Long-term trends in native mammal capture rates in a jarrah forest in south-western Australia

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Summary

The south-western Australian forests and woodlands are important refugia for many species of native mammals that were once widespread across the continent. In the late 1960s, the Perup jarrah forest was identified as being particularly rich in native mammals. Following light selection logging in the 1960s and early 1970s, the forest was primarily managed for the conservation of fauna in recognition of its outstanding conservation value. Detailed fauna studies commenced in 1974 following a preliminary survey and trapping in 1971. Mammal trapping has continued in the Perup forest for twenty-six years, making that forest the site of one of the longest mammal monitoring studies in Australia.

Long-term trends in the capture rates of four species, *Bettongia penicillata* (woylie), *Dasyurus geoffroii* (chuditch), *Isoodon obesulus* (quenda) and *Trichosurus vulpecula* (common brushtail possum), reveal that capture rates, which could be interpreted as mammal abundance, coincide with the level of effort to control the introduced fox (*Vulpes vulpes*). In the absence of fox control during the early 1970s capture rates of native mammals were less than 12% (i.e. fewer than 12% of traps set caught an animal overnight). In the northern part of Perup forest the woylie was presumed extinct as none was trapped or observed. Between 1977 and 1998, with ongoing fox control, capture rates increased to more than 70%. The woylie showed the greatest increase in capture rate and was the most widespread and commonly caught animal. The capture rates of the other species also increased, but more than 80% of mammals captured were woylies. The high abundance of woylies in recent times has compromised the monitoring protocol, with virtually all traps set catching or being tampered with by woylies, rendering them unavailable to other less-abundant species. A new monitoring protocol is suggested to accommodate the high population density of native mammals.

Keywords: forest ecology; nature conservation; sclerophyllous forests; endangered species; wildlife; fauna; marsupials; foxes; pest control; sampling; monitoring; Western Australia

Introduction

The modern decline of Australian mammals has been attributed to a number of causes, including loss of habitat by clearing, predation by introduced predators, competition with introduced herbivores, changed fire regimes and disease (Burbidge and McKenzie 1989; Morton 1990). While most declines and extinctions have occurred in the semi-arid and arid regions of the continent, mammal declines have also been observed in the mesic south-west of Western Australia. For example, between 1866 and 1869, Masters recorded a great diversity and density of mammals in the vicinity of Albany on the south-western coast (Glauert 1948), but by the turn of the century Shortridge (1909) reported the disappearance and decline of many species. He believed this decline occurred from about 1880, but noted that the declines in the south-west were not as severe as in the drier parts of the country. The Lake Muir region was an exception where, by 1911, the woylie and the boodie (*B. lesueur*) were reported to be declining (Kitchener *et al.* 1978). These declines pre-date the arrival of the fox, and Kitchener *et al.* (1978) suggest that the introduced cat (*Felis catus*) was probably the primary cause.

A second period of fauna decline was reported in the south-west between 1933 and 1944 (Serventy 1954; Perry 1973) resulting in range contractions for a number of species such as the quokka (*Setonix brachyurus*), the woylie, the chuditch, the common brushtail possum, the western ringtail possum (*Pseudocheirus occidentalis*), the tammar wallaby (*Macropus eugenii*) and the numbat (*Myrmecobius fasciatus*). Several authors (e.g. Troughton 1957; Calaby 1971; Christensen 1980a, b) suggested that the introduced fox was responsible for this second-wave decline of fauna in the south-west. More recently, circumstantial and experimental evidence has suggested that the fox is a serious threat to some medium-sized mammals (e.g. Kinnear *et al*. 1988, 1998). The extensive and relatively rapid clearing of native vegetation in the wheatbelt region of Western Australia has also had an immediate adverse impact on native fauna, because of loss of habitat alone.

Unlike the wheatbelt region, where about 94% of the original vegetation has been cleared, the south-western Australian forests are relatively intact. While there have been range contractions, there have been few mammal extinctions from the forests except for the boodie, which was recorded around the Lake Muir area, and the bilby (*Macrotis lagotis*), recorded in parts of the eastern jarrah (*Eucalyptus marginata*) forest and woodland. Thus, the south-western forests are an important refuge for many native mammal species that were once much more widely distributed.

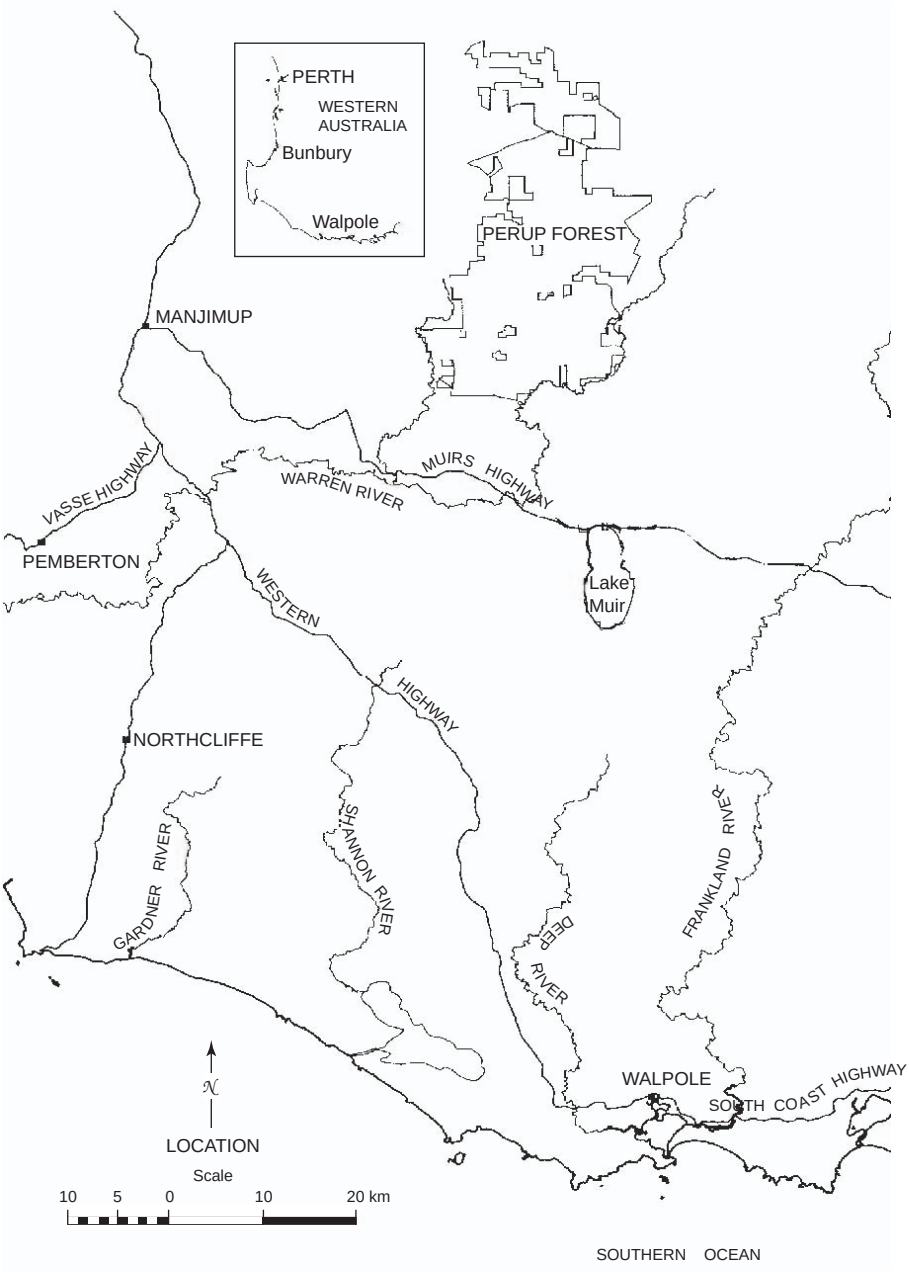

Figure 1. Location of the Perup forest, Western Australia

The Perup forest, in the south-west of Western Australia (Fig. 1), contains a particularly rich suite of native mammals. It is of outstanding conservation importance, primarily because of its diverse mammal fauna and the large number of rare and endangered species it contains. Twenty-two species of native mammal, 85 species of bird, 8 species of frog and 13 species of reptile have been recorded for the forest (CALM 1998). All mammal species in the southern and central forest regions of Western Australia, with the exception of the honey possum (*Tarsipes rostratus*) and the quokka, are present in the Perup forest. The forest is a particularly important reserve for medium-sized mammals that have either declined or become extinct in other parts of their range. These include populations of the woylie, tammar wallaby, chuditch, numbat, western ringtail possum, common brushtail possum, brush wallaby (*Macropus irma*), brush-tailed phascogale (*Phascogale tapoatafa*) and quenda. Throughout most of the monitoring period reported here (1974–1999), six of these mammals (woylie, tammar wallaby, quenda, chuditch, numbat and western ringtail possum) were listed as threatened (likely to become extinct or is rare) under Australian Commonwealth and Western Australian State legislation. As a result of management action, the conservation status of the woylie, the quenda and the tammar wallaby was recently reviewed using the International Conservation Union Red List criteria (IUCN 1994) and these taxa are no longer classified as threatened species (Start *et al*. 1998).

Following detailed ecological studies of the woylie and tammar wallaby (Christensen 1980b), a mammal trapping program has been maintained in the Perup forest since 1974 to monitor populations of four species: the woylie, the quenda, the chuditch and the common brushtail possum. This paper reports on long-term trends in the capture rates of these mammals and discusses possible reasons for fluctuations in capture rates over this time.

The Perup forest

The 40 000 ha Perup forest, a dry sclerophyllous forest dominated by jarrah and marri (*Corymbia calophylla*), lies between the headwaters of the Perup and Tone Rivers, some 50 km north-east of the town of Manjimup in the south-west of Western Australia (Fig. 1). The region experiences a moderate Mediterranean-type climate with warm dry summers and cool wet winters. Average annual rainfall varies along a north–south gradient of increasing rainfall but is about 700 mm, mostly falling between May and August. Annual rainfall over the monitoring period described here (1974 to 1999) is shown in Figure 2. Annual evaporation is about 1600 mm and the mean monthly maximum temperature ranges from 16°C to 31°C. The topography is a relatively simple system of gently undulating plateau tops, low lateritic ridges, broad valley floors, creeks and rivers. Uplands and ridges are characterised by sandy yellow/brown gravels with occasional boulders and sheets of laterite, while yellow/brown podsolic soils occur along drainage lines. Grey/brown clay loams are commonly associated with broad valley floors with sands occurring around the margins of swamps. The fauna monitoring sites reported here are located within the Darling Plateau geomorphic unit, a relatively high plateau (300 m above mean sea level) underlain by the Archaean Yilgarn Craton composed of granites and gneiss. A detailed description of the geology and geomorphology of the region is provided elsewhere (Fairbridge and Finkl 1979; Wilde and Walker 1984; CALM 1998).

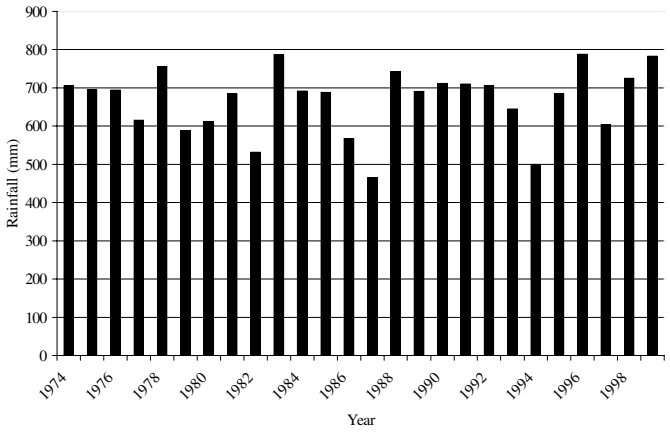

Figure 2. Annual rainfall for the Perup forest over the native mammal monitoring period 1974 to 1999. Source: Bureau of Meteorology, Westbourne site, latitude 34º05'3"S, longitude 116º39'37"E.

The predominant vegetation on the ridges and uplands is an open forest of jarrah and marri. The mature trees have a top height of about 20 m, a basal area of 20–25 m^2 ha^{-1} and an overstorey canopy cover of about 30%. The understorey vegetation on these sites is low (mostly <1.5 m high) and open (<45% cover) and consists of a diverse range of woody shrubs such as *Bossiaea ornata*, *Hakea lissocarpha* and *Leucopogon capitellatus*. In lower-lying areas with a more favourable moisture regime, the understorey is often dominated by *Hypocalymma angustifolium*. In treeless drainage lines on shallow soils, *Hakea prostrata*, *H. varia* and *Acacia saligna* form tall open thickets to 3 m. Wandoo (*E. wandoo*) woodlands with a sparse, open and often grassy understorey occur on the clayier soils in the valley floors. Heartleaf poison (*Gastrolobium bilobum*) thickets are usually found on the loamy soils in broad valleys or along the flanks of valleys. *Melaleuca viminea* thickets to 4 m occur beneath scattered flooded gums (*E. rudis*) in seasonally swampy areas, particularly along the upper parts of the Perup River.

The Mediterranean-type climate, together with accumulations of flammable fuel, makes the region prone to fire. Fire history prior to the 1930s is unclear, but records kept since 1938 reveal a mosaic of infrequent but often intense wildfires, prescribed burns of low to moderate intensity at intervals of 7–12 y, and long-unburnt periods (CALM 1998). Virtually the entire forest was burned by wildfire in 1951 (Table 1) and the northern portion was burned by wildfire in 1981. Current fire management aims to minimise the size and intensity of wildfires and to provide a fire-induced habitat mosaic by using prescribed fire in different seasons and at different intensities and frequencies (CALM 1998). One aspect of this mosaic, time since last fire, is shown in Figure 3.

Tracts of shallow, lateritic soils and the presence of extensive thickets of *Gastrolobium* species have probably contributed to the retention of the forest, making it unsuitable for agriculture. *Gastrolobium* species contain monofluoroacetic acid, a compound similar to sodium monofluoroacetate (1080), which is very toxic to introduced animals. Native animals, however, have evolved a high degree of tolerance to the toxin (King *et al*. 1981). Calaby (1971) suggested that the densities of populations of foxes might have been controlled in areas where *Gastrolobium* thickets occurred as foxes may have suffered secondary poisoning after eating native fauna. There is no scientific evidence, however, to support this theory, although Algar and Kinnear (1996) reported secondary poisoning of foxes following baiting of rabbits (*Oryctolagus cuniculus*) using the compound 1080. The large difference in susceptibility to poisoning by 1080 between native animals and introduced animals provides an important advantage to wildlife managers who use the toxin in the right doses and in the right medium to selectively target introduced predators such as foxes and feral cats.

Before it was recently gazetted as a nature reserve, the Perup forest was vested as State forest, available for commercial timber harvesting. The relatively poor quality of timber of the forest meant that it was harvested only lightly for sawlogs. Small patches of the northern portion of the forest were lightly logged in the 1950s, with more widespread but light selection logging occurring over the period 1961–1970 (Table 1). In 1971, in recognition of the conservation importance of the forest, the then Forests Department zoned the forest as a Management Priority Area (MPA) for fauna, flora and landscape values (Christensen 1974). Effectively, the area was managed as a nature reserve from this time. In 1971 Christensen commenced investigations of the

Table 1. A summary of the known history of fire, logging and fox control in Yendicup and Boyicup blocks, Perup forest

Fire history since 1938	Logging	Fox control
• General: Wildfire burnt most of the Perup forest in 1951. Another wildfire burnt Balban block and the northern portion of Yendicup block in 1981. • Yendicup block: About 900 ha of Yendicup block was set aside as a 'no planned burn' area and has not been burnt since 1954. The rest of Yendicup was burnt by low-intensity patchy prescribed fire in 1954, 1962, 1976, 1988 and 1994. • Boyicup block: Patchy low-intensity prescribed burns in 1977 and 1995.	• The Perup forest, including Yendicup and Boyicup blocks, was lightly logged during the period 1961–1970. Yendicup block was also lightly logged in1974. Logging was selective and patchy, reflecting the low timber value of the forest.	• No fox control prior to 1977. • Fox control commenced in 1977. From 1977 to 1989, fox baiting was irregular, with 1080 baits laid along tracks once every 1–2 y. • Broad-scale aerial baiting commenced in 1990. Single baitings (once per year) of 5 baits km^{-2} were carried out in 1990, 1992 and 1994. Double baitings (twice per year) were carried out in the intervening years and from 1995 to 1997. Since 1997, the Perup forest has been baited four times per year.

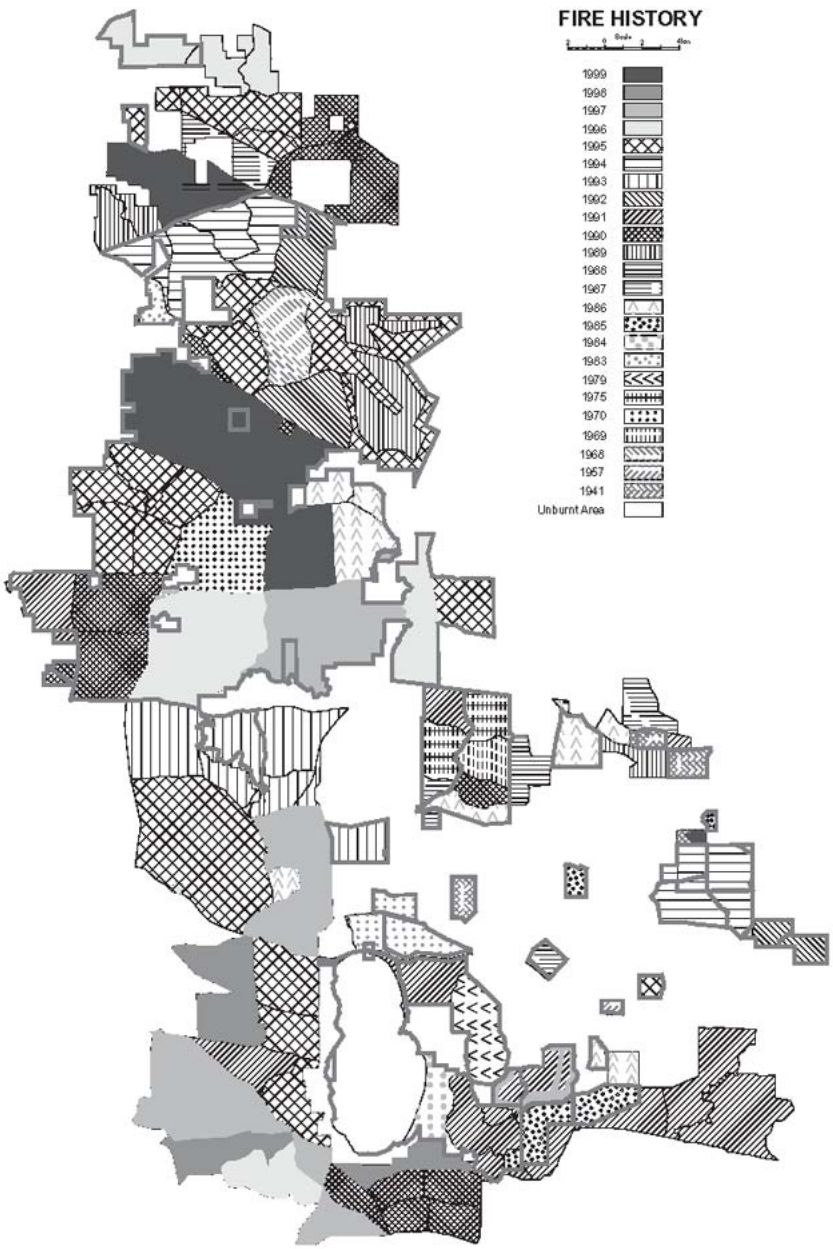

Figure 3. Recent fire history of the Perup forest and surrounds

distribution and abundance of native mammals by broadscale trapping and spotlighting. Later (1976) he commenced detailed studies of the biology and fire ecology of the woylie and the tammar wallaby (Christensen 1980b; Leftwich 1983). In 1974 Christensen was unable to trap woylies or observe any signs of them in the northern part of the Perup, so he presumed they had become locally extinct (Leftwich 1983). In 1977, Christensen and Leftwich carried out the first formal fauna reintroduction program in Western Australia when they successfully reintroduced woylies from the southern part of the Perup forest (Boyicup block) to the northern part (Yendicup block). Recognising the predation threat that foxes posed to native fauna, Christensen baited the northern area for foxes (Yendicup block) using 1080 poison baits ('crackle' baits) laid along roads and tracks prior to the woylie reintroductions (Christensen 1980b; Leftwich 1983). These studies became the foundation for an ongoing mammal monitoring program in the Perup forest.

Fox baiting continued at irregular intervals until 1990. Regular baiting of the entire forest commenced that year, using aircraft to deliver dry meat baits containing 1080 (Table 1).

Target species

The trapping method used to monitor native mammals targeted four nocturnal species: the woylie, the chuditch, the quenda and the common brushtail possum. The woylie is a small kangaroo-like marsupial with an adult body weight in the range 1.1–1.6 kg. (Christensen 1995). It takes refuge during the daylight hours in an elaborate ground nest constructed of grass and shredded bark from jarrah trees. Its diet consists predominantly of hypogeal fungi, supplemented by bulbs, tubers, seeds and insects (Christensen 1980a). Once widespread across much of southern Australia, its populations have contracted to a few in the south-west of Western Australia, the Perup forest being the site of one of these. Its distribution in the south-west has recently increased following fox control and reintroduction programs, and the species has been removed from the category of threatened taxa under Western Australian State and Australian Commonwealth legislation (Start *et al*. 1998). Details of the biology and ecology of the woylie are provided elsewhere (Sampson 1971; Christensen 1980b; Courtenay 1994; Start *et al*. 1998).

The chuditch is a carnivorous marsupial with a mean adult weight of around 1.3 kg for males and 0.9 kg for females (Serena and Soderquist 1995). Once widespread throughout the south-west of Western Australia and across the continent into western New South Wales and Queensland, it is now restricted to the south-west of Western Australia (Serena and Soderquist 1995). It is listed as a rare and endangered species in Western Australia. During daylight hours it takes refuge in hollow logs, old root channels and below-ground cavities. Its diet consists of a variety of small mammals, reptiles, insects and occasionally birds. Serena and Soderquist (1995) provide further details of the biology and ecology of the chuditch.

The quenda prefers areas of dense vegetation, which most often occur along creek lines and valley floors in the Perup forest. The mean weight of adults varies from about 0.5 to 1.6 kg. It is omnivorous and digs for bulbs, earthworms and insects. During the day, the quenda rests in a nest usually constructed at ground level amongst dense vegetation. Braithwaite (1995) provides further details of its biology and ecology.

The common brushtail possum, as the name suggests, is the most common and widespread of the Australian possums. Although arboreal, it spends sufficient time on the ground to be readily trapped. The Western Australian subspecies is smaller than its south-eastern Australian counterpart, with adults weighing about

Table 2. Number of trap sessions (per year), trap effort (number of trap nights) and mean capture rates of four native mammal species for Yendicup and Boyicup forest blocks over the period 1974–1999

Year	Yendicup			Boyicup		
	No. trap sessions	No. trap nights	Capture rate (%)	No. trap sessions	No. trap nights	Capture rate (%)
1974	0	0		9	1651	8.8
1975	0	0		13	2645	11.5
1976	2	660	0.9	9	3052	12.1
1977	3	1200	1.9	2	1140	11.3
1978	6	2400	2.8	3	912	10.5
1979	6	2400	5.9	2	912	12.5
1980	6	2400	11.0	2	912	36.3
1981	6	2400	10.7	4	1470	32.6
1982	5	2000	16.1	2	440	33.8
1983	3	186	22.6	4	1342	31.9
1984	4	201	30.2	4	900	35.9
1985	2	192	32.6	4	1000	30.8
1986	2	186	37.6	2	350	29.5
1987	1	192	37.8	0	0	
1988	1	186	37.9	0	0	
1989	2	192	33.9	0	0	
1990	1	228	55.6	0	0	
1991	0	0		0	0	
1992	0	0		0	0	
1993	0	0		0	0	
1994	1	150	52.7	0	0	
1995	0	0		0	0	
1996	1	150	56.4	0	0	
1997	0	0		0	0	
1998	1	150	75.2	0	0	
1999	1	150	72.0	1	150	48.6
Total	54	15 251		57	16 686	

1.2–2.0 kg. These animals are herbivores, feeding on a variety of foliage and blossoms. During daylight hours they rest in tree hollows. Further details of its biology and ecology are provided by How and Kerle (1995).

Methods

Trapping of the four species described above was carried out at two locations within the Perup forest: Yendicup block (34°09'S, 116°36'E) and Boyicup block (34°18'S, 116°34'E). These sites, each about 3000 to 4000 ha, were chosen because (a) they represent northern and southern elements of the Perup forest respectively and (b) they were the focal points of earlier fauna studies, including a woylie reintroduction project (Christensen 1980b; Leftwich 1983). Permanent trapping transects were established along vehicle access tracks within these forest blocks. Wire mesh cage traps (40 cm × 40 cm × 60 cm) with a bait consisting predominantly of peanut butter and rolled oats (universal bait) (Sampson 1971; Christensen 1980b) were set at marked and numbered locations at 200–300 m intervals along the network of tracks within the two blocks. The lengths of the transects varied over the period of monitoring, ranging from 15 to 20 km at each location. Traps were set on the edge of the road so that they were visible from a vehicle. They were placed on level ground and under a bush or adjacent to a large log to afford some shelter for the trapped animal and inspected early each morning. During the early stages (1972–1976) when Christensen was conducting detailed studies, detailed morphological measurements including head size and length of tail, body and pes were made and all animals were marked by ear tagging (for details see Christensen 1980b; Leftwich 1983). After 1983, and as part of the monitoring program, fewer measurements were made and animals were not marked (ear tagged) after 1990. Measurements after 1983 included species, sex, weight and breeding status. A trap session (Table 2) is a continuous period of trapping lasting usually 3 or 4 nights, and a trap night is one trap exposed for one night. Capture rate is the number of animals caught (including recaptures) per 100 trap nights. The annual capture rate reported here is the mean of the trap sessions for that year. This trapping method is unsuitable for other native mammals that occur in the area, such as numbat, tammar wallaby, western ringtail possum and brush-tailed phascogale because these animals are either not attracted to the bait (numbat, western ringtail possum), are too large for the traps (tammar wallaby), or are arboreal (brush-tailed phascogale).

Over the 26 years of monitoring, the frequency (number of trap sessions per year) and intensity (number of trap nights per session) varied as shown in Table 2. This was in response to the level of research activity and the availability of resources to carry out the monitoring. The most intense trapping took place in 1975 and 1976 as part of Christensen's detailed biological studies conducted in Boyicup block. Trapping methods employed by Christensen were the same as described above although he set traps at 100 m intervals, and in addition to cage traps he set pen traps to catch tammar wallabies, one of the species he was studying in detail.

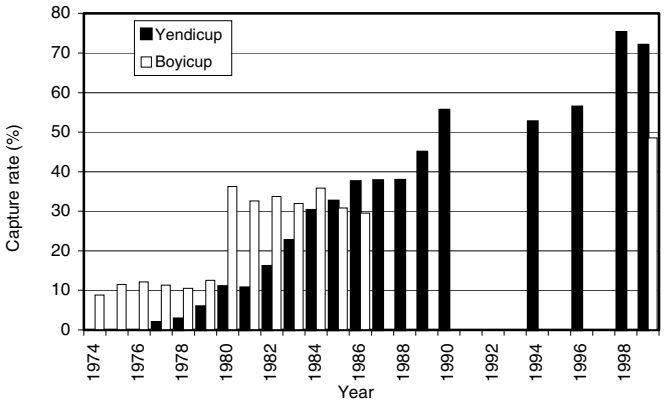

Figure 4. Mean annual capture rates for all target mammals (woylie, chuditch, quenda and common brushtail possum) in the Perup forest for the period 1974 to 1999. Monitoring was not carried out in 1991, 1992, 1993, 1995 and 1997 (see Table 2).

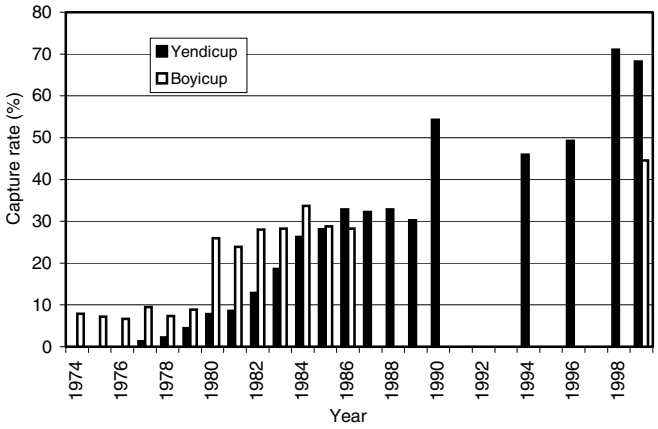

Figure 5. Mean annual capture rates for woylie in Perup forest

Results

More than 5403 individual adults of four native mammal species were trapped from a trap effort of 31 937 trap nights. The number of annual trap sessions, the annual trap effort and the mean annual combined capture rate for the four native mammals (woylie, chuditch, quenda and common brushtail possum) are shown in Table 2. The number of trap nights for both sites and over the 26 y monitoring period varied from nil in some years to over 3500 in others. Capture rate varied from a low of 0.9% from 660 trap nights at Yendicup block in 1976 to a high of 75.2% from 150 trap nights in Yendicup in 1998 (Table 2). Capture rate in Boyicup block increased from 8.8% in 1974 to 48.6% in 1999 (Fig. 4).

The number of animals trapped is shown in Tables 3 and 4, by species. Clearly, woylies were the most commonly caught animal and accounted for a high proportion (about 80% overall) of all captures shown in Figure 4. Woylies also showed the most dramatic increase in capture rate over the monitoring period, increasing from 0% at Yendicup block in 1974 (prior to their reintroduction), to 71% in Yendicup block in 1998 (Fig. 5). The increase in capture rate of woylies was accompanied by observed increases in sightings, road kills and in digging activity by the animals. The increase in woylie capture rate probably reflects a real and significant increase in abundance of the species. Almost twice as many males as females were trapped (Tables 3 and 4), suggesting a sex bias related to trapping. However, the sex ratio of joeys (pouched young) was similar (Tables 3 and 4), suggesting that the sex bias is real and not an artefact of trapping technique. The mean weight of adult woylies in Yendicup block (1388 g) was significantly greater than the mean adult weight for Boyicup block (1283 g) (Tables 3 and 4).

The capture rate of chuditch was low and quite variable from year to year, but showed an increasing trend with time from 1974 to 1997 and a decline in 1998 and 1999 (Fig. 6). When monitoring commenced in Boyicup block in 1974, the mean annual chuditch capture rate was 0.1%, but increased to around 2.5% in the 1990s following intensive, broadscale fox control. The capture rate of chuditch was consistently higher in Yendicup block, peaking at 4.9% in 1982. No chuditch were trapped at either location in 1999. Unlike woylies, there was no sex bias in animals trapped (Tables 3 and 4). The mean weight of adult chuditch was 783 g and 850 g for Yendicup and Boyicup blocks respectively. While males were heavier than females, these weights are considerably

Table 3. A summary of individual native mammals trapped at Yendicup forest block 1974–1990. Individuals were not marked after 1990

Species	Number of adults	Male : female ratio		Adult weight (g)	
		Adult	Joey	Mean (standard error)	Maximum
Woylie	1712	1.8:1	1.9:1	1388 (8)	2068
Common brushtail possum	228	1.8:1	2.4:1	1482 (22)	2030
Chuditch	61	1.1:1	1.2:1	783 (29)	1040
Quenda	59	0.7:1	0.7:1	1120 (136)	2137

Table 4. A summary of individual native mammals trapped at Boyicup forest block 1974–1990. Individuals were not marked after 1990

Species	Number of adults	Male : female ratio		Adult weight (g)	
		Adult	Joey	Mean (standard error)	Maximum
Woylie	2759	1.7:1	1.6:1	1283 (5)	2114
Common brushtail possum	407	1.6:1	1.7:1	1473 (23)	2195
Chuditch	46	0.9:1	0.9:1	850 (90)	1600
Quenda	131	1.9:1	2.1:1	1262 (43)	2700

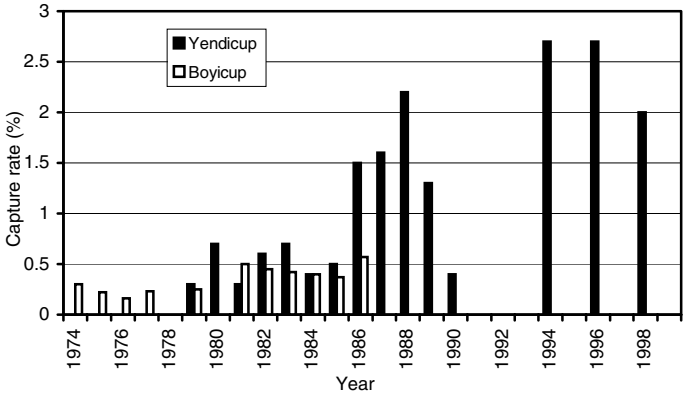

Figure 6. Mean annual capture rates for chuditch in Perup forest

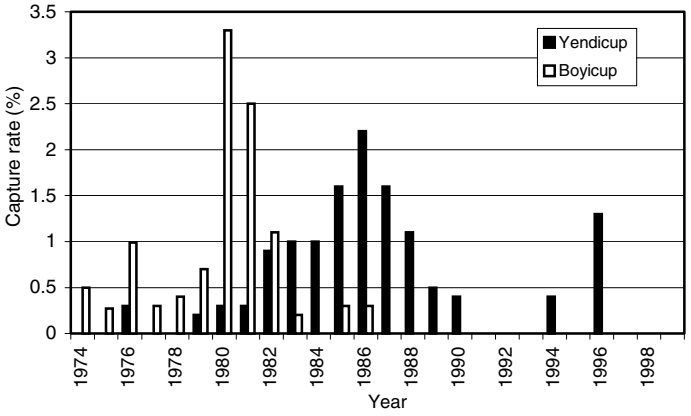

Figure 7. Mean annual capture rates for quenda in Perup forest

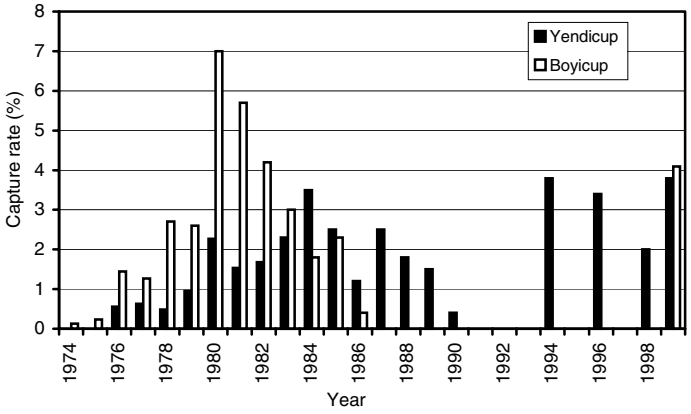

Figure 8. Mean annual capture rates for common brushtail possum in Perup forest

lower than mean weights reported by Serena and Soderquist (1995).

Quenda capture rates were also very low compared with the woylie, ranging from 0% to 3.3% (Fig. 7). The trends in the capture rate of the quenda differed from that of the woylie and the chuditch. Rather than showing an increase in capture rate with time, capture rates of quenda were low during the 1970s, then increased through the mid-1980s only to decline through the late 1980s and 1990s. No quenda were trapped at either location in 1998 and 1999. In Yendicup block, there were more females trapped than males (Table 3). The adult sex ratio was the same for joeys. However, in Boyicup block (Table 4) the sex ratio was the reverse, with almost twice as many males being trapped as females. This sex ratio was similar for joeys (Tables 3 and 4). Trends in capture rates for the common brushtail possum were similar to the quenda initially (Fig. 8), but after declining in the late 1980s, recovered and remained relatively high throughout the 1990s. There was a sex bias in adults trapped at both sites, with almost twice as many males being trapped as females (Tables 3 and 4). As with the woylies, the sex ratio of joey common brushtail possums was similar to the adult ratio, suggesting a sex bias in the population.

Discussion

Monitoring, while methodical, is neither scientific research nor a substitute for it. In the context of forest management, it is a process for checking management performance over large space and time scales in relation to stated goals. Monitoring serves management by demonstrating long-term trends in the performance of measured attributes. If trends are downward, or slow to improve, management is alerted to the need to conduct further investigations, which may include experimental research.

Native mammal conservation is a key management goal for the Perup forest. The long-term monitoring reported here shows that there has been an increase in the capture rates of woylies, chuditch and common brushtail possums over the monitoring period, and that after an initial increase, quenda capture rates have declined in the last ten years. Unlike scientific research, monitoring is not a process in which hypotheses can be tested. Nevertheless, it is underpinned by scientific knowledge and its results may assist interpretation of trends in the attribute being monitored, in this case, mammal capture rates.

The first formal native mammal trapping and spotlight survey in the Perup forest was conducted by Christensen and Leftwich in 1971, who reported a woylie capture rate of 24–30% (Leftwich 1983). When Christensen commenced detailed fauna studies in the area in 1974, he reported a mean woylie capture rate of about 8% for the southern part of the Perup forest (Boyicup block) (Table 2) and that woylies and other mammals had severely declined in the northern part (Yendicup block). In 1976, Christensen was unable to trap any woylies in Yendicup block despite a trap effort of 660 trap nights (Figs 4 and 5). He observed a relatively high density of foxes in the region and later reported that predation by foxes was probably the cause of the decline. Christensen (1979) observed that the increase in fox density occurred soon after a reduction in the rabbit poisoning effort on agricultural lands throughout the south-west during the early 1970s. He also reported high levels of fox predation on radio-collared animals during an investigation of the effects of fire on the woylie and the tammar wallaby (Christensen 1980b). These observations are consistent with those reported by Kinnear *et al.* (1988) and Kinnear *et al.* (1998), who recorded a significant increase in rock wallaby populations following fox control and a decrease in populations in the absence of control.

Management of the Perup forest over the monitoring period has consisted of a prescribed burning program, fox control by baiting and the reintroduction of woylies to Yendicup block. Fires, either planned or unplanned, that have occurred in the area over the

monitoring period (Table 1, Fig. 3) have had no discernible impact on the capture rate of native mammals, with trends in capture rates being independent of the time since the last fire. Similarly, there is no apparent relationship between mean annual rainfall and capture rates, as the variation in annual rainfall over the monitoring period (Fig. 2) was within normal limits (about 15% of the mean) and there were no years of drought or excessively high rainfall.

The trends in mammal capture rate coincide with trends in fox baiting effort (Fig. 4). For example, in the absence of fox control measures prior to 1977 (Table 1), mean annual capture rates were less than 12%. Woylies had apparently become extinct in Yendicup block (0% capture rate), or were at extremely low densities prior to the reintroduction of 52 animals in 1977. Over the period 1977 to 1989, the mammal capture rate increased to 35–38%, coinciding with the implementation of irregular baiting to control foxes (Table 1). The capture rates in Yendicup block were consistently lower than Boyicup block over this period because the mammal populations in Yendicup had declined to very low levels (Fig. 4) prior to woylie reintroductions and fox baiting. From 1990 to 1996, mean annual capture rates in Yendicup block increased to around 55%, coinciding with regular (once or twice yearly) broad-scale fox baiting using aircraft. Over the last two years of monitoring (1997–1999) the capture rate increased further to more than 70% in Yendicup block, coinciding with regular (four times yearly), broad-scale fox baiting (Table 1).

The 1999 capture rate in Boyicup block (49%) was considerably less than that for Yendicup block. The reasons for the lower capture rate are not clear. Both areas have experienced similar management histories (fire, logging, baiting), but there is a difference in geomorphology and climate between the two areas. The southern area (Boyicup) is generally more deeply dissected with more fertile soils, higher rainfall and denser understorey. Christensen (1980b) characterised these sites as being more suitable habitat for woylies, but his analysis of woylie occurrence and density may have been confounded by differences in predation pressure across the range of woylie distribution in the Perup forest. The potential carrying capacity in relation to habitat types and predator control needs further study.

As discussed, woylies have been by far the most common species trapped, especially since the late 1970s. This reflects a high population of this species compared with other species, but the trapping technique may also have contributed by favouring woylies over the other species. Woylies are ground-dwelling and occur across the landscape in a range of habitat types, so are more likely to encounter a trap. It is also possible that they have a superior sense of smell and are able to quickly locate the bait in the traps, in effect winning first access to the traps. Another possibility is that they are less cautious than other species about entering traps. The other species, as well as being less abundant, are probably less likely to be trapped because of their behaviour. For example, chuditch are carnivorous, so may not have been as attracted to the (peanut butter) bait as woylies. Quenda are omnivorous and are most commonly found in dense riparian vegetation, which comprises a relatively small proportion of the total landscape and habitat type. While they spend time on the ground, common brushtail possum are arboreal, so are less likely to encounter a trap placed on the ground.

An issue that emerged during the last two years of this monitoring program, when capture rates at Yendicup were greater than 70%, was the problem of trap availability, resulting mainly from the very high population density of woylies. In Yendicup block, about 70–75% of the traps were occupied by woylies, and another 15–20% of traps had been disturbed or tampered with (set off, turned over, etc.) by woylies (and other animals), significantly reducing the availability of traps to other species that occur in much lower population densities. For example, no chuditch or quenda were trapped in 1999, although these species are known from spotlight surveys to occur in the area (Graeme Liddelow, *pers. comm.*). Quenda diggings and scats are quite distinctive and quite abundant in certain habitat types, yet no quenda were trapped in 1999. The problem of reduced trap availability due to trap saturation by woylies, and trap tampering especially by woylies and common brushtail possums, gave rise to erroneous estimates of the densities of the less common species for the last two trap sessions (1998 and 1999). The problem of reduced trap availability to animals (such as the chuditch) due to very high population densities of woylies was clearly demonstrated by Wayne *et al*. (2000), who used a meat-meal and fish oil bait that improved chuditch capture rates by 800% and reduced woylie capture rates by 50%.

Conclusion

Monitoring by measuring capture rates over 26-y has shown that management strategies aimed at conserving native mammals in the Perup forest have been successful for woylie, chuditch and common brushtail possum. The trend of increasing capture rate over the 26-y monitoring period is most likely to be associated with increased fox control effort. Kinnear *et al*. (1998) have clearly demonstrated the positive impact of fox control programs on rock wallaby populations. We believe that the long-term monitoring data presented here further support their conclusions that effective fox control strategies are crucial for conserving extant populations of many medium-sized mammal species in south-western Australian ecosystems.

Monitoring has also shown that quenda capture rates declined after an initial increase. This decline is most likely an artifact of the monitoring protocol rather than a real decline in quenda abundance, but needs closer investigation. The trapping method used to monitor mammal populations was devised in the early 1970s when capture rates were mostly less than 10%. The technique is suitable when mammal population densities are low (capture rates say <35%), but is not suitable in situations of very high woylie densities because very few traps are available to less abundant species. We recommend that monitoring should continue in the Perup Forest, but that new methods be devised to accommodate the high abundance of mammals now in the forest. Trap effort may need to increase and/or different bait types may need to be tested in an attempt to adequately monitor the abundance of other, less common species. Trapping should be complemented by regular spotlight surveys to monitor the abundance of other species such as the brush wallaby, the brush-tailed phascogale, the western ringtail possum and possibly the tammar wallaby. The revised monitoring protocol should also include a method for estimating fox abundance.

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