Fire Management Guideline:

Ngwayir (western ringtail possum)

January 2006

Adrian Wayne

Science Division, Department of Conservation and Land Management
Locked Bag 2, Manjimup, 6258 Western Australia

Prepared by request from Roger Armstrong to be used as part of the Fire and Biodiversity program and linked with FDIS.

Species Name

Pseudocheirus occidentalis

Weight

800g – 1330g (mean = 1080g), for adult males and females. No sexual dimorphism.

Description

Dorsal and lateral coat colour very dark brown to almost black. Creamy white ventrally and behind the ears. Distinguishable from the koomal (common brushtail possum, *Trichosurus vulpecula hypoleucus*) by the ngwayir's smaller size, smaller rounded ears, long slender tail and relatively short coat. All ngwayir have a white tip to the tail (on average about 10cm white tip but variable). Some koomal also have white tipped tails of variable length but the tail is distinctly brushy, not slender, and slightly shorter relative to body length.

Other Common Names

ngwayir (pronounced 'n-waar-ear') or western ringtail possum

Distribution

Key To Map: Black = present distribution; Mid-grey = historic (> 30 years); Pale-grey = Fossil

The distribution and conservation status of the ngwayir is comprehensively reviewed by de Tores (in press). The contemporary known range of ngwayir is patchy and extends along the coast between Yalgorup National Park, south of Mandurah and Cheyne Beach, east of Albany. Inland populations are known in the lower Collie River valley, around Collie and Harvey, and in the southern forests around Manjimup, Pemberton and Northcliffe and particularly in the Upper Warren catchment area, east of Manjimup (including populations in the Perup Nature Reserve and the proposed National Park around Kingston forest block). Translocation release sites are located at Leschenault Peninsula Conservation Park, Yalgorup National Park, Lane Pool Reserve and Karakamia Wildlife Sanctuary.

Prior to European settlement the range of ngwayir extended from just north of Perth, east to Pingelly, and south east to Palinup River. The pre-historic range was even more extensive (de Tores in press).

Habitat

The habitat requirements of the ngwayir prior to European settlement are unknown, however, it is expected to have been different to some extent from what is suitable today. For example, the introduction of eutherian predators and substantial changes to vegetation structure and possibly composition in response to changed fire regimes, timber harvesting and climate change will have affected and will continue to do so, those habitat characteristics required to support viable ngwayir populations.

Currently, coastal populations of ngwayir are predominantly associated with the peppermint tree (*Agonis flexuosa*), which is its primary source of food in these habitats. *Agonis flexuosa*-dominated ngwayir habitat includes the peppermint woodlands, peppermint/tuart (*Eucalyptus gomphocephala*) forests, and other near-coastal vegetation types where *Agonis flexuosa* is common. Ngwayir populations in the Collie River valley are also generally associated with *Agonis flexuousa*, as are low-density populations found within the karri forests. Most other extant inland populations of ngwayir, including the most extensive inland populations of the Upper Warren region, are found in jarrah (*Eucalyptus marginata*) forest, where *Agonis flexuosa* is either rare or absent. In these habitats, young jarrah leaves, particularly from saplings, constitute the primary source of food.

Accessible foliar nutrients are believed to be a particularly important determinant of good quality ngwayir habitat (Wayne et al. 2005d). Populations associated with *Agonis flexuosa* are typically relatively dense, but are low or absent where foliar nutrients are relatively low (Jones et al. 1994a). Relatively more mesic and riparian areas (e.g. *Melaleuca incana* thickets in the jarrah forest) are generally thought to provide good habitat (Jones 1994a; Soderquist and MacNally 2000; Wayne et al. 2000). However, this is not necessarily always so. For instance, valleys with dense

Gastrolobium bilobum do not support as high-density populations as nearby upslope open jarrah forest (Wayne et al. 2005b). Although ngwayir abundances in the jarrah forest have been negatively associated with increasing fragmentation by farmland, the highly selective nature of agriculture for the more fertile land also coincides with what is likely to have been particularly good habitat for ngwayir (Wayne et al. 2006). Therefore, relatively unfragmented jarrah forest close to small, isolated farmland may support reasonable densities of ngwayir.

Midstorey and/or overstorey density that provides sufficient connectedness for arboreal travel (i.e. reduced vulnerability to terrestrial predators) is also an important determinant of contemporary habitat quality in the presence of introduced predators (Jones et al. 1994a, Wayne et al. in press). The abundance of tree hollows for diurnal shelter is also generally an important factor, particularly in more open habitats such as the tuart and jarrah forests (Jones et al 1994a, Wayne et al. in press). Where food resources are very good, ngwayir can be supported in high densities despite tree hollows, if dense midstorey vegetation is available to construct and conceal dreys (i.e. self-constructed nests) and/or where there is an abundance of large (>2 m tall), multi-headed balga (*Xanthorrhea preissii*) with well developed dead-leaf skirts (Wayne et al. 2000, in press).

Behaviour and Ecology

The ngwayir is nocturnal, highly arboreal and a specialised folivore (i.e. feeds on the leaves of a few select plant species). Although rarely and reluctantly terrestrial, when the ngwayir is moving on the ground it travels very low with the tail held straight and parallel to the ground. When approached, it generally remains stationary and is often difficult to detect by spotlight because it tends to look up or away (i.e. detection by eye-shine is limited) and is frequently concealed by the leaves in which it feeds. When imminent danger is perceived, most individuals rapidly climb to high points, preferably tree crowns when accessible. Vocalisations are rare, except when particularly stressed there may be the occasional alarm call (short, bird-like call with variable but high pitch). Ngwayir are predominantly solitary except for mothers with sub-adult offspring and during the breeding season when males are pursuing females that frequently still have offspring at heal.

Ngwayir are particularly sensitive to anthropogenic disturbance such as logging, fire, introduced predators and forest fragmentation (Wayne et al. 2006). The interaction between multiple disturbance factors may be especially detrimental to populations, such as the impact of introduced predators with logging, fire or forest fragmentation (Friend and Wayne 2003; Wardell-Johnson et al. 2004; Wayne et al. 2000, 2006).

The predator-naïve nature of the ngwayir and its limited reproductive capacity, (especially in the jarrah forest) are likely reasons for the slower and more limited recovery of ngwayir populations in areas subject to the standard ‘Western Shield’ fox-control program (CALM 2000). However, denser ngwayir populations in jarrah forest are associated with areas that have had more extensive fox-control sustained over a longer period of time (Wayne et al. 2006).

Tree hollows are the primary diurnal shelter resource used by ngwayir, and are especially important in more open habitats. Dreys are commonly used in the coastal

Agonis flexuosa woodlands and where midstorey density is sufficiently dense for effective concealment from predators and protection from the weather. Balga can also be used extensively where available. Hollow logs, burrows and forest debris are rarely used except in exceptional circumstances such as during logging disturbance (Wayne et al. 2000). Home-ranges based on the diurnal refuges used by individuals in the jarrah forest average 2.7 ha (0.2-11.1 ha) (Wayne et al. 2000). Home ranges in *Agonis flexuosa* habitat are generally less than 2 ha and average 0.4 ha and 0.3 for females and males respectively (Jones et al. 1994b). Individuals in the jarrah forest can disperse up to 1.5 km, however, these events are generally rare once maturity is reached (Wayne et al. 2000).

Diet

Nutrition is likely to be one of the most important factors associated with the abundance of ngwayir and the capacity of populations to withstand and recover from disturbance. The availability of nutrients within the food plants varies seasonally (e.g. leaf flushes, nutrient and anti-nutrient concentrations) and between plants. As a consequence ngwayir are necessarily highly selective of the plants they feed on.

Agonis flexuosa is the most preferred common food plant and is able support relatively high densities of ngwayir where it is available (i.e. mainly coastal and near-coastal *Agonis* woodlands, associated with tuart forests, in more mesic and riparian areas of the jarrah forest and to some extent in karri forests). Jarrah saplings about 2-6 m tall are the most important source of food in open jarrah forests. *Melaleuca incana* thickets can support high densities of ngwayir and *Corymbia callophyla* is also an important food source in the jarrah forest. Other possible foods in the jarrah forest include *Eucalyptus rudis*, *Melaleuca viminalis*, *Persoonia longifolia,* and *Bossiaea ornata*.

Breeding

Breeding seasonality in the jarrah forest is more acute than observed in coastal areas, with 77% of births occurring in May – June and 23% in October – November (Wayne et al. 2005d). Near-coastal populations can breed throughout the year but peaks occur April – June and October – December (Jones et al. 1994b). The period of late lactation by mothers and weaning offspring (i.e. 5-6 months of age) is when energy demands for both are particularly high (Munks and Green 1995). In the jarrah forest these seasonal periods coincide with peaks in food availability, i.e. the main peak of jarrah leaf flush in August – November and the secondary peak in autumn (Abbott and Loneragan 1986; Abbott et al. 1989). Similar temporal associations between breeding and nutritional quality and quantity occur in the *Agonis flexuosa* woodlands (Jones et al. 1994a, 1994b; Wayne et al. 2005d).

Litter sizes are also associated with nutrition and diet (Wayne et al. 2005d). In near-coastal populations litters range from 1-3 young (Jones et al. 1994b). In the jarrah only single young have been found viable (Jones et al. 1994b; Wayne et al. 2005d). Young become independent and mature by 12 months of age. Ngwayir in the wild are expected to live on average at least three years but rarely more than four or five years (Wayne et al. 2005d). Most adult deaths in the jarrah forest (84%) occur in the cooler-

wetter months (April – September) when quality food (i.e. young leaves of particular species) is scarce and body condition is poor (Wayne et al. 2005d).

Threatening Processes

Habitat loss, degradation and fragmentation are key threatening processes to remaining ngwayir populations. Clearing for urban and agricultural development in the Bunbury and Busselton areas is especially problematic but is also an issue around other coastal towns and settlements. The selection for the relatively more fertile land for agriculture has also probably removed much of the higher quality ngwayir habitat.

Introduced predators are also key threatening processes. Forest areas where fox control efforts have been substantial support higher densities of ngwayir (Wayne et al. 2006). Furthermore the maintenance of connectivity in arboreal vegetation is also expected to reduce the susceptibility of ngwayir to predation. Ngwayir are also known to be predated by cats (e.g. Dickman 1996; Wayne et al. 2000, 2005d). In some areas around Australia, reduced fox numbers can result in an increase in the numbers of feral cats (Christensen and Burrows 1995; Risbey et al. 2000; Read and Bowen 2001; Burrows et al. 2003). Concern exists that the same may occur in the jarrah forest and consequently be detrimental to ngwayir (Jones 2004; de Tores et al. 2004). Although it has been shown that ngwayir abundances are positively associated with increased fox baiting (Wayne et al. 2006) the potential remains that cats may substantially impact on ngwayir populations and their long-term viability.

Timber harvesting in the jarrah forest substantially reduces the survivorship on ngwayir individuals, due largely to an interactive effect with introduced predators (Wayne et al. 2000). At a landscape scale timber harvesting also has the potential to threaten the viability of populations (Wayne et al. 2001; 2006, unpublished data).

Changed fire regimes, particularly the increased frequency of intense fire events, are also thought to be responsible for the decline of ngwayir (Jones 2004; Wardell-Johnson et al. 2004, Wayne 2005). The most abundant populations of ngwayir in the jarrah forest have been associated with areas that have either remained unburnt for more than 20 years, or have more recently experienced low intensity fire (i.e. an average char height on mature jarrah trees less than 2 m) (Wayne et al. 2006). Small, patchy and low intensity fires may also be important for the long-term viability of ngwayir populations in *Agonis flexuosa*-dominated habitats (Jones et al. 2004).

Disease, climate change, *Phytophthora cinnamomi*, and possibly competition from other fauna that use tree hollows have also been identified as major threatening processes. All of these factors are discussed in more detail in the ngwayir recovery plan (in preparation).

Conservation Status

Under the Western Australian *Wildlife Conservation Act 1950* the ngwayir is listed as rare or likely to become extinct. It is considered Vulnerable under the *Environment Protection and Biodiversity Conservation Act 1999* and Threatened (Vulnerable) in the IUCN Red List (IUCN 2004). The conservation status of the ngwayir was recently reviewed (de Tores in press).

Management in Western Australia

The conservation and management of the ngwayir is outlined in detail in a recovery plan, which should be consulted for further information (in preparation).

Recommendations for Prescribed Burning

Preamble

Recommendations for fire management in relation to the conservation of ngwayir are presented in recognition that management decisions and actions affecting this species will necessarily continue in the absence of complete knowledge of the consequences. Therefore, the interim advice provided here is based on the best available knowledge at the time, based on scientific information (published and unpublished) and expert opinion. The intention is that the application of this advice will reduce the negative pressures on ngwayir populations and improve the conservation outcomes for this species. It is also recognised that some of the management recommendations presented may not necessarily result in optimal outcomes for the species. These recommendations are therefore presented on condition that they are applied within an active adaptive management context (*sensu* Walters and Holling 1990; Lee 1999) in which their effectiveness at achieving desirable conservation outcomes are assessed in a scientifically rigorous manner; thereby allowing fire managers to learn and improve while doing. Furthermore, recommendations for appropriate fire management strategies and actions will necessarily need to respond over time to new scientific information as it becomes available from other sources independent of the active adaptive management approach. In the meantime, where information is not substantiated by rigorous science a precautionary approach to management should be used.

It is also acknowledged that fire management must necessarily consider recommendations associated with ngwayir conservation within the complex context of the requirements of other specified flora and fauna, biodiversity conservation in general, other fire management objectives, and many other factors associated in and around an area under consideration.

Ngwayir distribution maps should be consulted and wherever ngwayir is present within or adjacent to the proposed burn the following strategy is recommended.

Fire Management Objectives:

- Protect ngwayir habitat from intense wildfire.
- Maintain viable ngwayir habitat in forest where the ngwayir is extant and likely to occur.
- Maintain viable ngwayir habitat in forest adjacent to and/or between extant ngwayir populations to assist in the recovery and communication between populations.

Fire Management Strategies:

Wildfire

The risks of wildfire should be minimised and suppression efforts maximised in areas supporting remnant ngwayir populations as well as potential habitat, provided that the cumulative effects of these activities do not in themselves threaten the viability of ngwayir populations.

The relatively low frequency of intense wildfires in the Perup and Upper Warren area has been postulated as a major contributing factor for the persistence of a diversity of mammalian species, including ngwayir, that have been lost from many other areas of jarrah forest (Wardell-Johnson et al. 2004).

Intense wildfires are detrimental to the survival of ngwayir individuals and potentially entire populations depending on the extent of the wildfire and the proximity of the affected area to other ngwayir populations that may function as source populations for recolonisation. Food and shelter resources within seriously affected areas may also take decades to recover before the habitat is suitable to support ngwayir again.

Prescribed burns

Nutrition is apparently fundamentally important to the life history and population viability of the ngwayir (Wayne 2005). Most births in the jarrah forest occur in May – June with a secondary peak in October – November. The greatest energy demands on most mothers and young coincides with the spring leaf flush of jarrah and the high energy demand of the secondary breeding peak is associated with the less pronounced and more variable autumn leaf flush. Most adult deaths occur in the cooler-wetter months (April – September) when quality food (i.e. young leaves of particular species) is scarce and condition is poor (Wayne et al. 2005d).

The effects on food availability are expected to be particularly important determinants of the response of ngwayir to a fire event. The effects of fire on shelter resources (particularly dreys in dense midstorey vegetation, balga, and hollows in trees) will also be important. Therefore, the intensity and timing of a fire will be particularly important considerations.

<u>Intensity:</u>

Ngwayir abundance is generally greatest in areas that have experienced fire that has resulted in an average char height on mature jarrah trees of less than 2 m (Wayne et al. 2006). Therefore, low intensity burns are generally recommended. Burns should aim, where possible, to retain the dead-leaf skirts on many of the large, multi-headed balga grass trees (e.g. more than 4 per hectare, where present), and maintain existing dense midstorey vegetation suitable for the construction and concealment of dreys.

Occasional moderate-high intensity fire may be required to regenerate dense midstorey vegetation before moderate-advanced senescence occurs and to assist in the development of a sustainable supply of tree hollows. More intense fires should

generally not be necessary for these purposes more than every 30 to 50 years, respectively.

Timing:

Burning in spring, especially prior to the completion of the jarrah leaf flush is considered most appropriate for ngwayir. Any leaf flush prior to the burn will have provided much needed nutrition to recover from the scarcity of good quality food over winter. If the fire is sufficiently early in spring, resprouting after fire is expected to be rapid and vigorous, resulting in a relatively short-term limitation of suitable food.

Fire in summer – autumn, particularly after any jarrah leaf flush, is expected to be the most detrimental to the short-term survival of ngwayir individuals and potentially the viability of the population. The removal of young jarrah leaves by fire in autumn are not expected to be replaced to any reasonable extent until the following spring. Given that this is the most important food source, it is expected that it will consequently be especially difficult for mothers and their young born in October – November to get sufficient nutrition to meet their energy demands when they are greatest. The ability for all adults and young alike to find enough suitable food to sustain themselves over winter, when food is already at its most limiting, is also substantially compromised by an autumn burn. Furthermore, the higher intensity fire behaviour typical of summer and autumn burning is likely to consume a large proportion of the understorey which will increase the vulnerability of ngwayir to predation and exposure to the weather, when they are at their most vulnerable.

If burning in autumn cannot be avoided then it is recommended that:

(i) the area of the burn be as small as possible, and/or numerous and substantial unburnt patches of habitat are retained within the burn boundary,

(ii) Especially high levels of introduced predator control be conducted immediately prior to and after the burn and until midstorey cover has largely recovered (i.e. at least 3 years). It is also important to consider that fox baiting is probably less effective during the wetter months, when ngwayir are most vulnerable, due to the accelerated moisture-driven deterioration of meat baits. Effective predator control immediately prior to the wet season is therefore particularly important.

Fire interval:

Ngwayir are generally more abundant in forest that has remained unburnt for more than 20 years when compared with forests burned in the last 8 years (Wayne et al. 2006). Therefore, fuel ages in ngwayir habitat in the jarrah forest should be

(i) on average greater than 20 years,
(ii) no older than the age at which the midstorey vegetation reaches a low to moderate state of senescence, and
(iii) in a condition that does not substantially compromise the risk of wildfire impacting on the entire ngwayir population.

Where this risk is considered unacceptably high, substantial areas of old fuels can be strategically 'broken up' by areas of younger fuel age in a manner that affords an acceptable security from wildfire, while continuing to support viable populations of ngwayir in high quality habitat with older fuels that can function as sources for recruitment into adjacent forests with younger fuels ages.

Given that more mesic areas such as riparian zones are generally thought to support higher densities of ngwayir (Jones et al. 1994a; see also Soderquist and Mac Nally 2000) these should generally be managed to have older fuels, while the upper slopes (which are generally, but not always, sub-optimal ngwayir habitat; Wayne et al. 2005 b) can be burned more frequently to provide greater security to these high value habitat areas.

If this is not sufficient to achieve security from wildfires and to meet other priority burning objectives, no more than 20-30% of substantial areas (i.e. >100 ha) of high-quality habitat should have suboptimal fuel age conditions (i.e. < 15-20 years). For example, the linear pattern of high-quality habitat associated with riparian vegetation along drainage lines and water courses can be 'broken up' with sections preferably no greater than 1 km and absolutely no greater than 2 km wide provided that high quality habitat adjacent and either side of these 1-2 km sections are maintained until such time as the more recently treated sections provide habitat suitable for supporting moderate densities of ngwayir (probably about 5-10 years).

Smaller areas of primary habitat need to take into greater consideration the suitability of adjacent habitat. For example, ensure that when burns are conducted in small areas of primary habitat, that the habitat conditions are optimised and maintained in the adjacent habitat (i.e. fuel ages) for at least a decade. Burn only a portion (preferably no more than half) of smaller primary habitat areas where possible, especially in the case of isolated populations (i.e. > 2-5 km from other known populations).

Spatial Extent:

The size of burns and the unburnt areas within a burn boundary that are suitable for sustaining viable populations of ngwayir is dependent on the extent and density of existing populations and the degree of isolation from other populations that may serve as sources for the recolonisation of suitable areas.

In general, however, a mosaic of multiple unburnt patches within the burn boundary, particularly within the core of the burn area are expected to provide a diversity of suitable food and shelter resources. All other things being equal and in the absence of further information, many 1-5 ha unburnt patches might be expected to provide greater benefit to ngwayir than a few larger unburnt patches within the burn area and may also be a more desirable outcome from a strategic fire control perspective. The percentage area unburnt within the burn boundary will depend on other burn and ngwayir habitat objectives but should generally aim to be at least 20-30% for burns greater than 400 ha (i.e. greater than 2 km across) and can be less if the burn size is smaller.

Other considerations:

Fire regimes can be used to promote food and shelter resources. Jarrah saplings 2-6 m tall are a particularly important source of food in open jarrah forest. Fire regimes that promote the establishment and maintenance of reasonable densities of saplings will be expected to favour the persistence of ngwayir populations. Fire regimes should also promote the growth and protection of other food plants where they are available such as *Agonis flexuosa*, *Melaleuca incana*, and *Corymbia callophyla.*

Silvicultural burns

Exclude where possible fire from all adjacent forest not requiring a silvicultural regeneration burn. Where this is not possible, minimise fire extent and intensity in non-treatment areas. Where this may be difficult, low intensity advanced burns prior to harvesting operations may be an option.

Logging heaps and trash remaining after roading and harvesting operations are used extensively by displaced ngwayir as diurnal refuge (Wayne et al. 2000). Burn these heaps and trash at night (preferably at least one hour after civil darkness) when they are not being used as refuge by ngwayir.

Considerations of predator control

Strategic and effective control of introduced predators is likely to be one of the most useful tools generally available for protecting viable populations of ngwayir (Wayne et al. 2005d). Jarrah forest areas that receive additional fox baiting over and above the standard Western Shield baiting program generally support higher population densities of ngwayir (Wayne et al. 2006). However, ngwayir are particularly vulnerable to introduced predators in the presence of contemporary disturbance such as fire or timber harvesting (Wayne et al. 2000) and in forest increasingly fragmented by farmland within at least a 5 km radius (Wayne et al. 2006). Therefore, where populations of ngwayir are known to occur or have a high likelihood of occurring within or adjacent to a burn, the following fox baiting program is recommended in addition to the standard 'Western Shield' program of four baitings per year at a density of 5 baits per square kilometre;

- The area within the burn boundary and a 5 km buffer surrounding the burn boundary should generally receive additional baiting (at a density of 5 baits

per square kilometre) every two months (i.e. increase frequency but not density of baiting).

- Although forest close to farmland is generally better habitat for ngwayir (presumed related to soil fertility and nutrition), the effectiveness of fox control reduces with proximity to farmland (Wayne et al. 2006; de Tores personal communication). Furthermore, the ngwayir is expected to be particularly sensitive to intense fire events and those that occur in summer – autumn (see above). Therefore if (i) the burn is within 5 km from farmland, (ii) the burn is moderate – high intensity and/or, (iii) the burn is in summer – autumn, then the same baiting area should be baited monthly.
- At least one, preferably two, additional baiting sessions should be conducted before the burn and should continue until the midstorey and overstorey cover has largely recovered (i.e. at least the next 18 months – 3 years). The additional baiting program should continue for at least 3 years for burns (i) within 5 km from farmland, (ii) burnt at moderate – high intensity and/or, (iii) burnt in summer – autumn.
- When and where there is an effective means of controlling cats in and around ngwayir populations, this should be undertaken in a manner that complements the fox-control.
- This predator control is also expected to afford benefit to most other native vertebrates, particularly mammals and large reptiles.

Considerations of potential competition

Responses to fire differ between the koomal and the ngwayir. Ngwayir are more abundant in long unburnt areas (Wayne et al. 2006). Koomal are more abundant in areas frequently burnt and close to fire boundaries (Wayne unpublished data). Both species are sensitive to fire intensity.

A potential impact of fire is increased competition from koomal on ngwayir. This additional pressure, particularly on isolated ngwayir populations, especially in fragmented habitat, is particularly important to consider and may threaten the viability of ngwayir populations. The differences in possum responses to fire may be used to minimise competition on ngwayir populations and surrounding areas.

Other Interesting Facts

- The ngwayir is close to the minimum physiological size limit for an animal on a strictly folivorous diet. The closely related common ringtail possum (*Pseudocheirus peregrinus*) in eastern Australia is slightly smaller. Some similarly sized species of lemur are also folivorous.
- The ngwayir is caecotrophic, meaning that in order to obtain sufficient sustenance from its food, it depends on an enlarged caecum for hind-gut fermentation, from which the food is passed and re-eaten (i.e. recycled) before the indigestible waste is defecated and discarded.

References

Abbott, I., B. Dell, and O. Loneragan. 1989. The jarrah plant. Pages 41-51 in B. Dell, J. J. Havel, and N. Malajczuk, editors. The Jarrah Forest: A Complex Mediterranean System. Kluwer Academic Publishers, Dordrecht.

Abbott, I., and O. Loneragan. 1986. Ecology of jarrah (*Eucalyptus marginata*) in the northern jarrah forest of Western Australia. Research Bulletin No. 1. Western Australian Government Department of Conservation and Land Management, Perth.

Burrows, N. D., D. Algar, A. D. Robinson, J. Sinagra, B. Ward, and G. Liddelow. 2003. Controlling introduced predators in the Gibson Desert of Western Australia. Journal of Arid Environments **55**:691-713.

CALM. 2000. Western Shield Fauna Recovery Program Strategic Plan (July 1999 - June 2004). Western Australian Government Department of Conservation and Land Management, Perth.

Christensen, P. E. S., and N. D. Burrows. 1995. Project Desert Dreaming: experimental reintroduction of mammals to the Gibson Desert, Western Australia. Pages 199-207 in M. Serena, editor. Reintroduction Biology of Australia and New Zealand Fauna. Surrey Beatty and Sons, Sydney.

de Tores, P. in press. Review of the distribution and conservation status of the western ringtail possum, Pseudocheirus occidentalis (Pseudocheiridae: Marsupialia), and implications for conservation management. Biological Conservation.

de Tores, P. J., M. W. Hayward, and S. M. Rosier. 2004. The western ringtail possum, *Pseudocheirus occidentalis*, and the quokka, *Setonix brachyurus*. Case studies for the February 2003 review of Western Shield. Conservation Science Western Australia **5**:235-257.

Dickman, C. R. 1996. Overview of the impacts of feral cats on Australian native fauna. Australian Nature Conservation Agency, Canberra.

Friend, G. R., and A. F. Wayne. 2003. Relationships between mammals and fire in south-west Western Australian ecosystems: what we know and what we need to know. Pages 363-380 in I. Abbott, and N. D. Burrows, editors. Fire in Ecosystems of South-West Western Australia: Impacts and Management. Backhuys Publishers, Leiden, The Netherlands.

Jones, B. 2004. The possum fauna of Western Australia: decline, persistence and status. Pages 149-160 in R. L. Goldingay, and S. M. Jackson, editors. The Biology of Australian Possums and Gliders. Surrey Beatty and Sons, Sydney.

Jones, B. A., R. A. How, and D. J. Kitchener. 1994a. A field study of *Pseudocheirus occidentalis* (Marsupialia: Petauridae). I. Distribution and habitat. Wildlife Research **21**:175-187.

Jones, B. A., R. A. How, and D. J. Kitchener. 1994b. A field study of *Pseudocheirus occidentalis* (Marsupialia: Petauridae). II. Population studies. Wildlife Research **21**:189-201.

Jones, B. A., C. E. Meathrel, and M. C. Calver. 2004. Hypotheses arising from a population recovery of the western ringtail possum *Pseudocheirus occidentalis* in fire regrowth patches in a stand of *Agonis flexuosa* trees in south-western Australia. Pages 656-662 in D. Lunney, editor. Conservation of Australia's Forest Fauna. Royal Zoological Society of New South Wales, Sydney.

Lee, K. N. 1999. Appraising adaptive management. Conservation Ecology **3**:3.

Munks, S. A., and B. Green. 1995. Energy allocation for reproduction in a marsupial arboreal folivore, the common ringtail possum (*Pseudocheirus peregrinus*). Oecologia **101**:94-104.

Read, J., and Z. Bowen. 2001. Population dynamics, diet and aspects of the biology of feral cats and foxes in arid South Australia. Wildlife Research **28**:195-203.

Risbey, D. A., M. C. Calver, J. Short, J. S. Bradley, and I. W. Wright. 2000. The impact of cats and foxes on the small vertebrate fauna of Heirisson Prong, Western Australia. II. A field experiment. Wildlife Research **27**:223-235.

Soderquist, T. R., and R. Mac Nally. 2000. The conservation value of mesic gullies in dry forest landscapes: mammal populations in the box-ironbark ecosystem of southern Australia. Biological Conservation **93**:281-291.

Walters, C. J., and C. S. Holling. 1990. Large-scale management experiments and learning by doing. Ecology **71**:2060-2068.

Wardell-Johnson, G., M. C. Calver, D. A. Saunders, S. Conroy, and B. Jones. 2004. Why integration of demographic and site-based studies of disturbance is essential for the conservation of jarrah forest fauna. Pages 394-417 in D. Lunney, editor. Conservation of Australia's Forest Fauna. Royal Zoological Society of New South Wales, Sydney.

Wayne, A. F. 2005. The ecology of the koomal (*Trichosurus vulpecula hypoleucus*) and ngwayir (*Pseudocheirus occidentalis*) in the jarrah forests of south-western Australia. Centre for Resource and Environmental Studies. The Australian National University, Canberra.

Wayne, A. F., A. Cowling, D. B. Lindenmayer, C. G. Ward, C. V. Vellios, C. F. Donnelly, and M. C. Calver. 2006. The abundance of a threatened arboreal marsupial in relation to anthropogenic disturbances at local and landscape scales in Mediterranean-type forests in south-western Australia. Biological Conservation **127**:463-476.

Wayne, A. F., A. Cowling, C. G. Ward, J. F. Rooney, C. V. Vellios, D. B. Lindenmayer, and C. F. Donnelly. 2005b. A comparison of survey methods for arboreal possums in jarrah forest, Western Australia. Wildlife Research **32**:701-714.

Wayne, A. F., S. O. Knapp, C. G. Ward, C. V. Vellios, J. F. Rooney, and D. B. Lindenmayer. submitted-b. Habitat selection for hollow-bearing trees by arboreal marsupials in the Mediterranean-type jarrah (Eucalyptus marginata) forest, Western Australia: II the ngwayir (Pseudocheirus occidentalis).

Wayne, A. F., J. F. Rooney, C. G. Ward, C. V. Vellios, and D. B. Lindenmayer. 2005d. The life history of *Pseudocheirus occidentalis* (Pseudocheiridae) in the jarrah forest of south-western Australia. Australian Journal of Zoology **53**:325-337.

Wayne, A. F., J. F. Rooney, C. G. Ward, I. B. Wheeler, and A. Mellican. 2001. Spotlight surveys to investigate the impacts of timber harvesting and associated activities within the jarrah forest of Kingston State Forest, with particular reference to the koomal (*Trichosurus vulpecula*) and ngwayir (*Pseudocheirus occidentalis*). Unpublished Progress Report. Pages 1-30. Western Australian Government Department of Conservation and Land Management, Manjimup.

Wayne, A. F., C. Ward, J. Rooney, and I. Wheeler. 2000. The immediate impacts of timber harvesting and associated activities on the ngwayir (*Pseudocheirus occidentalis*) in the jarrah forest of Kingston State Forest Block. Unpublished

Progress Report. Western Australian Government Department of Conservation and Land Management, Manjimup.