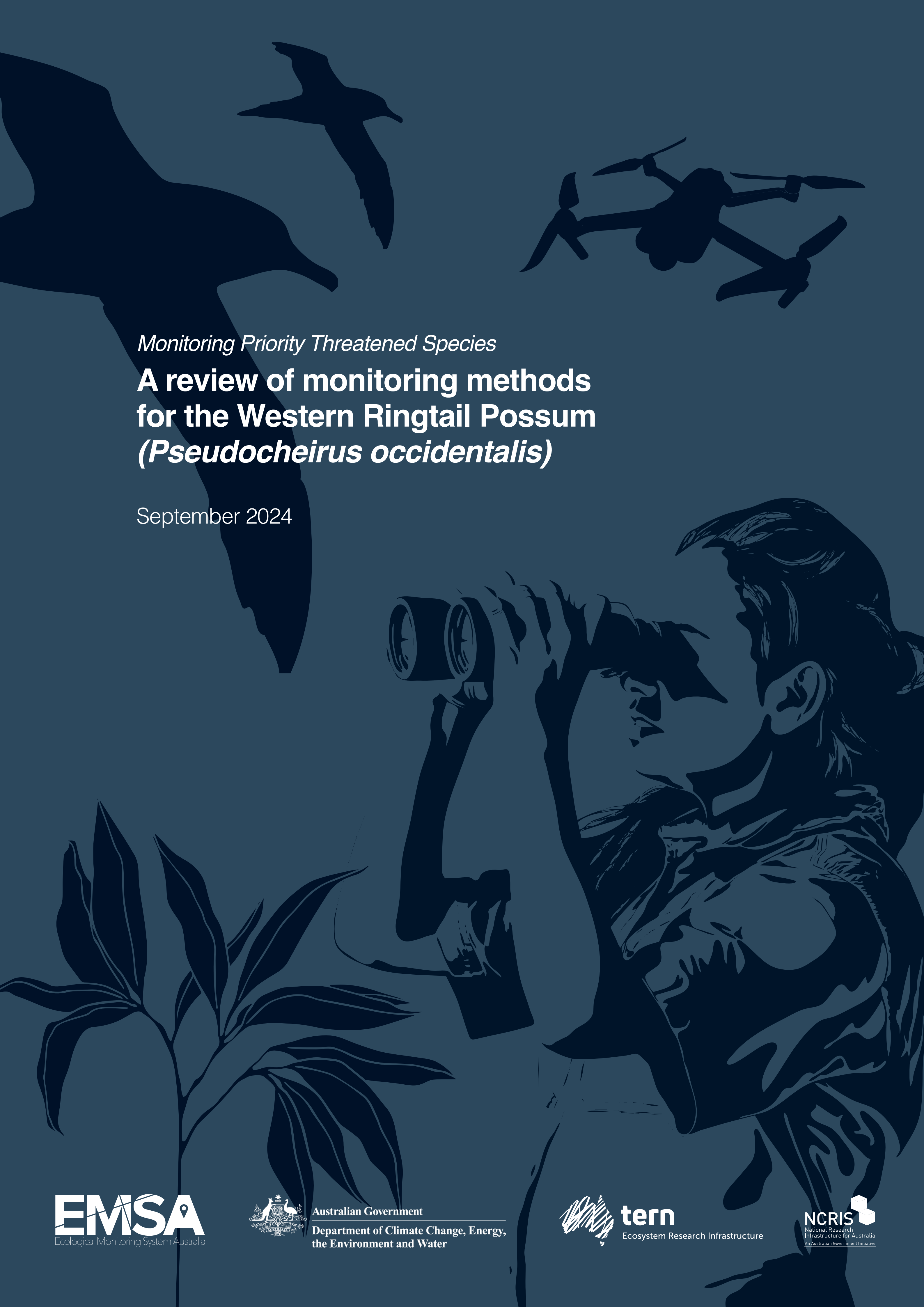

Monitoring Priority Threatened Species

A review of monitoring methods for the Western Ringtail Possum *(Pseudocheirus occidentalis)*

September 2024

EMSA
Ecological Monitoring System Australia

Australian Government
Department of Climate Change, Energy, the Environment and Water

tern
Ecosystem Research Infrastructure

NCRIS
National Research Infrastructure for Australia
An Australian Government Initiative

Citation

TERN Australia (2024) Monitoring Priority Threatened Species: A review of monitoring methods for the Western Ringtail Possum (*Pseudocheirus occidentalis*) Version 1 Report to the Department of Climate Change, Energy the Environment and Water. TERN, Adelaide.

Version

Version 1.

Last updated: 2 September 2024

Acknowledgements and contributions

This work was funded by the Australian Government Department of Climate Change, Energy, the Environment and Water.

Acknowledgement of Country

We acknowledge the Traditional Custodians of Australia and their continuing connection to land and sea, waters, environment and community. We pay our respects to the Traditional Custodians of the lands we live and work on, their culture, and their Elders past and present.

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About

This literature review collates information on one of the 110 priority threatened species identified in the *Threatened Species Action Plan 2022-2032* and has been reviewed by invited practitioners experienced in monitoring the species.

The *Survey Guidelines for Monitoring Threatened Species* project, a collaboration of the Department of Climate Change, Energy, the Environment, and Water (DCCEEW) and the Terrestrial Ecosystem Research Network (TERN), aims to improve our knowledge of threatened species by enhancing accessibility and sharing of quality scientific threatened species data. By developing best practice field survey guidelines and recommendations, practitioners will be better equipped to conduct standardised, repeatable surveys.

By identifying the monitoring methods typically implemented by practitioners, documenting and assessing the techniques known to work, and identifying opportunities to standardise the methods, we can move towards ensuring all monitoring is species-appropriate, comparable between practitioners and populations, and repeatable over time. Further, together with consistent terminology, guidelines, instructions, and data collection, we can refine efforts and resources to measure and share information. Data collected using robust, standardised methods will improve our knowledge of threatened species and underpin threatened species recovery at scale. This project is essential to establishing monitoring protocols and data repositories to enhance the accessibility and sharing of threatened species data.

TERN has prepared the literature reviews for the Department of Climate Change, Energy, the Environment, and Water. For further information, please visit the EMSA Threatened Species Survey Guidelines website. Additional information, particularly monitoring methods and techniques not included that should be considered, can be brought to the author's attention by emailing tern@adelaide.edu.au for consideration for future updates.

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1 Background

1.1 Species name

Western Ringtail Possum (*Pseudocheirus occidentalis*) (Thomas, 1888). Indigenous names for this species include Ngwayir, Womp, Woder, Ngoor and Ngoolangit (Department of Parks and Wildlife 2017; Department of the Environment 2023).

1.2 Conservation status

The Western Ringtail Possum is listed as Critically Endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth), and in Western Australia under the *Biodiversity Conservation Act 2016*. The species is also listed as Critically Endangered on the International Union for Conservation of Nature (IUCN) Red List, and the *Action Plan for Australian Mammals* (Woinarski et al. 2014). This status is justified by the species' small and severely fragmented populations, and continuing decline caused by threats of a drying climate, urban development, inappropriate fire regimes and Red Fox (*Vulpes vulpes)* and Feral Cat (*Felis catus*) predation (Burbidge & Zichy-Woinarski 2014). This possum is one of 21 mammals identified as a Priority Threatened Species under the *Threatened Species Action Plan 2022-2032*.

Table 1. National, international and state conservation status for the Western Ringtail Possum

Jurisdiction	Conservation status	Legislation
Commonwealth	Critically Endangered	*Environment Protection and Biodiversity Conservation Act 1999*
Western Australia	Critically Endangered	*Biodiversity Conservation Act 2016*
IUCN	Critically Endangered	IUCN Red List of Threatened Species

1.3 Summary of data held in the Threatened Species Index

The Threatened Species Index (TSX) provides reliable and robust measures of change in the relative abundance of Australia's threatened and near-threatened species at national, state and regional levels. Understanding these changes in species populations is crucial for monitoring Australia's conservation progress and allows users to measure and report on the benefits of conservation investments and to justify and design targeted management responses. Currently, the index is restricted to birds, plants and mammals, with new groups to be added in the near future.

The table below summarises the Western Ringtail Possum data held in the TSX. More information on the TSX, including how to contribute threatened species monitoring data to the index, can be found on the TSX website.

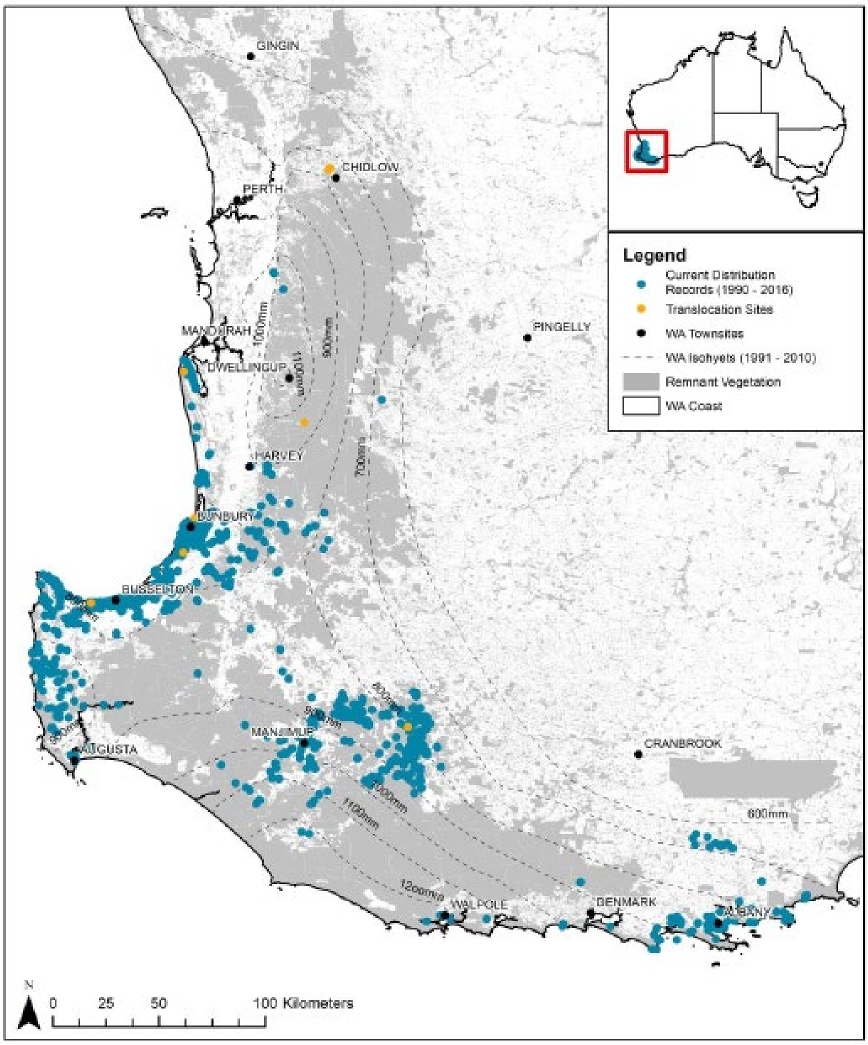
Table 2. Summary of Western Ringtail Possum data held in the TSX

TSX information	Western Ringtail Possum data held in the TSX
Data held in the TSX?	Yes
Number of data sources	1
Number of unique sites	1
Average time series length (years)	25
Average number of sampling years	25

1.4 Distribution and abundance

The Western Ringtail Possum is endemic to the south-west region of Western Australia (de Tores & Elscot 2010; Department of Parks and Wildlife 2017). Sub-fossil records indicate that the historic distribution of the Western Ringtail Possum extended from Geraldton in the north west down to the Nullarbor Plain on the south coast, ~200 km east of the WA/SA border (Department of Parks and Wildlife 2017; Woinarski et al. 2014). However, at the time of European settlement the geographic range was believed to be from just north of Perth to just east of Albany and included Pingelly and Borden. Since the 1820s, the distribution of the Western Ringtail Possum has contracted by 80-90 % (Department of Parks and Wildlife 2017; Jones et al. 2004; Wayne et al. 2005a), and has largely persisted in three locations: around Bunbury and Busselton, around Albany, and inland in the Upper Warren region (Figure 1) (Jones et al. 2004; Wayne et al. 2005a). The highest densities of possums occur on the Swan Coastal Plain while the population in the Upper Warren region has dramatically declined with a drop in sightings by over 95 % since 1998 (Woinarski et al. 2014).

Figure 1 Western Ringtail Possum distribution as of 2015



Source: Department of Parks and Wildlife 2017

The total population in the wild is projected to be less than 8,000 mature individuals with this number likely to decline further (Woinarski et al. 2014). The predicted area of occupancy for the Western Ringtail Possum is <500 km^2 (Woinarski et al. 2014). The Western Ringtail Possum has been reintroduced to several locations since 1991 including Lane-Poole Reserve and Keats State Forest Block near Dwellingup, Yalgorup National Park south of Mandurah, Leschenault Peninsula Conservation Park near Bunbury and Locke Nature Reserve at Busselton (Woinarski et al. 2014). However, the majority of these translocations have been unsuccessful due to predation and poor habitat quality (Woinarski et al. 2014). A small population has been successfully introduced to Karakamia Reserve (predator free exclosure managed by the Australian Wildlife Conservancy) (Figure 1) (Department of Parks and Wildlife 2017; Woinarski et al. 2014).

1.5 Habitat requirements

Key habitat essential for Western Ringtail Possums is not completely clear and differs between the three population regions, or key management zones (Department of Parks and Wildlife 2017). These three zones are identified as:

- Swan Coastal Plain: peppermint (*Agonis flexuosa*) woodlands and peppermint/tuart (*Eucalyptus gomphocephala*) forests from north of Bunbury to Augusta.
- Southern Forest: jarrah (*Eucalyptus marginata*) forests, mainly around Manjimup.
- South Coast: diverse range of vegetation communities between Walpole and Cheynes beach including coastal heath, peppermint woodland, riparian, jarrah/marri (*Corymbia calophylla*) and karri (*Eucalyptus diversicolor*) woodlands and forests.

Habitat features which have been identified as important across all zones include access to foliage with high nutrient contents, the presence of suitable resting and nesting structures and crucially, habitat corridors or continuity of canopy to facilitate escape from threats such as predators (Department of Parks and Wildlife 2017).

On the Swan Coastal Plain, Western Ringtail Possums are associated with peppermint (*Agonis flexuosa*) and other Myrtaceous species which are generally situated in wetter more fertile areas such as drainage lines, swamps, floodplains and topographic depressions (de Tores et al. 2004; Department of Parks and Wildlife 2017; Jones et al. 1994a). Remnant patches of mature peppermint woodland which are long unburnt with high nutrient foliage, and habitat corridors linking patches, are critical for maintaining optimal possum densities and ensuring survival of the species' (Jones et al. 1994b; Jones et al. 2004; Wayne et al. 2006).

Western Ringtail Possums are associated with jarrah (*Eucalyptus marginata*) or marri (*Corymbia calophylla*) dominated forests, riparian areas often with flooded gum (*Eucalyptus rudis*), and wandoo (*Eucalyptus wandoo*) forests in the southern forest zone (Department of Parks and Wildlife 2017). Minimal disturbance from fires and logging, low habitat fragmentation and areas with intensive fox baiting are deemed critical for survival of these populations (Wayne et al. 2006; Wayne et al. 2005c). Western Ringtail Possums have also been observed in remnant vegetation along drainage lines within blue gum (*Eucalyptus globulus*) and pine (*Pinus* spp.) plantations (Department of Parks and Wildlife 2017).

On the south coast, possum populations have been associated with a diverse range of vegetation communities such as peppermint woodlands, jarrah/marri woodland and forest, karri forest, riparian zones, coastal heath and myrtaceous heath and shrublands (Bader et al. 2019; Department of Parks and Wildlife 2017). In recent years, the Western Ringtail Possum has also been found occupying sheoak (*Allocasuarina fraseriana*) woodlands (Bader et al. 2019).

1.6 Biology and ecology

The Western Ringtail Possum is a medium-sized marsupial weighing between 0.8 and 1.3 kg with a distinctive prehensile tail up to 40 cm long with a white tip (Menkhorst & Knight 2001; Wayne et al. 2005a; Yokochi 2015). They generally have a cream to grey underside and are dark brown above (Department of Parks and Wildlife 2017). The Western Ringtail Possum is nocturnal, largely arboreal and exclusively consumes leaves and some flowers of particular trees (Jones et al. 1994a). In the northern population around Bunbury and Busselton, peppermint trees are the foremost food source comprising 90-95 % of their diet (Jones et al. 1994b; Wayne et al. 2005c). This is also the case for the population around Albany where peppermint trees are dominant. For the inland population in the Upper Warren region, jarrah and marri form the major constituents of the possums' diet (Jones et al. 1994b; Wayne et al. 2005c). Introduced garden species are also eaten in urban areas (Burbidge & de Tores 1998; Department of Parks and Wildlife 2017; Van Helden et al. 2021).

Western Ringtail Possums can breed all year round if conditions are suitable, however, they typically breed twice a year. In the south-coast region dominated by peppermint they breed between April to June and September to November, while in the inland jarrah forests they breed predominantly in May to June with a small second breeding season in October and November (Jones et al. 1994b; Wayne et al. 2005c). Gestation is 2-4 weeks and litters usually consist of one young, but two or three young have been recorded on occasion (Jones et al. 1994b; Wayne et al. 2005c). Young are weaned at 6-8 months and disperse at 8-12 months (Ellis & Jones 1992; Jones et al. 1994b; Wayne et al. 2005c). Juveniles can breed a year after birth and it is believed their longevity is around 4-5 years in the wild (Ellis & Jones 1992; Van Helden et al. 2021; Wayne et al. 2005c).

Habitat quality has been found to impact reproductive rates. Jarrah forests, which are lower in foliage nitrogen, have been linked to lower birth rates compared to peppermint woodlands which have higher foliage nitrogen (Jones et al. 1994b; Wayne et al. 2005c). Sex ratios may also be influenced by habitat condition. High quality habitat can lead to a female bias and an expanding population, while a male bias usually indicates marginal or deteriorating habitat (Jones et al. 1994b).

The Western Ringtail Possum displays high site fidelity and is territorial (Ellis & Jones 1992; Van Helden et al. 2021; Yokochi 2015). The average home range size is <5 ha (Department of Parks and Wildlife 2017), but varies from an average of 2.7 ha in jarrah forest to 0.4 ha and 0.3 ha for females and males respectively, in peppermint woodlands (Jones et al. 1994b). Population densities are lower in inland jarrah forests with around four possums per hectare, in contrast with coastal peppermint woodlands where up to 20 individuals per hectare have been recorded around Busselton (Jones et al. 2004).

Western Ringtail Possums prefer tree hollows as diurnal refuges but will also construct nests from vegetation ("dreys"), or use hollow logs, understorey vegetation, *Xanthorrhoea* spp. skirts or abandoned rabbit warrens, where tree hollows are scarce (Ellis & Jones 1992; Jones et al. 1994b; Wayne 2005). In urban areas, they can rest in roof spaces and other dark cavities. Western Ringtail Possums can use 20 or more refuges in a year (Wayne 2005). Tree hollows are a significant resource influencing possum abundance across their range (Department of Parks and Wildlife 2017). In jarrah forests, 70 % of refuges used by this species were hollows (Wayne 2005; Wayne et al. 2000).

1.7 Threats

Threats to the Western Ringtail Possum are multifaceted and vary between populations. For populations in the Swan Coastal Plain and south coast regions the biggest threat is habitat loss and fragmentation through urban expansion, while possums in the southern forests are more vulnerable to logging, fire, introduced predators and climate change (Department of Parks and Wildlife 2017; Wayne et al. 2006).

The destruction of native vegetation and resulting loss of habitat connectivity is the primary factor threatening the Western Ringtail Possum. High quality habitat has been lost due to agricultural and urban developments, or through the construction of dams, and remaining habitat has been highly fragmented (Department of Parks and Wildlife 2017). This has led to an overall reduction in possum numbers and overpopulated and overgrazed remnant patches (de Tores et al. 2004; Wayne et al.

2006). Fragmentation also restricts movement and increases the risk of predation and chances of being struck by traffic (Department of Parks and Wildlife 2017; Yokochi 2015).

Predation by introduced predators such as the red fox (*Vulpes vulpes*) and cat (*Felis catus*) are also a major threat to the survival of the Western Ringtail Possum (Jones et al. 1994b; Jones et al. 2004; Wayne et al. 2005c). The risk of predation is exacerbated by the lack of continuous canopy as animals must then come to the ground. Breaks in the canopy can arise through habitat loss, or fire and logging in the jarrah/marri forests (Wayne et al. 2006; Wayne et al. 2005a). Intense fox-baiting programs can be beneficial to Western Ringtail Possums but can also be detrimental. Fox-baiting can increase predation by other predators like cats, wedge-tailed eagles (*Aquila audax*) and chuditch (*Dasyurus geoffroii*), as well as increase numbers of common brushtail possums (*Trichosurus vulpecula hypoleucus*), which aggressively compete with the ringtail possums (Clarke 2011; de Tores et al. 2004; Wayne et al. 2006). Domestic dogs in urban areas may also pose a risk.

In the jarrah/marri forests greater numbers of Western Ringtail Possums have been recorded in unlogged areas, or forests which have undergone light logging (e.g., areas logged prior to 1960) (Wayne et al. 2006). Timber harvesting can have a significant impact in the immediate term (i.e., through direct mortality; Morris et al. 2000), as well as over the longer term by increasing the possum's vulnerability to predation via loss of refuges and connecting canopy. In one study, average life expectancy during logging was found to be 40% lower than individuals in adjacent unlogged forests (Wayne et al. 2000). In the same study, one area post-logging, spotlight records decreased by 80% (Jones 2004), and numbers have remained very low along these spotlight transects since 2000 (Wayne et al. 2005a).

Fire is a significant threat to Western Ringtail Possums, particularly in the southern forests. Fire can directly kill individuals as well as reduce food availability, make refuges scarce and increase the risk of predation as a consequence of reduced vegetation cover, food and the attraction of predators to recently burnt areas (Jones et al. 1994a; Wayne et al. 2006; Wayne et al. 2005a). Consequently, Western Ringtail Possums have be associated with long unburnt areas, i.e. greater than 20 years since fire, or areas which have undergone low intensity burns (Wayne et al. 2006). In fragmented coastal pockets, fire has the potential to wipe out subpopulations (Woinarski et al. 2014).

Due to their poor ability to disperse, habitat constraints and susceptibility to heat stress, Western Ringtail Possums are vulnerable to climate-induced changes (Jones et al. 1994b; Shedley & Williams 2014). Reduced rainfall and higher temperatures predicted for south-west WA are likely to result in a habitat and range contraction of up to 60 % by 2050 (Molloy et al. 2014). A decline in habitat trees and available tree hollows (through removal of trees or by being outcompeted) are also threats to the survival of the Western Ringtail Possum.

2 Existing monitoring

2.1 Overview of monitoring methods

Indicators of Western Ringtail Possum presence include nocturnal (e.g., spotlighting) counts, opportunistic diurnal sightings, and active searches for signs such as dreys, scats and claw marks on trees.

Key population monitoring measures for the Western Ringtail Possum include:

- Population abundance (estimated)
- Population density
- Occupancy
- Distribution
- Demographics

2.2 Monitoring resources

Key resources with information for monitoring the Western Ringtail Possum include:

- DSEWPC (2011) *Survey guidelines for Australia's threatened mammals*
  - Provides survey guidelines to detect the presence of threatened non-flying mammal species at a site (does not offer survey effort to assess abundance).
  - Prescribes method guides based on mammals of a similar body weight and habit, i.e., small and medium-sized arboreal species (100-500 g weight).
  - Survey effort is not specific to each species, but a general baseline is provided for each method and mammal group.
  - Recommends the following survey methods for Western Ringtail Possums in an area up to 5 ha:
    - Diurnal searches for potential resting/nesting sites in hollow-bearing trees. Surveys should be conducted on foot at a speed of roughly 10 m per minute. A 100 m transect should be surveyed for each hectare.
    - Diurnal searches for signs such as dreys, scats at the base of potential denning trees or scratches on tree trunks. Recommended effort is two hours per hectare. Where evidence of presence is detected, follow up survey methods may be required such as stag watching, spotlighting, hair sampling or potentially arboreal trapping.
    - Stag watching at likely nest sites (tree hollows or dreys). Suggests an observer watch for 30 minutes before dusk until an hour after sunset.
    - Spotlight surveys along tracks, roads or transects. Transects should be at least 200 m long and a minimum of 2 transects should be surveyed per 5 ha. A distance of 100 m between transects is ideal and a speed of 10 m per minute is recommended. Surveys should be repeated on at least two separate nights avoiding unfavourable weather (wind and rain).
    - Arboreal cage trapping can be undertaken in habitats other than jarrah forests, in combination with spotlight and scat surveys. However, trapping is labour intensive and time-consuming.
    - Hair tubes can be used as an alternative method of detection.

- Environmental Protection Authority (2020) *Technical guidance - terrestrial vertebrate fauna surveys for environmental impact assessment*
  - Provides advice on survey preparation including a desktop analysis, habitat mapping, deciding the appropriate survey type, design and techniques, and the necessary data analyses and reporting.
  - Information on survey design includes choosing sites, timing and duration.
  - Proposes medium to large aluminium box traps (e.g., Elliot traps), cage traps, spotlighting from a vehicle and on foot, searching for tracks and other signs, and camera traps for medium-sized mammals (<2.5 kg). Guidelines for each method are also provided.
  - Faecal DNA analysis, hair tubes and examination of predator guts are also included as potential methods of detection.

- Woinarski et al. (2014) *The Action Plan for Australian Mammals 2012*
  - Acknowledges that monitoring by traditional methods (e.g., trapping), is difficult as they are an arboreal species.
  - Highlights that repetition is important for spotlighting surveys and results should be interpreted with caution.
  - Identifies scat counts as being a more reliable and cost-effective monitoring method.
  - Identifies that monitoring has been opportunistic to date with no consistent monitoring currently being done across the possum's entire range.

2.3 Survey methods

Methods which have been used to determine the distribution and occupancy of the Western Ringtail Possum include nocturnal spotlighting counts (Bader et al. 2019; Jones et al. 1994a; Wayne et al. 2001; Wayne et al. 2005a; Wayne et al. 2005b), and active searches for signs such as dreys, scats and scratch marks on trees (Jones et al. 1994a; Thompson & Thompson 2009; Wayne et al. 2006). Opportunistic records can also help inform on the species' distribution. The Nature Conservation Margaret River Region runs an annual 'Ringtail Tally', a citizen science project to count Western Ringtail Possums each Autumn.

Habitat use and home range sizes have been revealed through radio-telemetry (Clarke 2011; de Tores et al. 2004; Van Helden et al. 2021; Van Helden et al. 2018; Yokochi 2015), and information on habitat and use of tree species has also been determined from nocturnal spotlighting surveys (Bader et al. 2019; Thompson & Thompson 2009; Wayne et al. 2005a) and vegetation assessments at occupied sites (Jones et al. 1994a). Desktop habitat suitability assessments have also been carried out (Shedley & Williams 2014).

Population abundance can be estimated from spotlighting survey counts (Jones et al. 1994a; Thompson & Thompson 2009, 2011; Wayne et al. 2001; Wayne et al. 2005a). However, specifically undertaking distance sampling during spotlighting can provide a more robust and repeatable measure of population density and abundance (Clarke 2011; de Tores & Elscot 2010; de Tores et al. 2004; Finlayson et al. 2010). Scat counts have been compellingly correlated with spotlighting counts of abundance and can therefore be used as an alternate relative measure of abundance (Jones et al. 1994a; Wayne et al. 2005b). Relatedly, density estimates can be made from drey locations (Jones et al. 1994a; Thompson & Thompson 2009).

Capture of individuals provides an assessment of the number of individuals known to be alive (KTBA) (Wayne et al. 2005b), and may be necessary for determining population demographics and if conducting radio-tracking surveys or translocating individuals (e.g., de Tores et al. 2004; Jones et al.

1994b; Van Helden et al. 2018). Ground and arboreal trapping can be carried out to capture individuals (Van Helden et al. 2021; Wayne et al. 2005b; Wayne et al. 2005c), though Western Ringtail Possums can be difficult to trap, and trapping surveys are often labour-intensive and costly. As such, alternatives to cage trapping which have been utilised include a capture pole (Wayne et al. 2005c), tranquiliser dart gun (Clarke 2011; Van Helden et al. 2018; Wayne et al. 2005c), or hand capture from resting locations such as dreys and hollows (Clarke 2011; Jones et al. 1994b; Wayne et al. 2005c).

2.3.1 Direct counts

Spotlighting and distance sampling

The most commonly used method to survey Western Ringtail Possums is nocturnal spotlighting. Repeated spotlighting surveys can deliver equivalent or improved detection rates compared to extensive trapping but involves less time and effort (Wayne et al. 2005b). Additionally, conducting distance sampling during spotlighting can provide more reliable measures of abundance and density by accounting for detection bias (de Tores & Elscot 2010; Finlayson et al. 2010; Shedley & Williams 2014). However, there are a few caveats that need to be considered when undertaking spotlighting surveys.

The experience and consistency of observers across surveys is critical (de Tores & Elscot 2010; Finlayson et al. 2010; Thompson & Thompson 2011; Wayne et al. 2005a; Wayne et al. 2005b). It is also important to standardise speed across surveys as there is a compromise between being slow enough to detect animals whilst also being quick enough so as not to allow too much time for animals to detect and thus avoid the observer (Wayne et al. 2005a; Wayne et al. 2005b). Speed is dependent on whether the surveys are carried out on foot or are vehicle based, and on the density of the vegetation (Shedley & Williams 2014; Wayne et al. 2005a). As well as increased speed, vehicle-based surveys have the added advantage of being able to cover a greater area and an increased height perspective which decreases ground-based visual obstructions (Wayne et al. 2005a).

Environmental factors such as moon phase, cloud cover, season and hour of darkness, have also found to significantly affect possum detections in some instances (Wayne et al. 2001), but not all (e.g., Wayne et al. 2005a), and weather features like temperature and rainfall can also reduce detections (Wayne et al. 2005a). Western Ringtail Possums have been found to be most active a few hours after dusk and therefore survey start time can impact detections (Thompson & Thompson 2011; Wayne et al. 2005a). It is recommended that surveys conclude by midnight and at least two surveys should be undertaken at a site (Thompson & Thompson 2011). However, start time was not found to influence detections in jarrah forests (Wayne et al. 2005b).

The suggested distance to avoid overlap between transects is 50-100 m as possums are generally detected less than 50 m from transect lines and possum movements are limited (Bader et al. 2019; Wayne et al. 2005b). A 50 W spotlight is recommended for increasing detections, while any brighter can negatively impact the possums (Wayne et al. 2005b). Light colour did not affect detections. Finally, surveys should be carried out between October and April when the population is at its greatest and detection rates are at their highest (Wayne et al. 2005a; Wayne et al. 2005c). More information on direct count methods can be found in Table 3.

Table 3. Methods overview of key studies using direct count surveys

Survey type	Study design	Survey effort	Location	Reference
Spotlighting	• Head torches were 350 lumens • Search speed ~600 m/hr • Searches began 1 hr after sunset • For each possum sighted, time, transect number, latitude and longitude, distance and direction from transect, height within tree,	• Six parallel transects, 200m long surveyed at each of the 4 sites • Transects 50 m apart, surveyed by 2 surveyors on 5 nights between	Albany region, WA	(Bader et al. 2019)

Survey type	Study design	Survey effort	Location	Reference
	height of tree and tree species, were recorded	late March and early April 2018		
Spotlighting	• Search focus: 10-15 m either side of transects • Surveys undertaken at about 22:45 hr, 01:15 hr and 04:00 hr each night. Location of each possum was recorded using GPS, along with tree species and height of each possum in the tree.	• Transects 18 m apart surveyed by 2 observers with head torches on 2 consecutive nights in December 2008	Busselton, WA	(Thompson & Thompson 2011)
Spotlighting	• One site divided into three zones: remnant vegetation (47.8 ha); residential (57.4 ha); • and road side verges (21.7 ha) • Area traversed between 1930 and 0200 hrs • Possums detected using a handheld spotlight • Due to the size of the survey area it was not • possible to cover all of the area every night • A different combination of observers searched each area during the second search	• No area searched on multiple occasions on a single night, but each area searched on at least two occasions on non-consecutive evenings in late March	Dunsborough, WA	(Thompson & Thompson 2009)
Spotlighting	• Three light intensities trialled: 20W, 50W and 100W, in two colours: white and red • Two surveys of each transect conducted in a night: 1hr after sunset and 4hrs after sunset • Handheld spotlights used and a speed maintained of 1 km/hr • Cloud cover, wind, temperature, moon phase and presence recorded for each survey • Data for each individual sighted included time, number of animals, species, perpendicular distance to transect, height above ground, animal location (tree species, ground, etc), tree maturity and possum behaviour	• Six study sites each with 5 parallel, 600m long transects 100m apart Spotlighting carried out on the central and 2 outer transects (spaced 200 m apart, 1800 m total spotlight length per site) • 18 spotlight surveys at each site between November 2001 and March 2002	Perup Nature Reserve, WA	(Wayne et al. 2005b)
Spotlighting	• Three road transects established: 10.9 km, 10.6 km and 10.3 km long • Survey frequency varied throughout the project Surveys began 30min - 3hr after sunset with vehicles travelling at a speed of ~5km/hr • Two spotlights per vehicle – one each side of the road • Four principal spotlighters led teams • Weather conditions, start and finish times and observers were recorded along with possum locations and logging treatments	• Spotlighting conducted over 65 nights between February 1996 and December 2003 • Total of 169 surveys completed	Greater Kingston area, WA	(Wayne et al. 2005a)
Spotlighting	• Three transects established: 10.91 km, 10.65 km, and 10.33 km long • Surveys conducted from vehicles ~half to 1 hr after sunset and at a speed of 4-5 km/hr • Two spotlights per vehicle on either side of the road Information collected included distance along transect, time, species, number of individuals, logging treatment, behaviour, animal location and tree maturity • Distance from the road recorded from February 1999	• Between November 1995 and January 2001, 189 spotlight surveys conducted	Formerly Kingston State Forest, now Kingston National Park, WA	(Wayne et al. 2001)

Survey type	Study design	Survey effort	Location	Reference
Spotlighting	• Nocturnal spotlighting from vehicle in open forest and on foot in coastal vegetation • Different sites surveyed in different seasons • Site descriptions included details of vegetation structure and floristics, topography and disturbance • factors such as clearing or thinning of trees	• 61 sites surveyed between 1990 and 1992	South-west WA	(Jones et al. 1994a)
Distance sampling	• Spotlighting was carried out along transects 1-2 km long • 30W spotlights were used and speed was 0.5 km/hr • GPS location of each sighted possum was recorded along with time, height in tree, observer, tree species, vegetation density and vegetation type	• field sites • Spotlighting conducted at each site over 20 nights in January-February 2008 • Each transect was walked for 10 consecutive nights with two surveyors	Leschenault Peninsula Conservation Park and Yalgorup National Park, WA	(Clarke 2011)
Distance sampling	• Nine transects 220 m long and 18 m apart • Surveys commenced soon after sunset • Once located, perpendicular distance from the transect to the possum's location was recorded	• Monthly 2 consecutive night spotlighting surveys conducted by 2 surveyors between November 2008 and April 2009 and another 2-night survey in September 2009.	Busselton, WA	(Finlayson et al. 2010)
Distance sampling	• Systematic parallel transects: 12 at Locke Nature Reserve (av. spacing 116m) and 5 at Lot 5 (av. spacing 39m) • Transects orientated north-south at Locke NR and east-west at Lot 5 and lengths of individual transects varied across both sites A handheld 30W spotlight was used • GPS location of each individual and location observed on the transect was recorded along with tree height and species, height of animal in tree and age of individual (adult, subadult or juvenile)	• Each transect surveyed twice at night by two surveyors between November 2008 and February 2009	Locke Nature Reserve and Lot 5 near Busselton, WA	(de Tores & Elscot 2010)
Distance sampling	• A spotlight transect 1.4 km long established at each release site and surveyed over 14 consecutive nights in March/April 2002 • Further details provided in unpublished references	• Annual spotlighting between 1996 and 1998 • Two vehicle driven spotlighting transects established, each spotlighted for 6-9 consecutive nights between mid-March and early June each year • One driver and one spotlight surveyor for each survey	Leschenault Peninsula Conservation Park, WA Yalgorup National Park, WA	(de Tores et al. 2004)

2.3.2 Live capture

Several methods have been used to capture Western Ringtail Possums. This includes ground and tree trapping (Van Helden et al. 2021; Wayne et al. 2005c), a pole and hook technique (Wayne et al. 2005c), tranquiliser dart gun (Clarke 2011; Van Helden et al. 2018; Wayne et al. 2005c), or hand capture from resting locations such as dreys and hollows (Clarke 2011; Jones et al. 1994b; Wayne et al. 2005c). Arboreal trapping has been found to be nine times more effective than ground trapping (Wayne et al. 2005a; Wayne et al. 2005b), with less non-target species captured. The specific placement of arboreal traps, namely height and tree species, does not impact capture efficiency (Wayne et al. 2005b). Similarly, bait type (universal, rose or eucalyptus oil) has not been found to influence capture rates (Wayne et al. 2005b). Overall, trapping offers a poor estimate of actual population size compared to spotlighting (Wayne et al. 2005b). However, capture may be necessary for studying population demographics, radio-tracking experiments and translocations. In such cases, tranquiliser dart guns provide a more feasible option (Clarke 2011; Van Helden et al. 2018; Wayne et al. 2005c; Yokochi et al. 2015). More information on live capture techniques are provided in Table 4.

Table 4. Methods overview of key studies using live capture surveys

Survey type	Study design	Survey effort	Location	Reference
Cage trapping	• Within residential private gardens, possums trapped using Sheffield wire cage traps (22 x 22 x 45 cm), baited with almond meal soaked in strawberry essence and placed on movement pathways like fences and tree branches • Possums then fitted with VHF collars for radio-tracking	• Possums captured in 16 separate private gardens between 28 May and 5 June 2019 • 28 possums were fitted with radio tracking collars	Albany, WA	(Van Helden et al. 2021)
Cage trapping + additional capture techniques	• Each trap location had a wooden platform set ~1.8 m above ground with Sheffield wire cage traps (22 x 22 x 59 cm) placed on top secured using elastic hooks • Hessian bags placed over traps for protection against weather • Traps baited with flour and vegetable oil dough scented with rose essence • Trapping also supplemented by hand capture (0-4 m above ground), catch-pole or tranquiliser dart gun	• Trapping grid 500 m x 500 m established with 121 arboreal trapping locations 50 m apart (11 parallel transects with 11 points each) • Ten trapping sessions conducted between June 2002 and November 2003, each for 3-4 consecutive nights, ~8 weeks apart	Perup Nature Reserve, WA	(Wayne et al. 2005c)
Cage trapping	• Ground traps placed at 50 m intervals and arboreal traps were set every 100m (35 arboreal and 65 ground traps per site) • See Wayne et al. 2005c above for arboreal trap design • Three bait types trialled – universal bait, rose oil and eucalyptus oil • Traps checked in the morning and species, sex, age and individual ID recorded	• Six study sites, each with 5 parallel 600 m long transects 100 m apart • Six trapping sessions of 3 consecutive nights conducted between November 2001 and February 2002 at each site • Trapping conducted over 6 fortnights with traps opened for three consecutive nights with a break of 11 days between trapping sessions	Perup Nature Reserve, WA	(Wayne et al. 2005b)
Capture using tranquiliser dart gun	• Western Ringtail possums located at night using spotlights then captured using dart gun • Body weight and sex recorded before being fitted with GPS and VHF collar and then released at point of capture	• Survey conducted within two remnant vegetation sites	Albany, WA	(Van Helden et al. 2018)
Capture using tranquiliser dart gun	• Possums captured from 4 study blocks using a modified tranquiliser dart gun	• Four 200 × 200 m study blocks set up	Locke Nature Reserve	(Yokochi et al. 2015)
Capture using tranquiliser dart gun	• Possums found at night using spotlights and then captured using tranquiliser dart gun • Some also opportunistically darted during the day or caught by hand from rest sites Captured possums underwent health screening before being fitted with radio collars for tracking	• Resident P. occidentalis at building development sites captured over a period of 1-8 nights immediately prior to land clearing	Busselton, Leschenault Peninsula Conservation Park, Yalgorup National Park, WA	(Clarke 2011)

2.3.3 Habitat assessment

Assessments of habitat include examining what vegetation communities are being occupied, which tree species are being used for foraging and resting/nesting, and what habitat features are critical to this species. Methods used to assess habitat use include nocturnal spotlighting (Bader et al. 2019; Thompson & Thompson 2009; Wayne et al. 2001; Wayne et al. 2005a), diurnal and nocturnal radio-telemetry (Clarke 2011; de Tores et al. 2004; Van Helden et al. 2021; Van Helden et al. 2018; Yokochi 2015), opportunistic observations, sign-based surveys (e.g. active searches for dreys) (Thompson & Thompson 2009), and site surveys of vegetation structure and floristics, topography and disturbance (Jones et al. 1994a). Assessments of habitat suitability have also been carried out using GIS mapping and a review of available literature (Shedley & Williams 2014). More detailed information regarding methods to determine habitat use can be found in Table 5.

Table 5. Methods overview of key studies using habitat assessment surveys

Survey type	Study design	Survey effort	Location	Reference
Radio-telemetry	• Possums fitted with VHF collars (see Table 4 for capture details) • At each location, structure use, behaviour and refuge recorded	• 20 possums captured for tracking • Individuals tracked on 4 days each week, 3 nocturnal and 1 diurnal location, until 50 locations recorded	Albany, WA	(Van Helden et al. 2021)
Radio-telemetry	• Body weight and sex recorded before being fitted with GPS and VHF collar and then released at point of capture • GPS fixes were scheduled for every 15 mins between 1700 and 0700 hrs and at 30 min intervals between 0700 and 1700 hrs • Possums also tracked using VHF receiver and antenna with locations recorded once found • Tree species, minimum canopy height and height of tree recorded	• Possums captured within 2 remnant vegetation sites (see Table 2 for capture details) • Possums tracked twice a week during the day between July and August 2016	Albany, WA	(Van Helden et al. 2018)
Radio-telemetry	• Possums captured using tranquiliser dart gun before being fitted with a VHF radio collar with a mortality function	• 52 individuals monitored over 3 years	Locke Nature Reserve	(Yokochi et al. 2015)
Radio-telemetry	• Possums captured from development sites (see Table 4 for capture details) or obtained from wildlife carers • VHF radio collars fitted to individuals who were then released at translocation sites • Diurnal tracking identified rest sites while nocturnal tracking provided information on foraging and social interactions (e.g. offspring, presence of mates, etc.) • Data on home range and habitat use also collected	• Survival checked weekly, and tracking undertaken both at night and during the day	Busselton, Leschenault Peninsula Conservation Park, Yalgorup National Park, WA	(Clarke 2011)
Radio-telemetry	• Subset of animals released as part of translocations were radio-tracked to determine survivorship, home range and habitat use • Further details provided in unpublished references	• No specific information provided	Leschenault Peninsula Conservation Park, Yalgorup National Park, WA	(de Tores et al. 2004)
Habitat assessments	• At each occupied site information on vegetation structure and floristics, topography and disturbance collected • Vegetation descriptions undertaken per using the system from (Muir 1977)	• Vegetation descriptions collected from 2-6 plots of 20 m radius • Detailed information on tree variables (e.g., hollows, burns scars, etc)	South-west WA	(Jones et al. 1994a)

Survey type	Study design	Survey effort	Location	Reference
		also collected for 2-6 sets of adjacent trees		
Habitat suitability assessment	• Literature review used to determine which habitat values were important for Western Ringtail Possums • A series of GIS data layers was then created based on these variables • From this a habitat classification and GIS mapping data set of suitable habitats was generated	• Habitat review and GIS mapping conducted on broader area of interest from Binningup in the north to Dunsborough in the south and out to the Whicher Range. • The spatial mapping dataset was divided into five *P. occidentalis* management zones within 10 km of the coastline	South-west WA	(Shedley & Williams 2014)

2.3.4 Sign-based surveys

Sign-based surveys can provide a rapid, cost-effective, simple, ethical and reliable method of species detection (Wayne et al. 2005b). Furthermore, these types of survey can reduce biases associated with observer differences. For instance, scat searches can be used as an effective alternative to spotlighting to assess distribution and relative abundance (Shedley & Williams 2014; Wayne et al. 2006; Wayne et al. 2005b). However, limitations to this method include variable defecation and scat decay rates, as well as impediments from dense understorey and heavy litter (de Tores & Elscot 2010; Shedley & Williams 2014; Wayne et al. 2005b). Ideally, scat searches should be conducted in January and February when scat decay is lowest (Wayne et al. 2006). More information regarding sign-based surveys are provided in Table 6.

Table 6. Methods overview of key studies using sign-based surveys

Survey type	Study design	Survey effort	Location	Reference
Active searches for signs	• Day searches for dreys, scats and scratches on trees	• 61 sites surveyed between 1990 and 1992	South-west WA	(Jones et al. 1994a)
Drey searches	• Dreys located by systematically searching the area on foot during the day • When found, locations recorded using GPS • Other data recorded included drey category, tree species, height of tree, height of drey above ground, condition of drey and presence of possum(s)	• A section of the Dunsborough town site surveyed by four people between 25 and 31 March 2007 • Surveyed area was divided into three zones; remnant vegetation (47.8 ha); residential (57.4 ha); and road side verges (21.7 ha)	Dunsborough, WA	(Thompson & Thompson 2009)
Scat searches	• At each site, presence or absence of Western Ringtail Possum scats within 42 circular (1m diameter) plots recorded • Plots 15 m apart along 2,300 m parallel transects • Plots situated beneath trees, away from tracks and disturbance	• Scat searches undertaken at 90 sites • Surveys conducted in January and February 2004	Upper Warren region, WA	(Wayne et al. 2006)
Scat searches	• Transects offset by ~10 m to avoid disturbing traps and spotlighting • Scats identified to species and a relative index of abundance derived • Quadrats located below trees and each quadrat searched for 2 minutes by same observer at all sites	• Scat surveys conducted adjacent to 3 parallel 600 m long spotlighting transects set 200 m apart • Scat transects include 60, 1 x 1 m quadrat surveys	Perup Nature Reserve, WA	(Wayne et al. 2005b)

Survey type	Study design	Survey effort	Location	Reference
		(180 quadrats per site)		

2.3.5 Other methods

Other monitoring methods that have been used, but have not been widely implemented include:

- Camera trapping (Seidlitz et al. 2022)
- Nestbox use (Clarke 2011; Moore 2007; Moore et al. 2010)

Additional methods that may have future application include:

- Stagwatching (e.g., Smith et al. 1989)
- Hair tubes (e.g., Goldingay & Daly 1998; Lindenmayer et al. 1999)
- Predator scat analysis (e.g., Goldingay & Daly 1998; Lunney 1987)
- Thermography (e.g., Dymond et al. 2000; Vinson et al. 2020)

3 Key agencies and organisations involved in the species research and recovery

Key agencies, organisations or individuals identified as having been previous, or currently actively involved in monitoring the Western Ringtail Possum include:

- Nature Conservation Margaret River Region
- Bronte Van Helden, South Coast NRM
- Paul de Tores, WA Department of Environment
- Adrian Wayne, WA Department of Environment

4 Survey guideline recommendations gathered from the literature

This literature review of monitoring methods for the Western Ringtail Possum has identified some key points that must be addressed when developing species-specific guidelines. These points include:

- Undertaking distance sampling during spotlighting can provide a more robust and repeatable measure of population density and abundance (Clarke 2011; de Tores & Elscot 2010; de Tores et al. 2004; Finlayson et al. 2010).
- Sign-based surveys can provide a rapid, cost-effective, simple, ethical and reliable method of species detection (Wayne et al. 2005b). These types of survey can also reduce biases associated with observer differences. For instance, scat searches can be used as an effective alternative to spotlighting to assess distribution and relative abundance (Shedley & Williams 2014; Wayne et al. 2006; Wayne et al. 2005b).
- Density estimates can be made from drey locations (Jones et al. 1994a; Thompson & Thompson 2009).
- Overall, trapping offers a poor estimate of actual population size compared to spotlighting (Wayne et al. 2005b). However, capture may be necessary for studying population demographics, radio-tracking experiments and translocations. In such cases, tranquiliser dart guns provide a more feasible option (Clarke 2011; Van Helden et al. 2018; Wayne et al. 2005c; Yokochi et al. 2015).

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