rabbit	0.3483	0.5301	0.4317	0.5112
Reptile	<0.0000	0.5636	0.0000	1.0000
Rodent	0.0000			
Tinsel	0.2429	0.5944	0.1671	0.6827
Audio/Visual	-0.0864	0.3946	0.0479	0.8267
Rabbit activity				
Rabbit-25-50	0.3448	0.4116	0.7017	0.4022
Rabbit-50-75	-0.1591	0.7703	0.0426	0.8364
Rabbit-75+	0.0000			

Table 8b

Estimated coefficients and standard errors for 1st multivariate logistic regression of potential bait uptake (post 25.1.2000).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Intercept	-258.1000	120.2000	4.6124	0.0317
Temp	16.7044	7.9388	4.4275	0.0354
TMinRF	1.5421	0.6843	5.0791	0.0242
Wetb	-14.1321	9.6640	2.1384	0.1437
WetbMin	-0.5350	0.6030	0.7871	0.3750
WMaxRF	0.7901	0.5996	1.7364	0.1876
RH	2.9220	1.3562	4.6423	0.0312
Kmh	-0.0728	0.0290	6.3096	0.0120
CldCode	-1.0295	0.9192	1.2543	0.2627
Luminosity	0.5964	0.3193	3.4880	0.0618
Dwpt	-2.9652	5.7011	0.2705	0.6030

Table 8c

Estimated coefficients and standard errors for 2nd multivariate logistic regression of potential bait uptake (post 25.1.2000).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Intercept	-173.1000	89.8462	3.7105	0.0541
Temp	12.5683	6.9222	3.2965	0.0694
TMinRF	1.1857	0.5726	4.2877	0.0384
Wetb	-13.5533	7.5478	3.2244	0.0725
WMaxRF	0.4958	0.5284	0.8806	0.3480
RH	2.0645	1.0848	3.6220	0.0570
Kmh	-0.0665	0.0284	5.4748	0.0193
Luminosity	0.3902	0.2384	2.6782	0.1017

Table 8d

Estimated coefficients and standard errors for 3rd multivariate logistic regression of potential bait uptake (post 25.1.2000).

Variable	Parameter Estimate	Estimated Standard error	Wald Statistic	P - value
Intercept	-174.2000	92.4315	3.5529	0.0594
Temp	12.5600	7.1126	3.1183	0.0774
TMinRF	1.3020	0.5684	5.2465	0.0220
Wetb	-13.5023	7.7529	3.0331	0.0816
RH	2.0672	1.1152	3.4358	0.0638
Kmh	-0.0606	0.0277	4.7891	0.0286
Luminosity	0.3768	0.2407	2.4499	0.1175

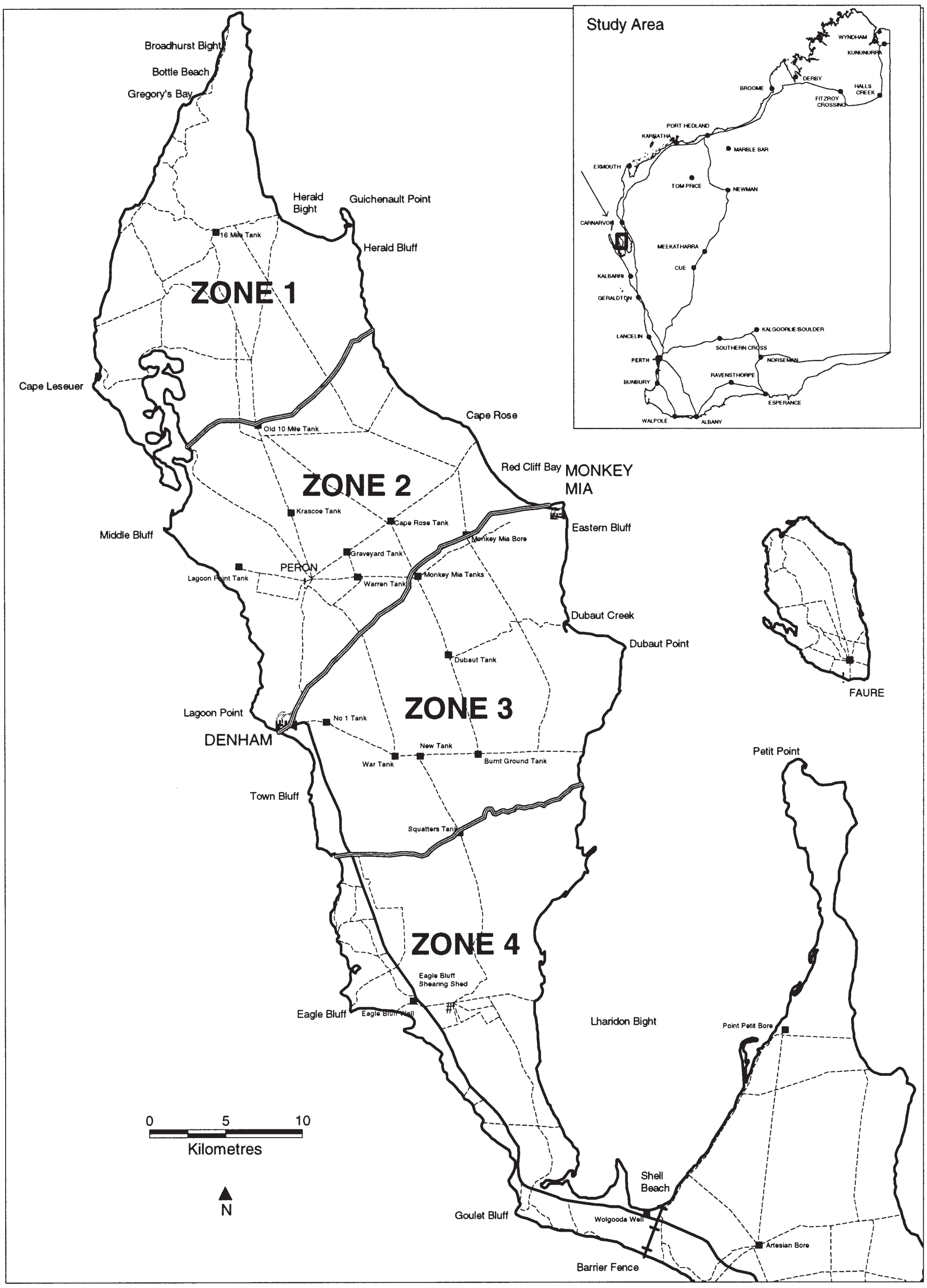

Figure 1. Peron Peninsula.

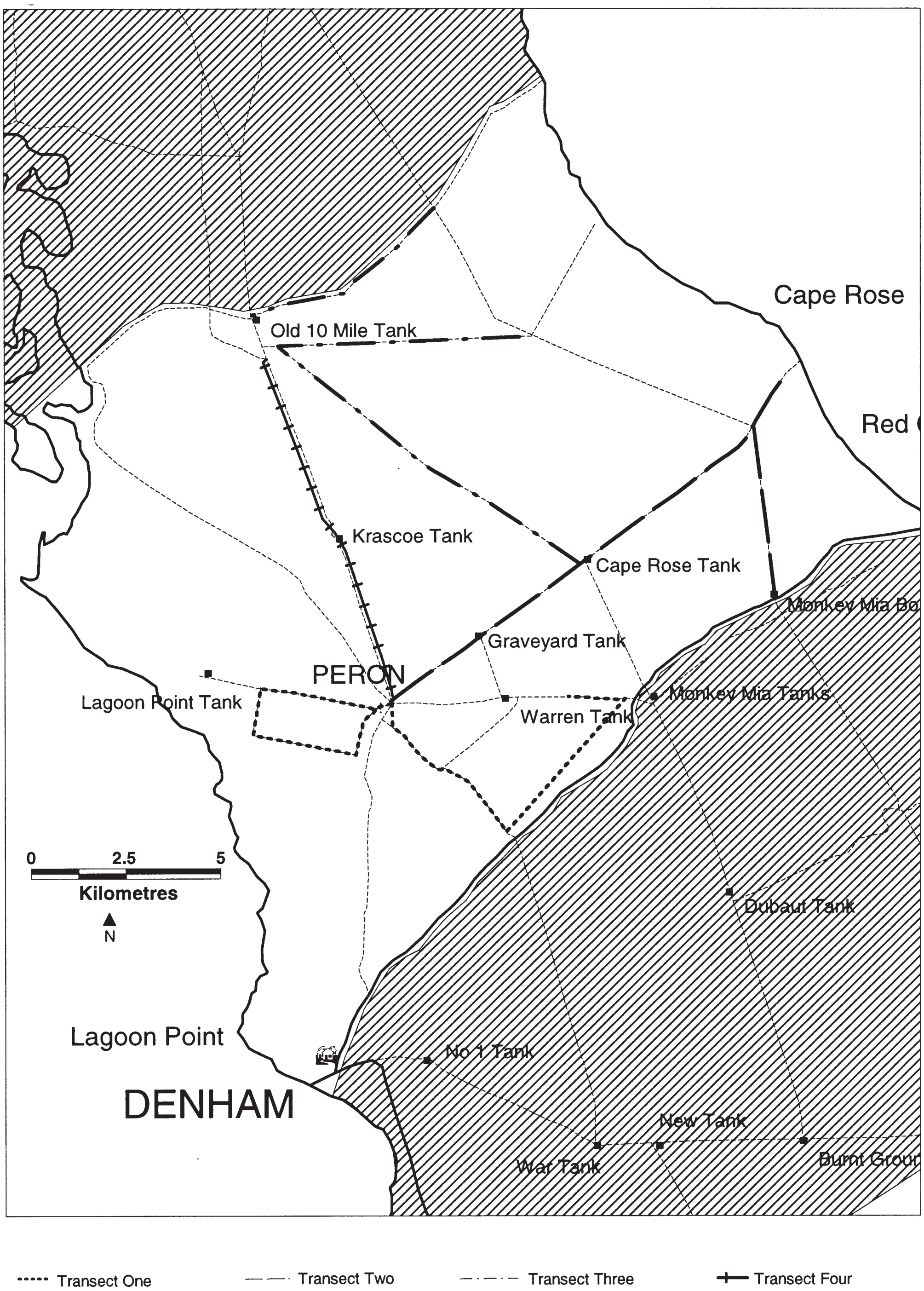

Figure 2. Zone Two.

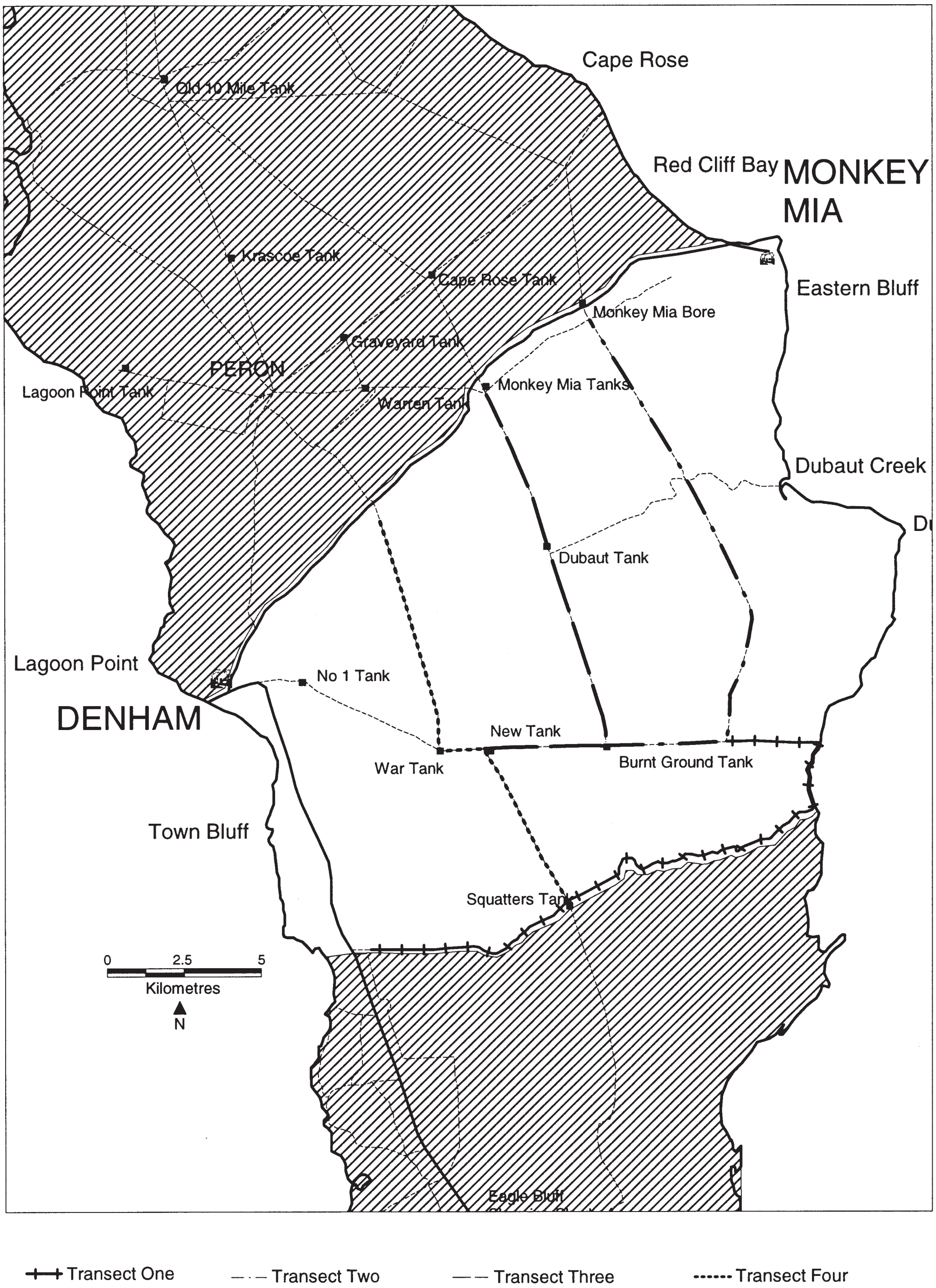

Figure 3. Zone Three.

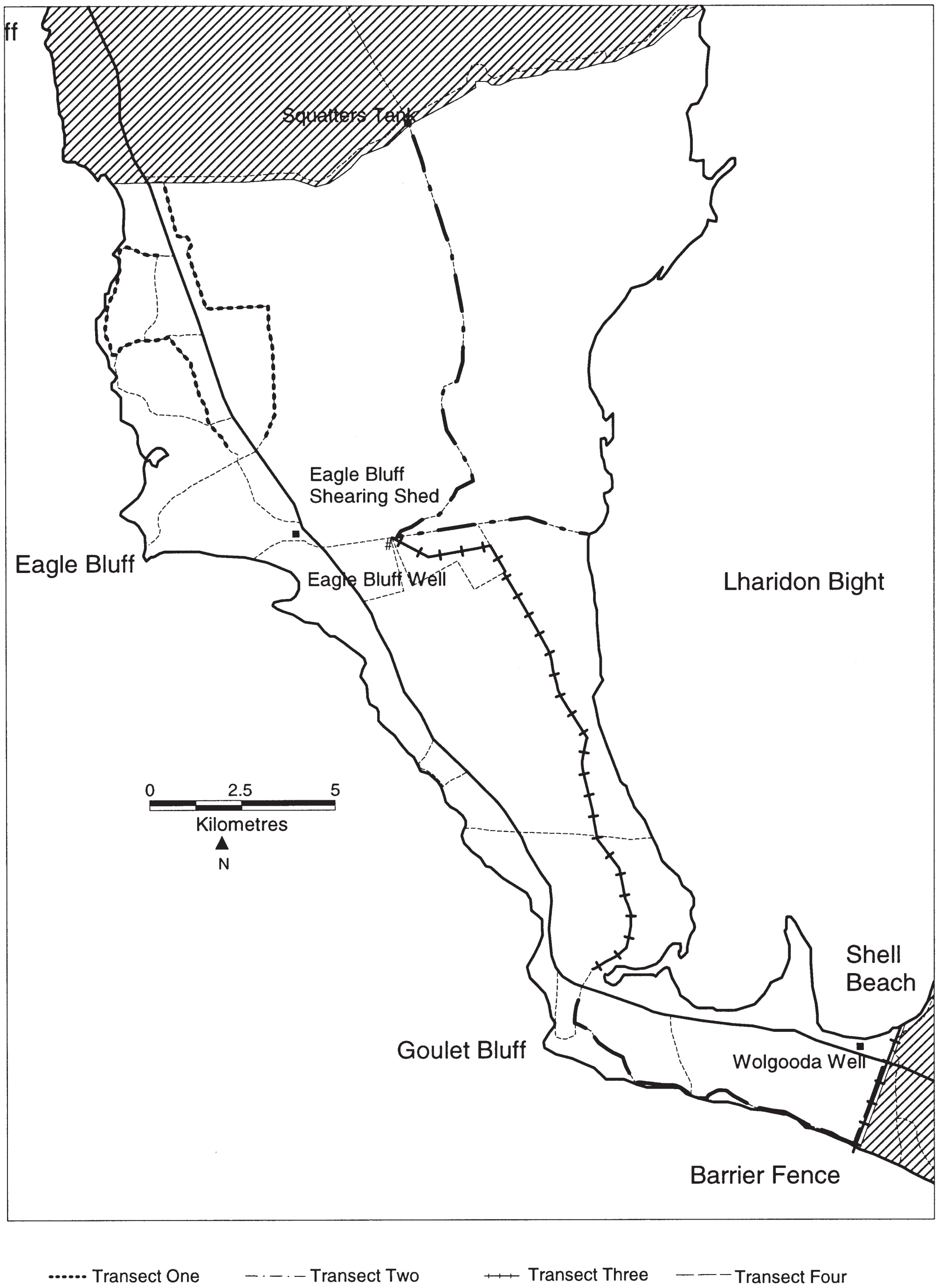

Figure 4. Zone Four.

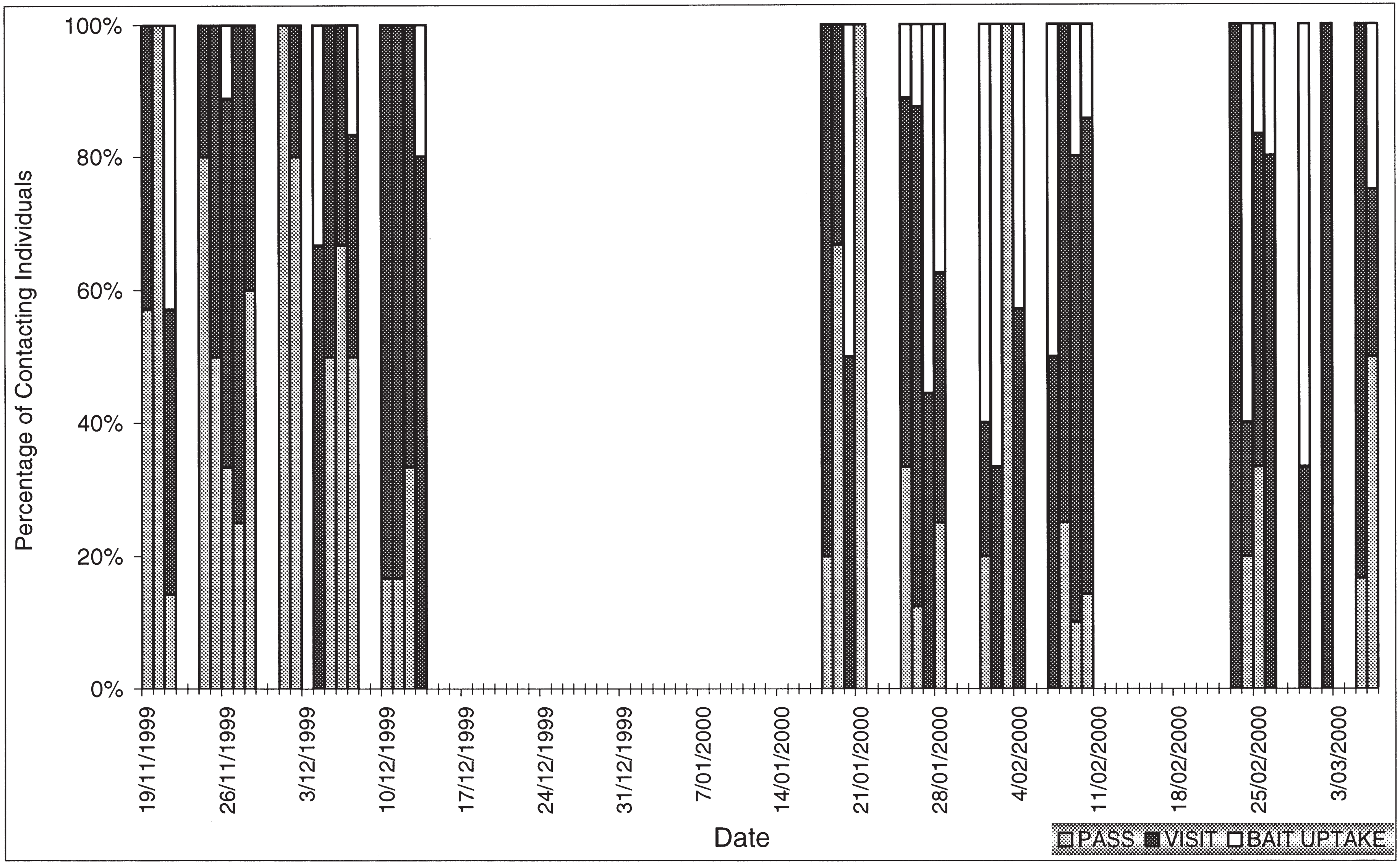

Figure 5. Bait interactions for the entire sampling period (probable uptake categorized as visit).

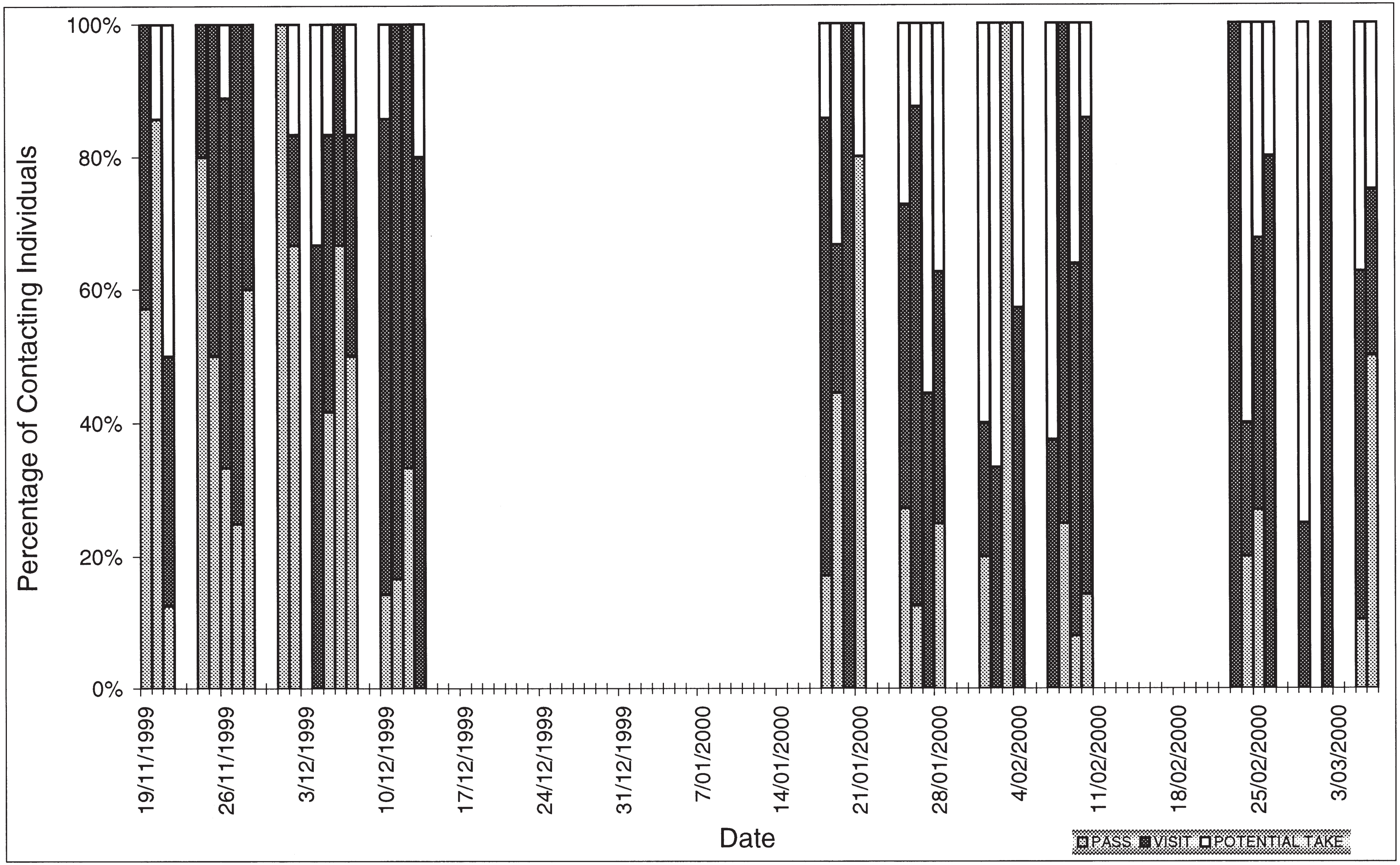

Figure 6. Bait interactions for the entire sampling period (probable uptake categorized as uptake).

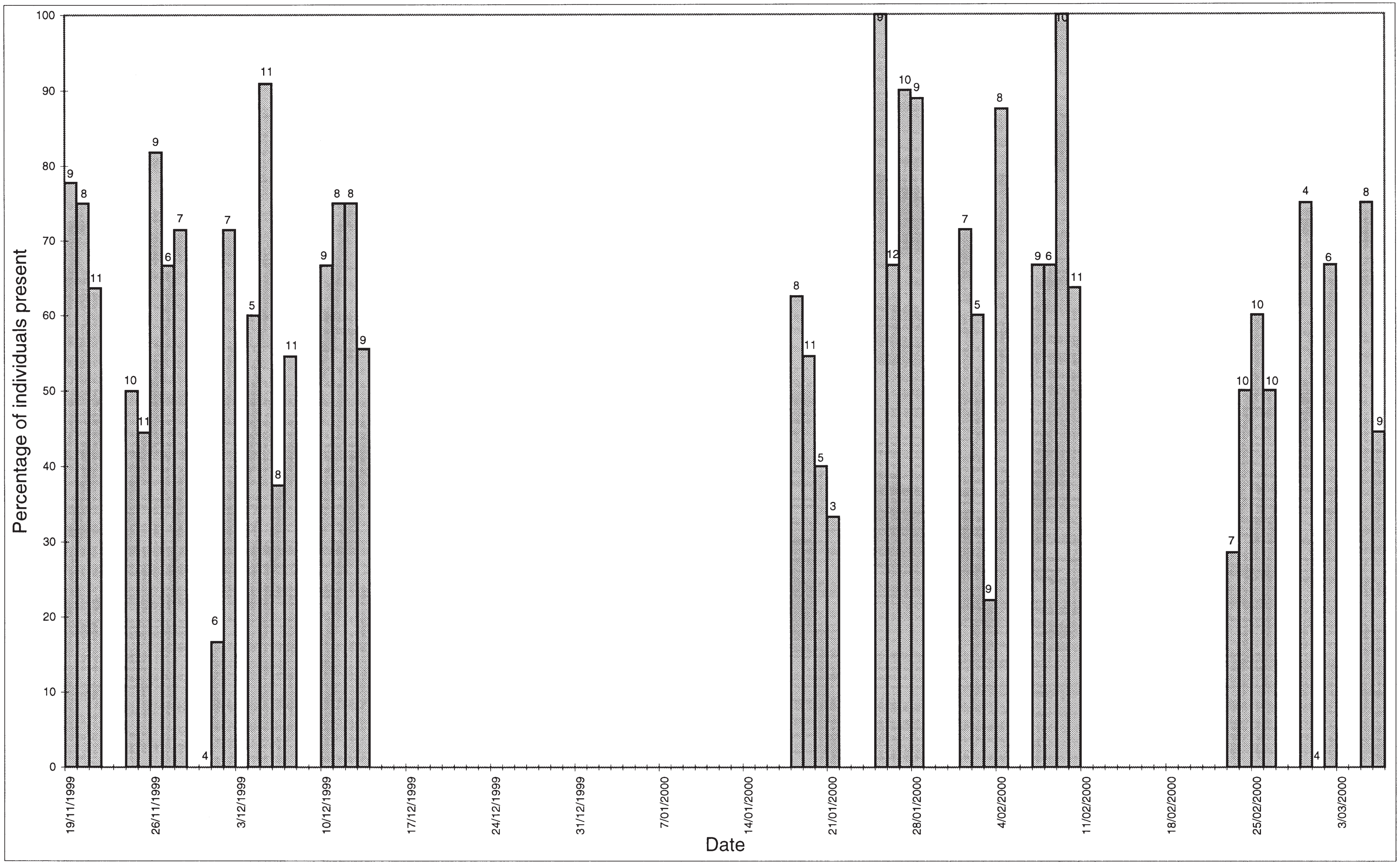

Figure 7. Percentage of individuals recorded on the transect that contacted a bait station.

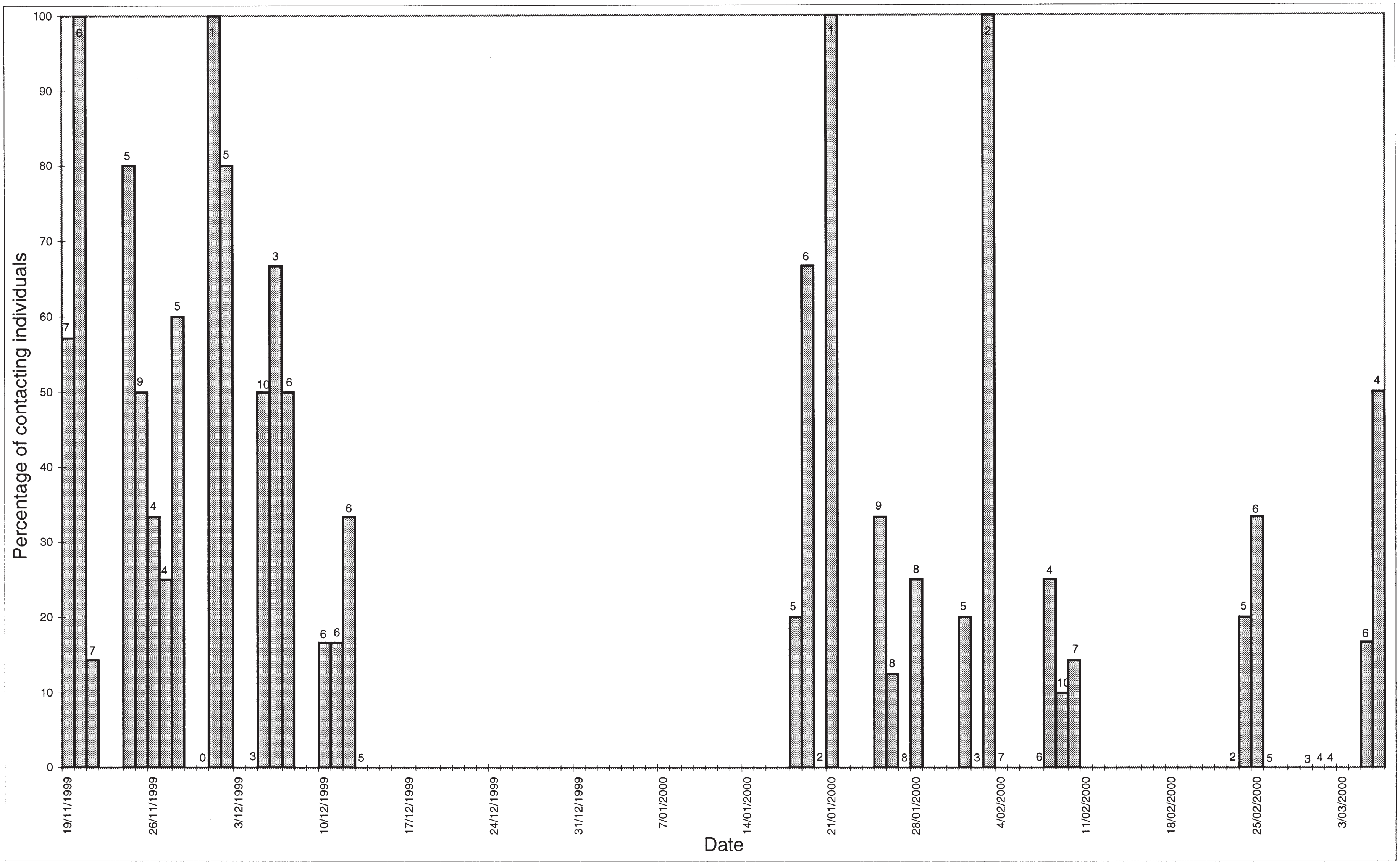

Figure 8. Percentage of contacting individuals that passed a bait station.

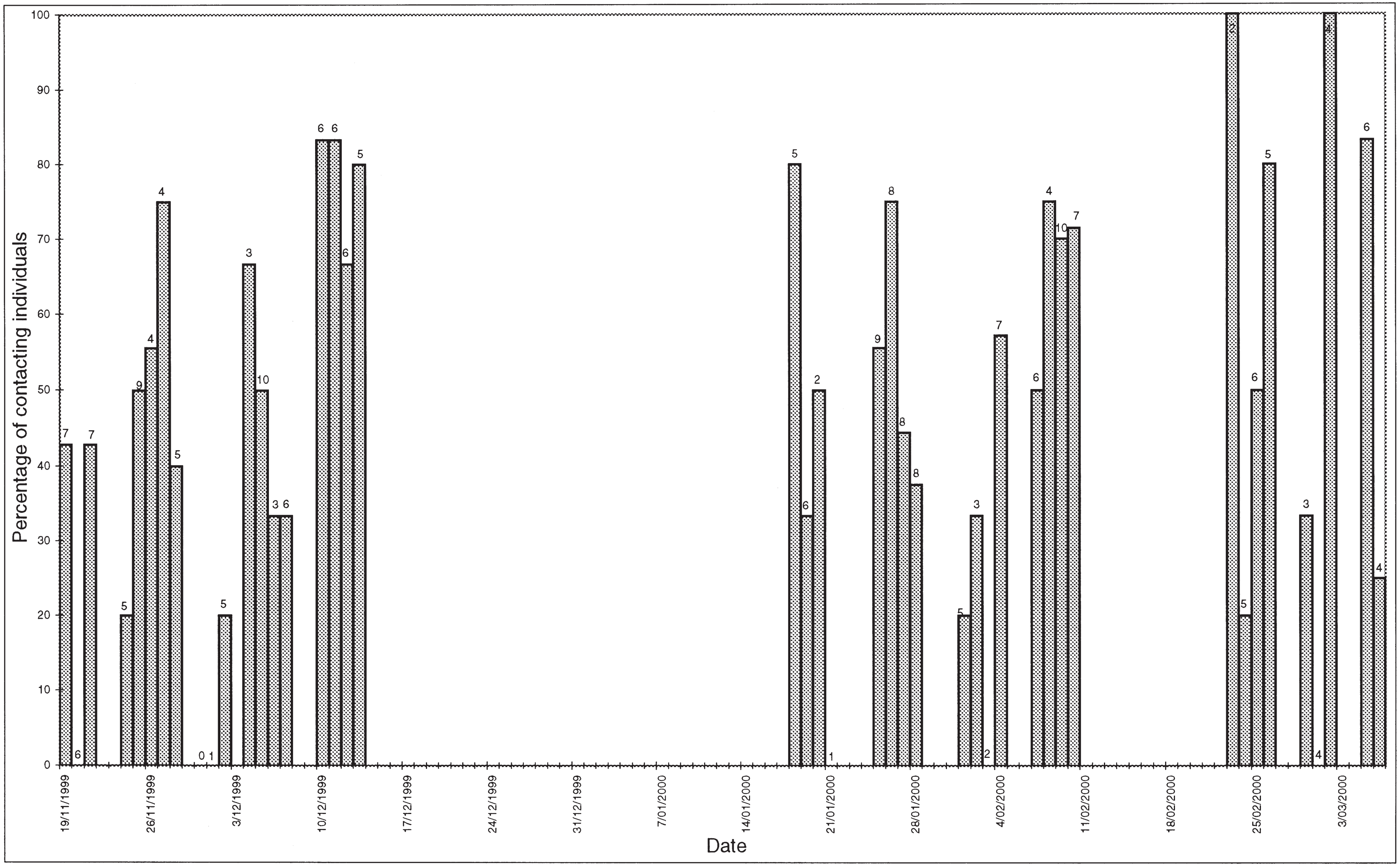

Figure 9. Percentage of contacting individuals that visited a bait station.

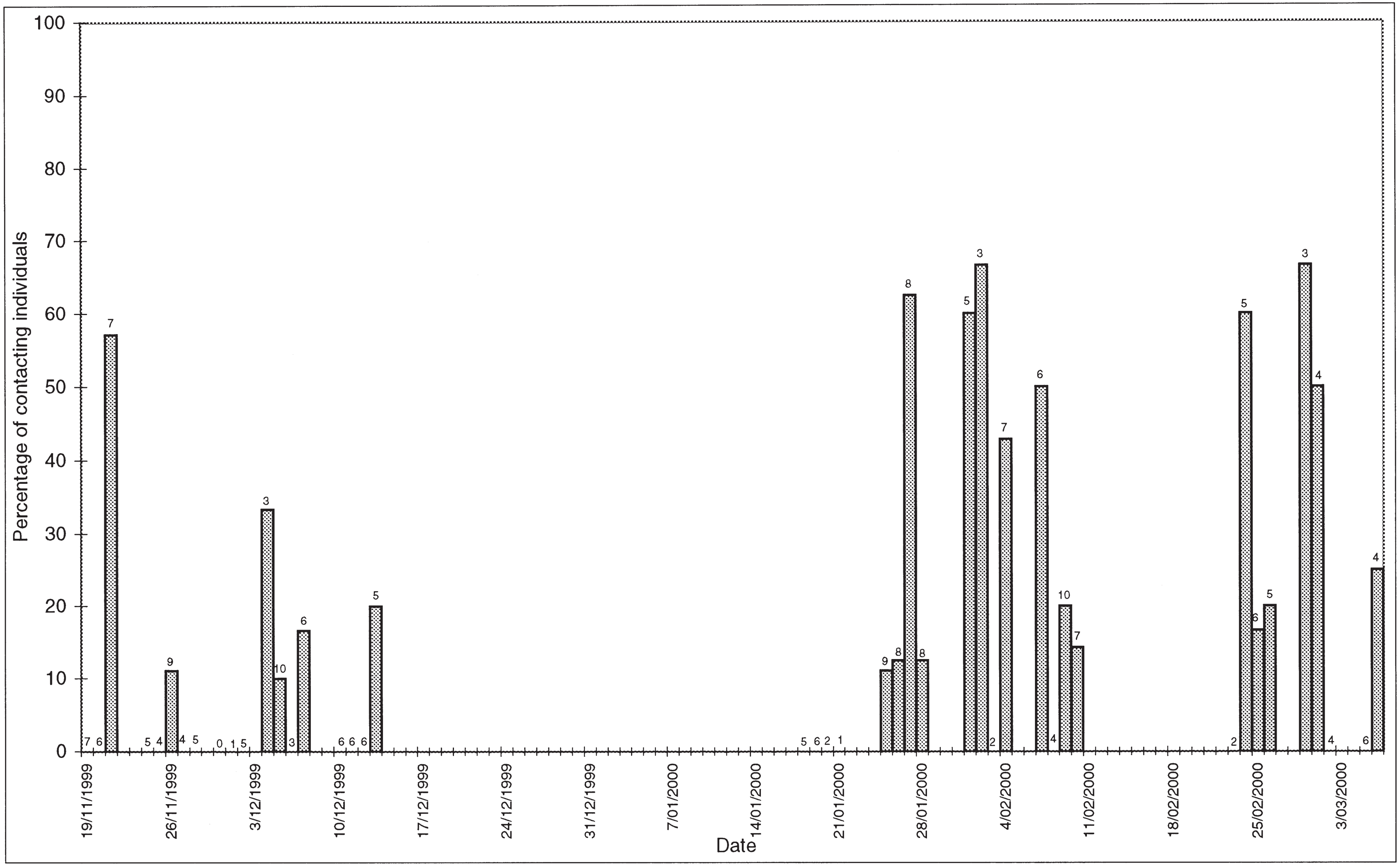

Figure 10. Bait uptake by contacting individuals.

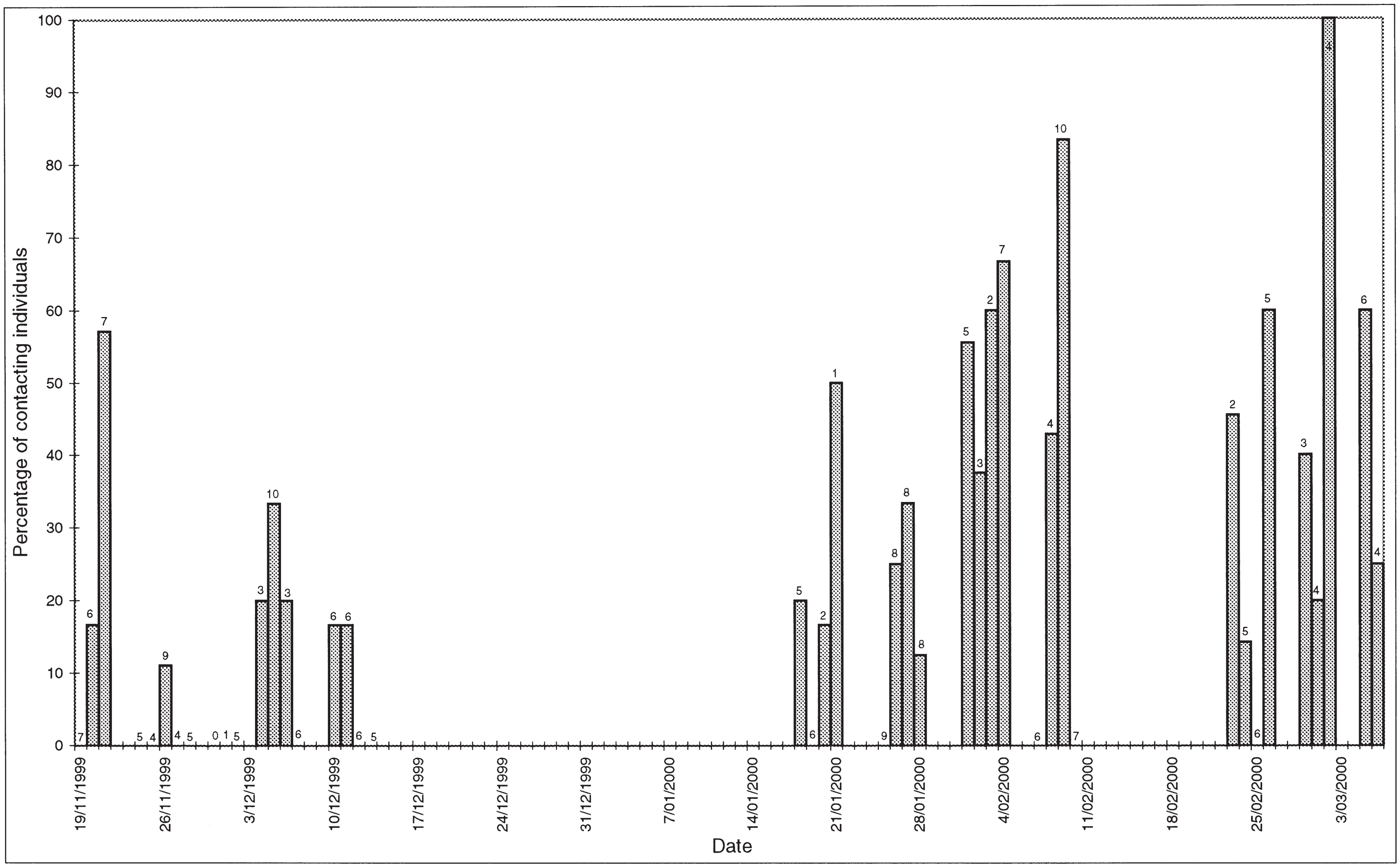

Figure 11. Potential uptake by contacting individuals.

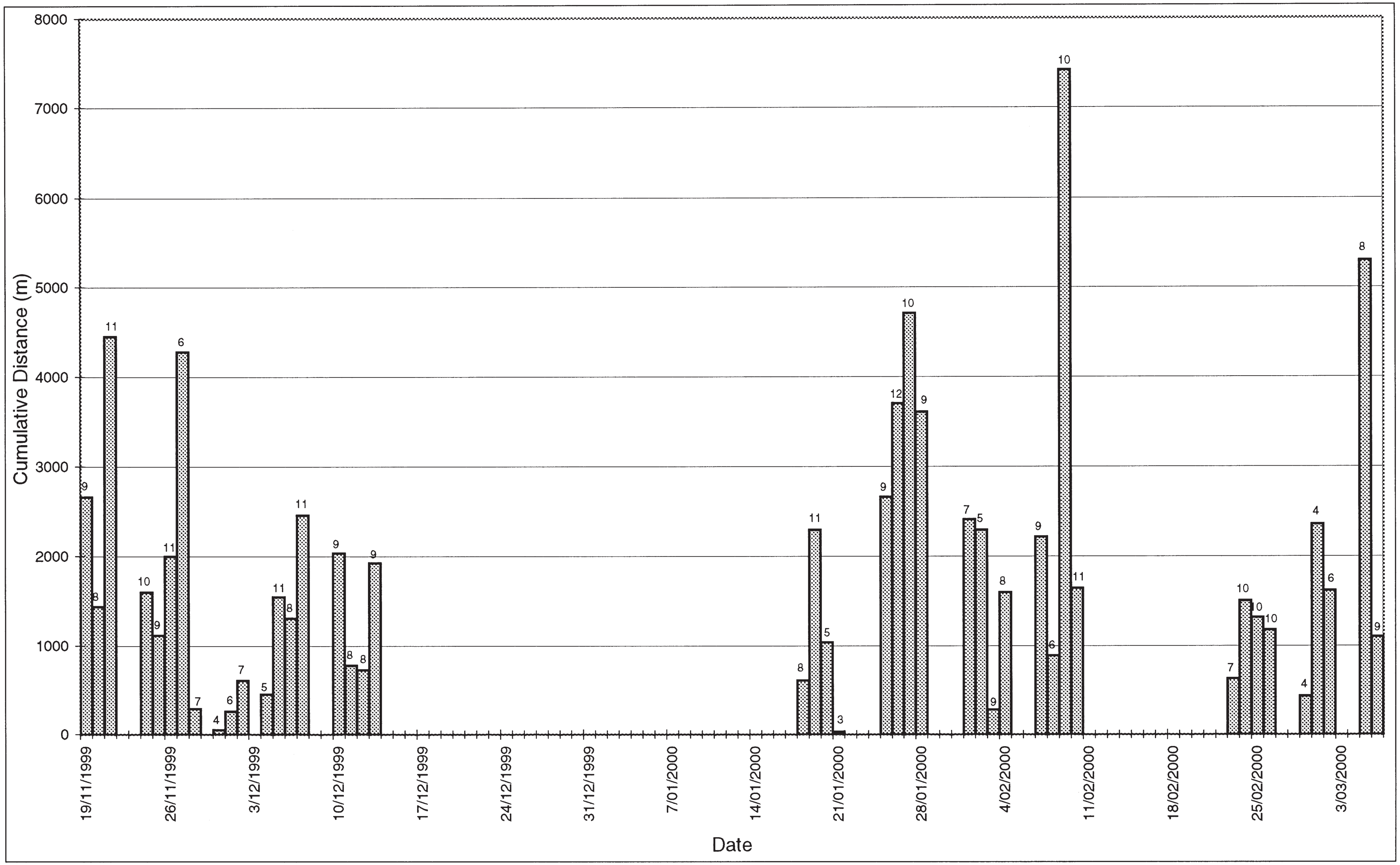

Figure 12. Cumulative daily on-track distances travelled.

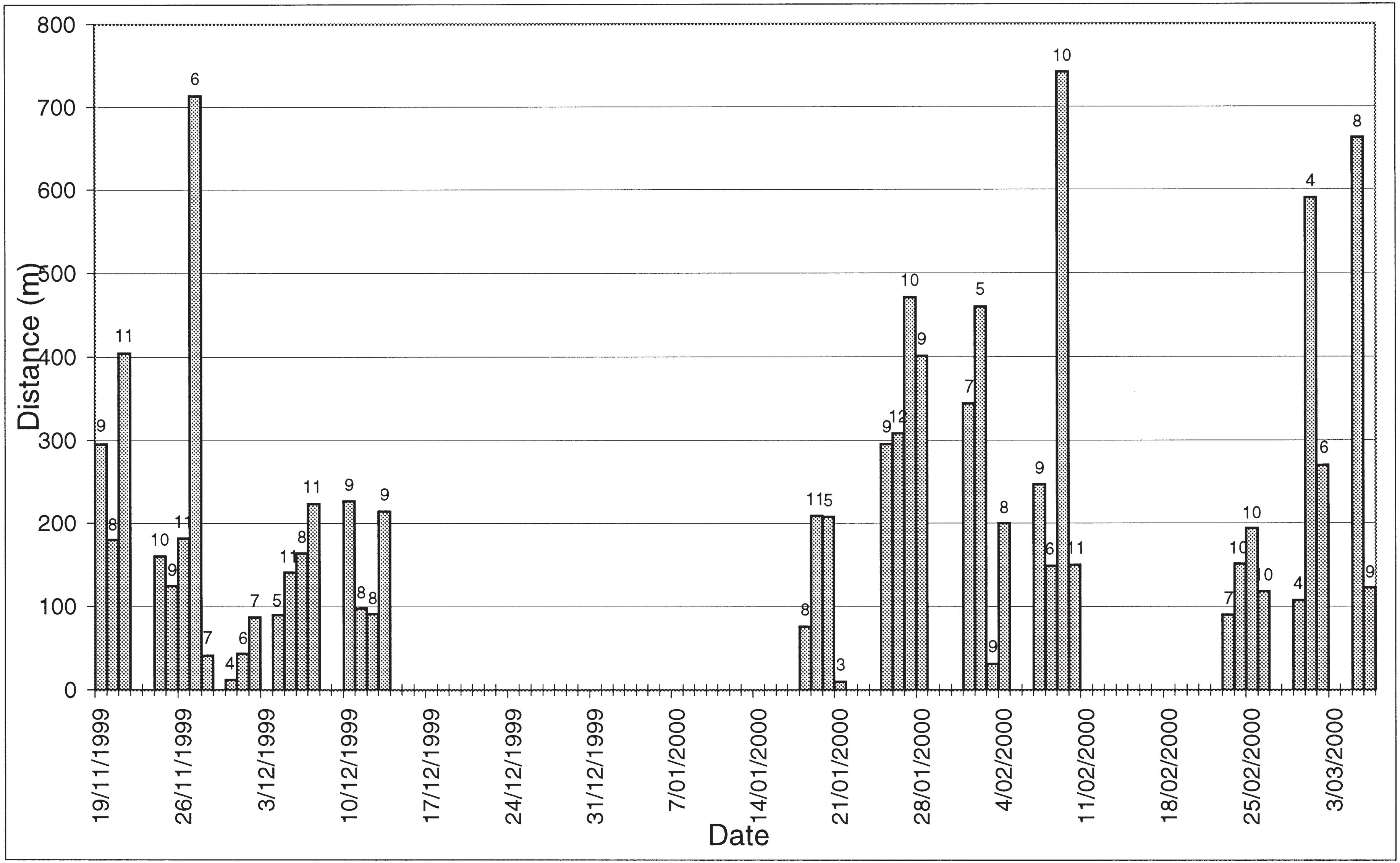

Figure 13. Mean daily on-track distances travelled.

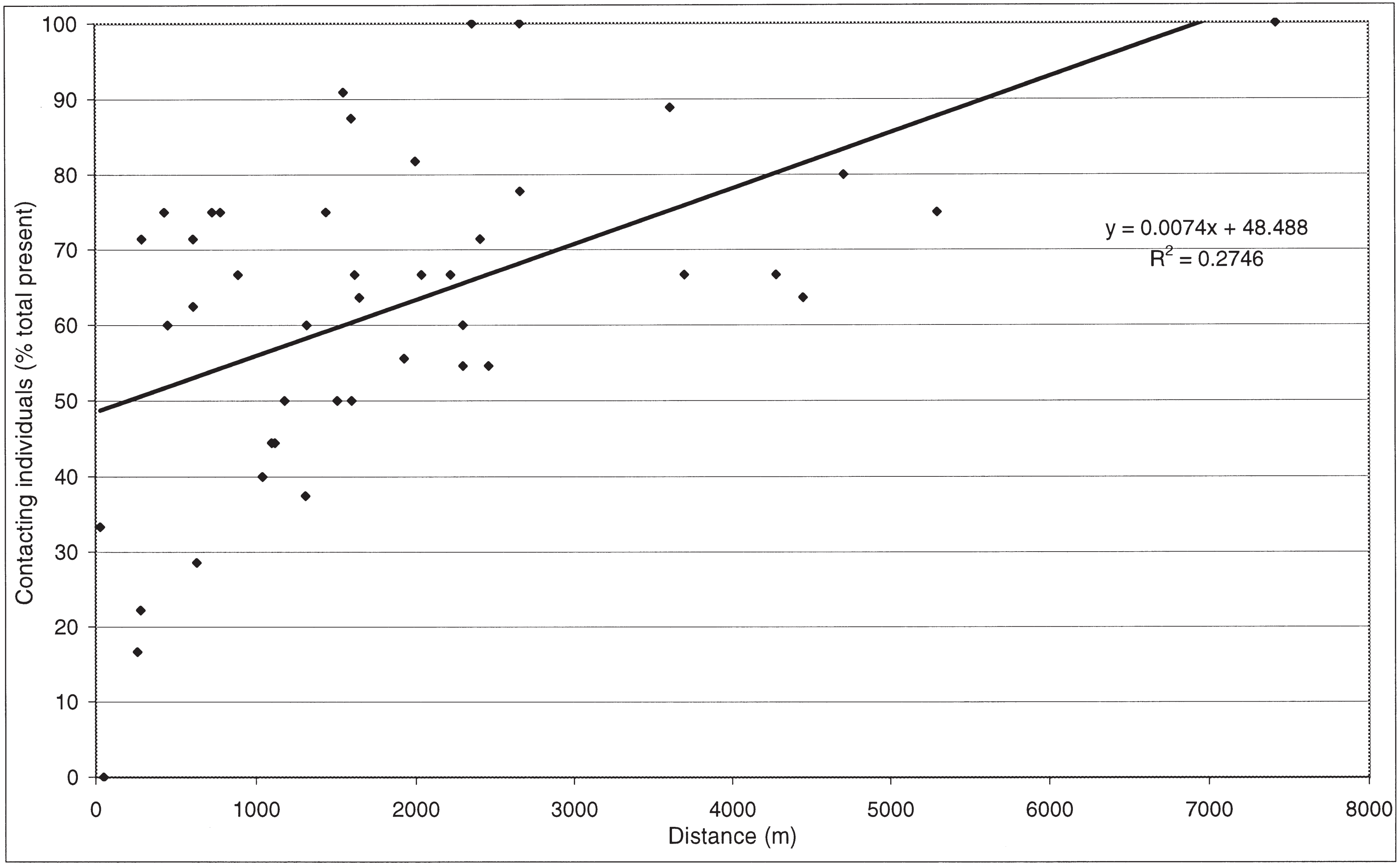

Figure 14. Cumulative on-track distances travelled v rate of contact (entire sampling period).

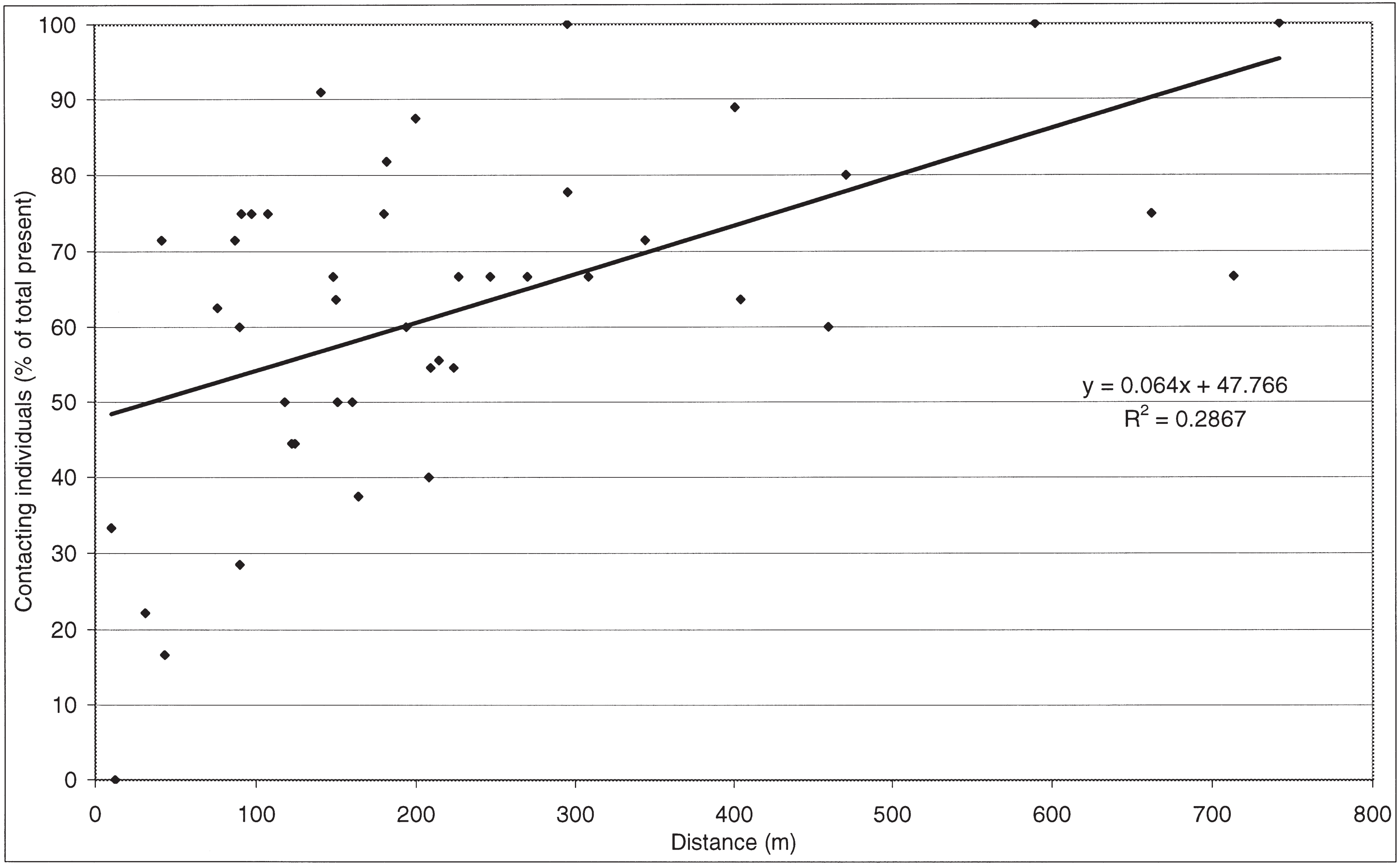

Figure 15. Mean daily on-track distances travelled v rate of contact (entire sampling period).

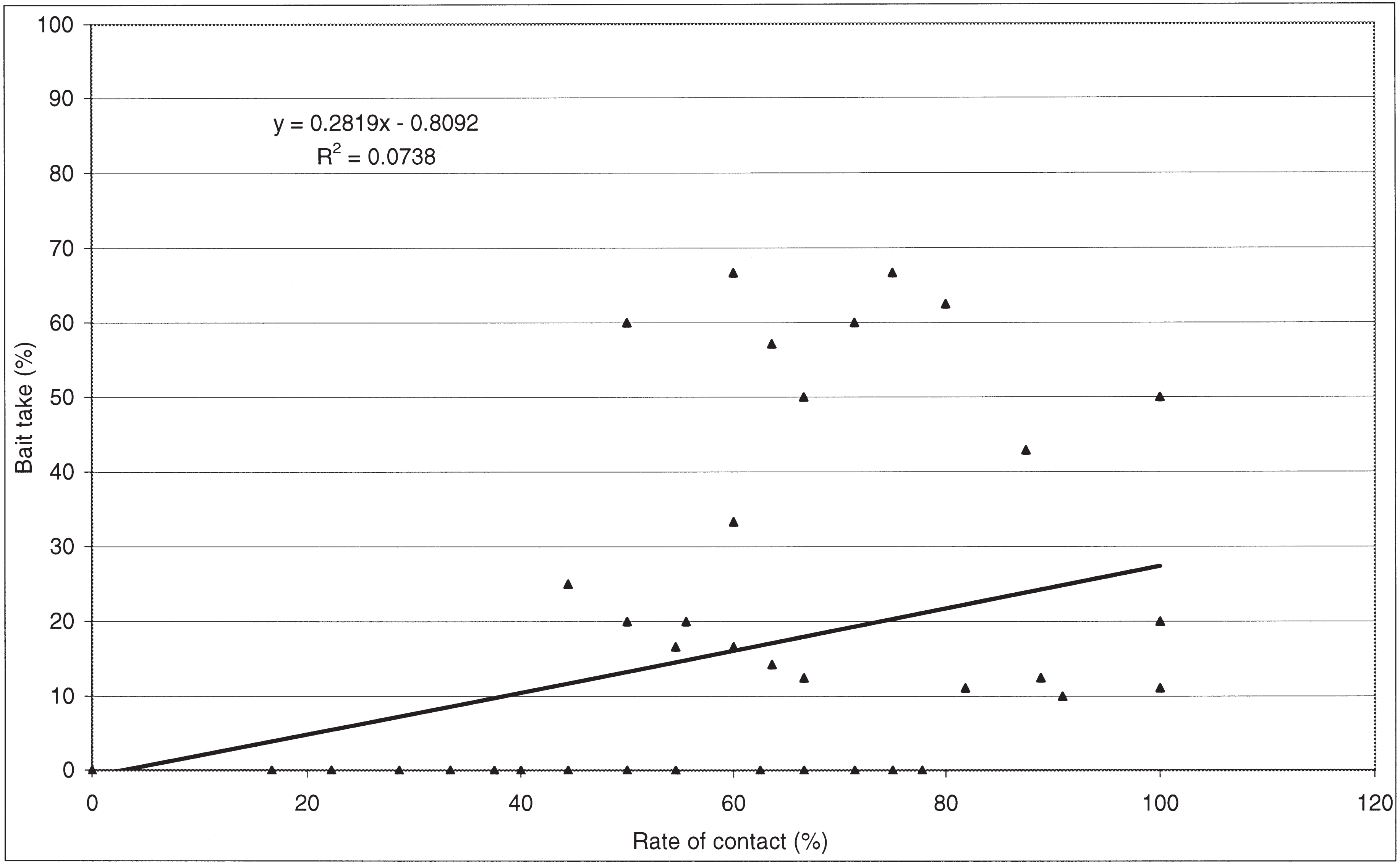

Figure 16. Rate of contact v rate of bait uptake (entire sampling period).

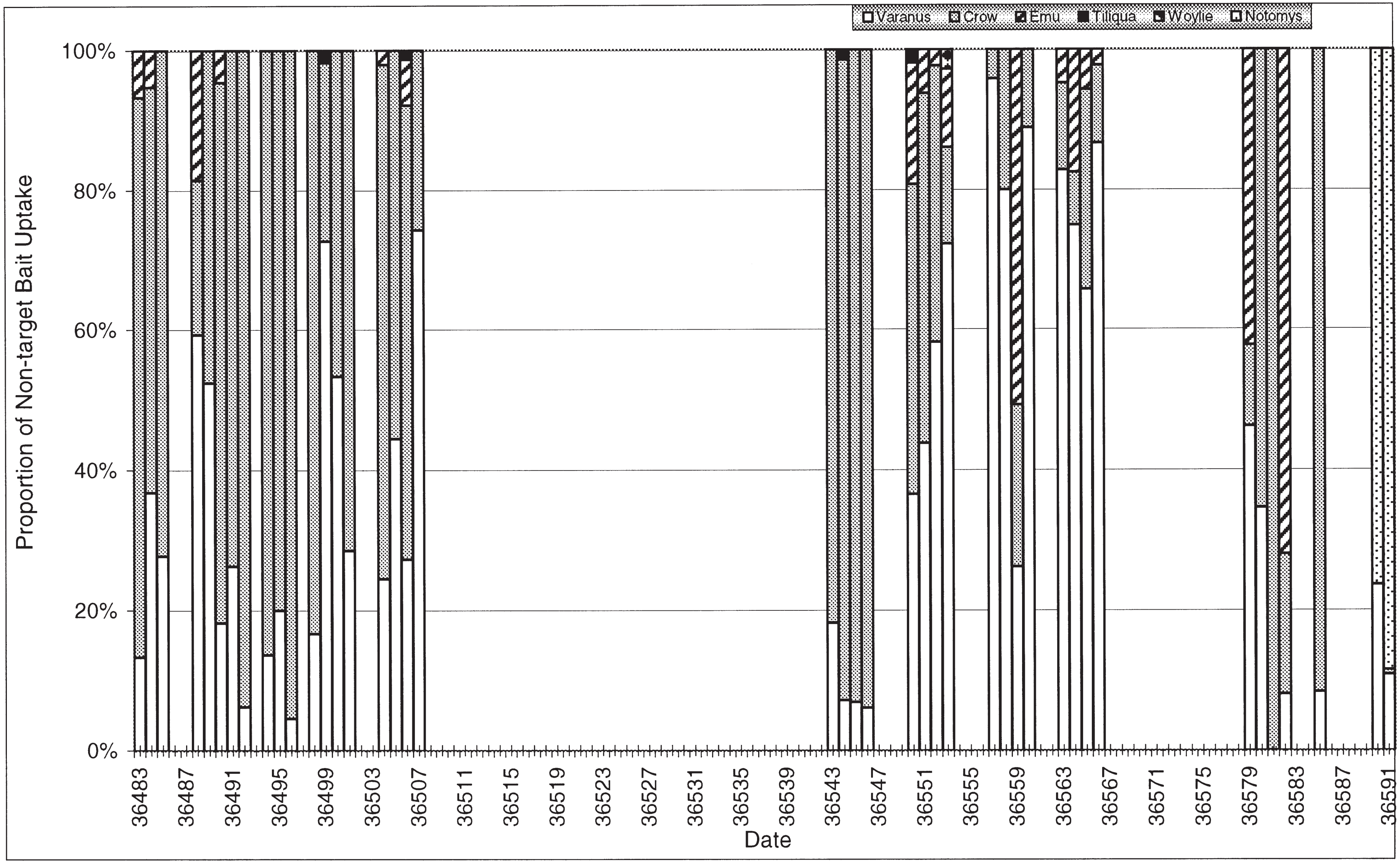

Figure 17. Relative frequency of bait uptake by non-target species.

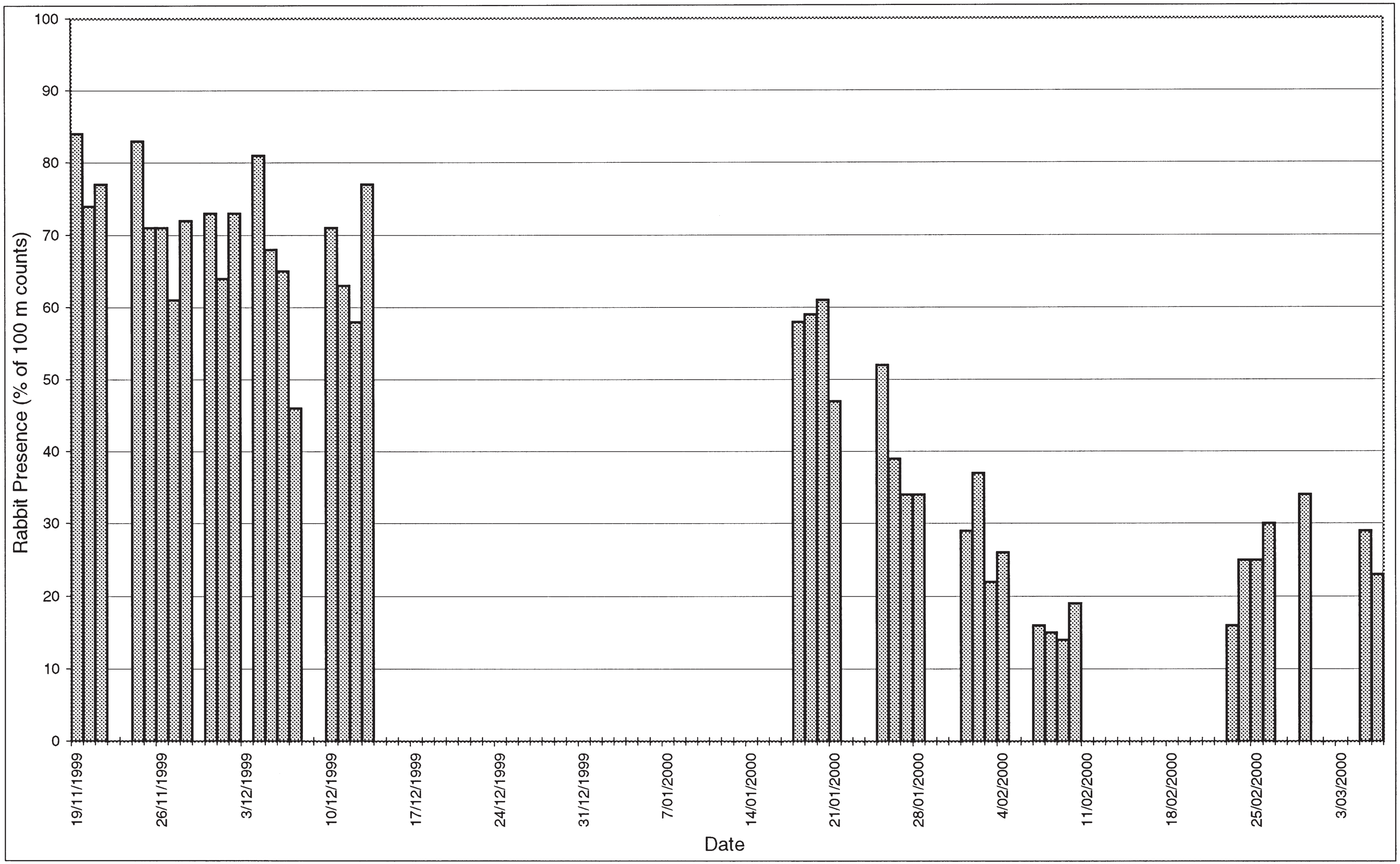

Figure 18. Rabbit presence on bait uptake transects.

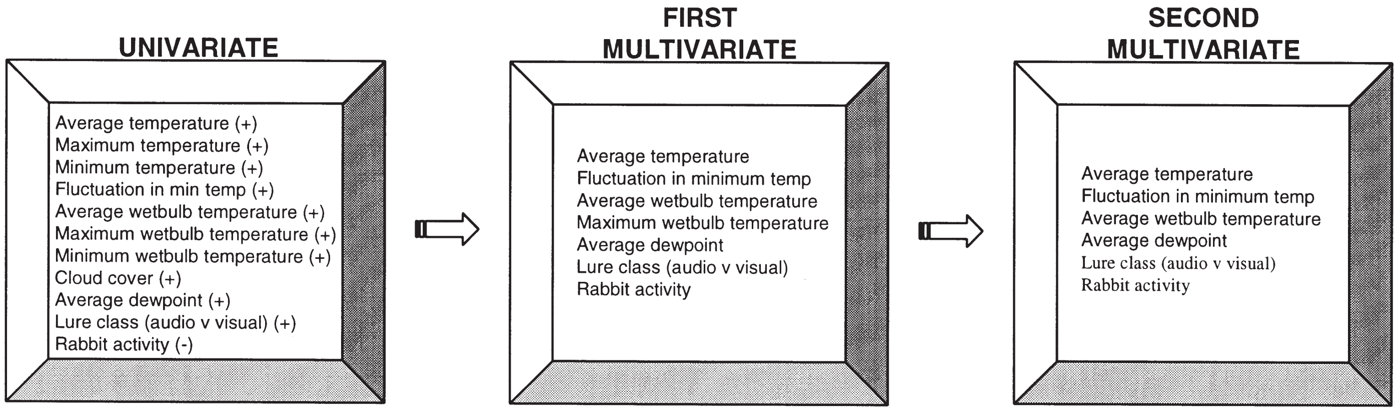

Figure 19. Regression model building steps for bait uptake (entire sampling period).

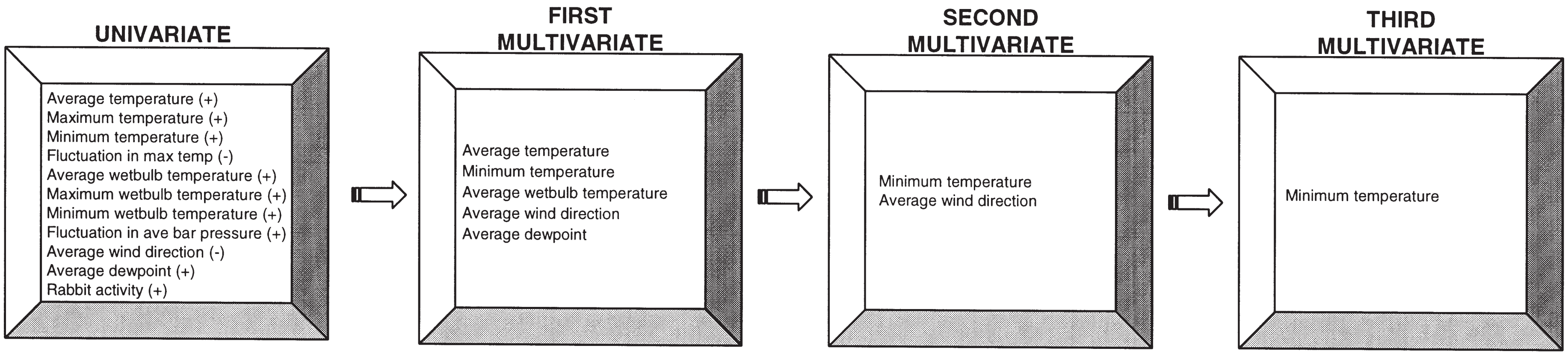

Figure 20. Regression model building steps for potential bait uptake (entire sampling period).

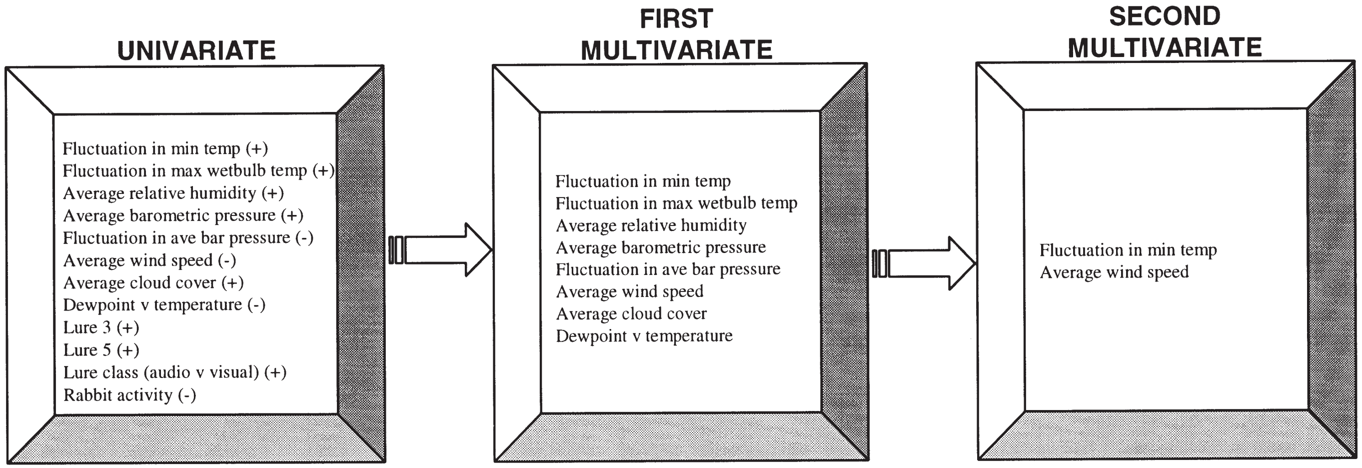

Figure 21. Regression model building steps for bait uptake (post 25 January).

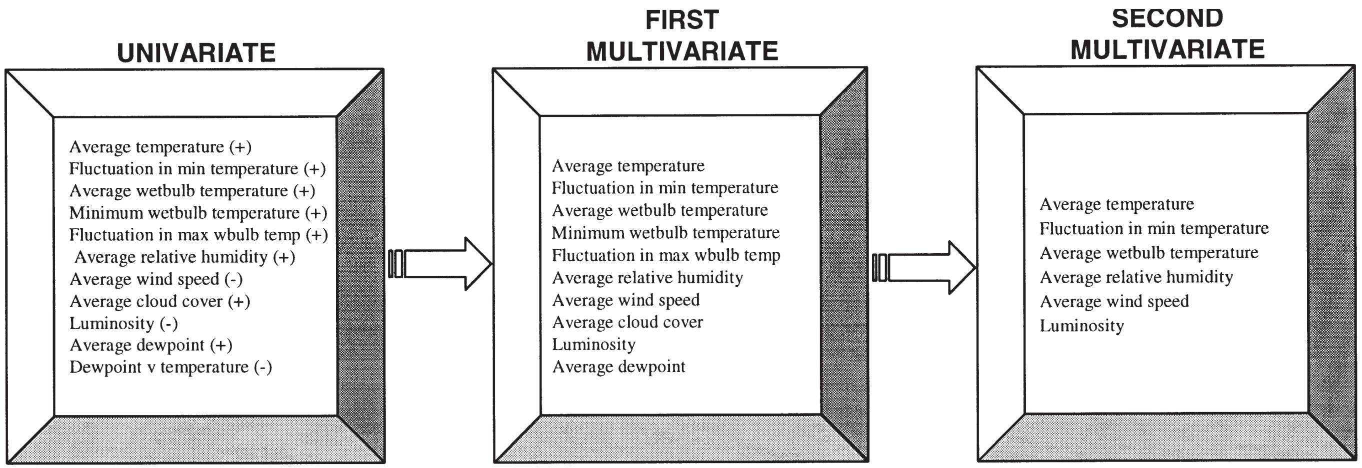

Figure 22. Regression model building steps for potential bait uptake (post 25 January).

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BiblioHeathMouse: the heath mouse, *Pseudomys shortridgei* (Thomas, 1907), a subject-specific bibliography

JOANNE A. SMITH, LISA J. WRIGHT AND BRENT W. JOHNSON

ABSTRACT

This bibliography contains 109 items concerning the heath mouse, *Pseudomys shortridgei*. The list includes published as well as un-refereed and/or unpublished documents bringing their existence to the attention of researchers. The majority of these titles can be viewed in the Wildlife Science Library, Department of Environment and Conservation (DEC). An index to the broad subject areas of Behaviour, Conservation Status, Description, Diet, Disease, Distribution, Ecology, Evolution, General, Genetics, Management, Physiology, Reproduction and Threatening Processes is provided.

INTRODUCTION

This is a bibliography of information about the heath mouse, *Pseudomys shortridgei*. The bibliography is updated as new materials become available. Updates can be obtained from the Wildlife Science Library, DEC on request. Notification of relevant materials for inclusion can also be sent to the Library.

The bibliography was started with titles extracted from CONSLib, the Departmental Library Catalogue. The references contained within these titles were checked and added. This process continued until all relevant references had been included. Internet searches were also performed, and the site specific information printed out. The URLs have been included, but because of the temporary nature of URLs they should not be relied upon. More references from these and other World Wide Web sources were added.

Every effort has been made to obtain a copy of each reference and lodge them in the Library. However in some cases this has not been possible. A Library file has been created to hold a copy of complete articles and cover pages of shelved items.

For ease of use the references are listed alphabetically and have been allocated an item number. This item number can be found under one or more of the 14 broad subject categories.

Figure 1. Heath Mouse (Pseudomys shortridgei). *Photograph courtesy of Brent Johnson, DEC)*

DESCRIPTION

The heath mouse *Pseudomys shortridgei* also known as dayang (Braithwaite et al. 1995) or heath rat (e.g. Cockburn 1995), is one of the largest pseudomyine rodents in Australia, with a body mass of 55–80 g. Detailed descriptions and illustrations are available in Watts and Aslin (1981), Cockburn (1995) and Menkhorst (1995).

Visually similar to the more common bush rat *Rattus fuscipes,* the heath mouse is smaller and thickset. It has brownish-grey fur flecked with black and dark guard hairs giving it a fluffy appearance. It has bulging eyes and a blunt-nosed face. The tail is shorter than the combined head-body length and has a distinct bi-colouration with darker fur above and pale fur beneath. This furred tail contrasts with the sparsely-haired, annulated tails of the sympatric bush rat and introduced *Rattus* species. It is also sympatric with the swamp rat *Rattus lutreolus* in Victoria with which it can be confused.

REPRODUCTION AND DIET

Reproductive information is available for a Victorian population (Cockburn 2000). There, heath mice are thought to be sexually mature at about one year old with breeding occurring in spring and summer. One or two litters of up to three young are produced during that period. Resident mature adults appear to be territorial and the young are forced to disperse into unoccupied territory once weaned. In Western Australia captive heath mice have been known to live for up to five years. Heath mice consume a wide range of plant parts including seeds, flowers, stems and leaf material suggesting that they are generalist herbivores (Meulman 1997). In Western Australia, underground burrows with entrances hidden under shrubs are their most common refuge. (Cancilla & Johnson 2005).

DISTRIBUTION AND CONSERVATION STATUS

The heath mouse was first collected by GC Shortridge in 1906 from an area east of Pingelly, Western Australia. The sub-fossil record indicates that, before European colonisation, the heath mouse was present in the south-west of WA from Shark Bay in the north to Eucla in the east. Sub-fossil material has also been found on the Eyre Peninsula and the Nullarbor in South Australia (Baynes 1987). Following its discovery in 1906 and the capture of two individuals in 1931, it was not recorded again in WA until 1987 when specimens were obtained from the Ravensthorpe area (Baynes et al. 1987). A disjunct population in south-western Victoria was first discovered in 1961. This eastern population appears to be restricted to the Grampians and Wannon region of Victoria and just across the South Australian border in the Lower Glenelg region. (Menkhorst 1995; Cooper et al. 2003). A specimen from Kangaroo Island, collected in 1967, was also identified as a heath mouse although it has not been recorded there since. These records suggest that a continuous coastal and sub-coastal distribution may have existed from Shark Bay in Western Australia to the Grampians in Victoria. Since its rediscovery in WA, low numbers of heath mice have been recorded in remnant vegetation within the southern wheatbelt but the most recent studies suggest that it may now be restricted to Lake Magenta Nature Reserve and Fitzgerald River National Park.

Both the eastern and western populations appear to favour floristically-rich, dry heathland although the post-fire age of preferred habitat differs. In Victoria, the species tends to prefer recently burnt areas (Cockburn 1978; Cockburn et al. 1981; Cockburn 2000) whilst in WA, heath mice inhabit long unburnt vegetation (Quinlan 2001). Despite the geographical separation of these populations, the low level of genetic divergence suggests that a single species is involved (Cooper et al. 2003)

The heath mouse has suffered a major decline in its distribution and there are serious concerns for its survival. Lee (1995) listed it as 'Rare and insufficiently known', it is listed as 'Vulnerable' under Commonwealth legislation, in Western Australia it is listed as 'Schedule 1 – Fauna that is rare or is likely to become extinct' and in Victoria it is listed as 'Rare'.

Modification to land management practices and clearing for agriculture have reduced and fragmented heath mouse habitat. Plant pathogens, feral predators and competition with introduced rodents are thought to be other major factors in the decline of the heath mouse. (Burbidge 2004, Burbidge & McKenzie 1989), (Morris 2000). Although Lee (1995) lists recovery objectives and management actions, further information on these potentially limiting factors and additional ecological data are required so that a workable management or recovery plan can be developed.

ACKNOWLEDGEMENTS

The authors would like to thank Tony Start and Lesley Gibson for their constructive comments on the original manuscript.

BEHAVIOUR:

22, 23, 49, 52, 54, 69, 74, 77, 79, 82

CONSERVATION STATUS:

11, 18, 19, 20, 38, 40, 48, 49, 59, 64, 66, 75, 91, 99, 103

DESCRIPTION:

17, 21, 24, 42, 49, 52, 54, 63, 64, 66, 79, 86, 92, 94, 96, 101, 104, 107, 109

DIET:

22, 23, 24, 39, 48, 64, 67, 68, 102, 105, 107

DISEASE:

22, 23, 67

DISTRIBUTION:

1, 2, 3, 4, 5, 6, 9, 10, 11, 18, 21, 22, 23, 24, 26, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 43, 44, 46, 47, 48, 49, 51, 55, 56, 57, 58, 59, 61, 62, 64,

ECOLOGY:

EVOLUTION:

GENERAL:

GENETICS:

MANAGEMENT:

PHYSIOLOGY:

REPRODUCTION:

THREATENING PROCESSES:

BiblioHeathMouse

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BiblioRingtailPossum: the western ringtail possum, *Pseudocheirus occidentalis* (Thomas, 1888), a subject-specific bibliography

LISA J. WRIGHT, JOANNE A. SMITH AND JEFF RICHARDSON

ABSTRACT

This bibliography contains 403 items concerning the ringtail possums, *Pseudocheirus occidentalis* and *P. peregrinus*. Most of these have been published and reviewed outside the Department of Environment and Conservation (formerly the Department of Conservation and Land Management). They have been arranged into the broad subject areas of Behaviour, Conservation Status, Description, Diet, Diseases, Distribution, Ecology, Evolution, General, Genetics, Management, Physiology, Reproduction and Threatening Processes. The majority of these titles can be viewed in the Wildlife Science Library, Woodvale.

INTRODUCTION

This is a bibliography of information about the ringtail possums, *Pseudocheirus occidentalis* and *P. peregrinus*. Both species are included for two reasons. Firstly, these species were once taxonomically synonymous and many Western Ringtail Possum specific papers where published under the former taxonomy. Secondly, the species share some aspects of biology and ecology.

Most references are from the scientific literature, but general articles have also been included. The bibliography is updated as new materials become available. Updates can be obtained from the Wildlife Science Library on request. Notification of relevant materials for inclusion can also be sent to the Library.

The bibliography was started with titles extracted from CONSLIB, the Departmental Library Catalogue. The references contained within these titles were checked and added. This process continued until all relevant references had been included. Internet searches were also performed, and the site specific information printed out. The URLs have been included, but because of the temporary nature of URLs they should not be relied upon. More references from these and other World Wide Web sources were added.

Every effort has been made to obtain a copy of each reference and lodge them in the Library. However in some cases this has not been possible, especially with the older material.

For ease of use the references are listed alphabetically and have been allocated an item number. This item number can be found under one or more of the 14 broad subject categories.

DESCRIPTION

The ngwayir (pronounced 'n-waar-ear') (western ringtail possum, *Pseudocheirus occidentalis*, Thomas 1888) is a folivorous marsupial endemic to south-western Australia. It is small (0.8 to 1.3 kg), usually dark brown to black (though sometimes dark grey) above, with cream or grey fur on the belly, chest and throat. It is easily distinguished from the sympatric koomal (common brushtail possum, *Trichosurus vulpecula hypoleucus*) by its smaller size, smaller round ears and absence of a brush tail.

Figure 1. Western Ringtail Possum (Pseudocheirus occidentalis) *(Photograph courtesy of Adrian Wayne, DEC)*

Near-coastal populations of the ngwayir can breed throughout the year but breeding peaks occur April–June and October–December (Jones et al. 1994). Further inland, breeding seasonality in the jarrah forest is more acute than in coastal areas, for example, in Perup 77% of births occurred in May–June and 23% in October–November (Wayne et al. 2005). Females can breed at less than 12 months of age and can breed continuously, occasionally breeding twice in the same year (Ellis and Jones 1992). The gestation period for the species is around 2–4 weeks. Litter size is usually one, with twins uncommon (Jones et al. 1994; Wayne et al. 2005) and a litter size of three rare (de Tores, unpublished data). The young stay in the pouch around 100 days, they are weaned between 6 to 8 months and disperse between 8 to 12 months of age (Ellis and Jones 1992; Jones et al. 1994; How 1978; Wayne et al. 2005).

Diurnal resting sites include dreys, platforms, tree hollows, hollow logs, within vegetation such as balga (grasstree, *Xanthorrhoea preissii*) skirts, on the ground under sedges, forest debris and disused rabbit warrens (Jones et al. 1994, Wayne et al. 2000; Wayne 2005). In suburban situations the species uses roof spaces and other dark cavities.

Five Noongar names have been suggested by Abbott (2001). Ngwayir and nguara (both pronounced 'n-waar-ear') are the most commonly used (Wayne et al. 2001 and Jones 1995 respectively).

DISTRIBUTION AND CONSERVATION STATUS

The ngwayir was first described from a specimen collected at King George Sound, Western Australia. At the time of European settlement the species had a range extending from just north of Perth to Waychinicup National Park (east of Albany) including scattered populations through the wheatbelt (Jones, 1995). The subsequent range contraction was noted as early as 1907 (Shortridge 1909). Currently, the species is found mainly in and near coastal areas from Bunbury to east of Albany as well as around Manjimup (Jones, 1995).

Contemporary range contractions are due to a range of influences including inappropriate land management, clearing for urban and agricultural development and introduced predators (foxes and cats) (Wayne et al. 2006; de Tores, 2005).

The ngwayir is listed as Vulnerable under the 2000 IUCN Red List of Threatened Species; Vulnerable under the Commonwealth government's Environmental Protection and Biodiversity Conservation Act 1999; and Specially Protected Fauna that is listed as rare or likely to become extinct under the West Australian Wildlife Conservation Act 1950.

A recovery team has been established and a recovery plan is presently being written for the species.

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BEHAVIOUR:

23, 24, 44, 46, 47, 65, 66, 68, 69, 70, 71, 72, 73, 75, 76, 78, 80, 94, 96, 99, 125, 136, 176, 178, 189, 204, 210, 215, 217, 242, 244, 245, 246, 260, 263, 272, 275, 306, 309, 310, 320, 322, 338, 340, 341, 343, 352, 369, 370, 374, 382

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ECOLOGY:

EVOLUTION:

GENERAL:

GENETICS:

MANAGEMENT:

PHYSIOLOGY:

REPRODUCTION:

THREATENING PROCESSES:

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