# Western Ringtail Possum *Pseudocheirus occidentalis* Regional Surveys


**Main Roads Western Australia**

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Biota Environmental Sciences



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# Western Ringtail Possum Regional Survey

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**Figures**

# 1.0 Summary

This report presents the findings from Distance Sampling surveys conducted to estimate the density (and population size) of Western Ringtail Possum (*Pseudocheirus occidentalis*) at over 40 sites across the species' documented geographic range. During the planning stage, the design and approach to this study were refined during presentations to, and discussions with the Western Ringtail Possum Recovery Committee and key ecologists within the Department of Biodiversity, Conservation and Attractions.

The entire study surveyed 114,243 ha using 1,249 transects equating to a total effort of 1,287.2 km of transect. Across these transects 2,939 detections of 3,677 individual WRP were made. Survey effort was divided amongst the three WRP key management zones; Swan Coastal Plain, Southern Forest and South Coast.

Within each of the management zones, sites were selected based on four key criteria: sites would ideally support, or once have supported, Western Ringtail Possums; sites represented the geographic extent of each management zone; sites were readily accessible to survey and sites needed to be sufficiently large to undertake distance sampling.

Within and between study sites the average encounter rate (number of individual WRP per kilometre of transect) was found to be variable and ranged between 0 and 15.9, and for some sections of transects even higher encounter rates were recorded. The variable encounter rates translate into variable density estimates both within and between sites, though no site yielded a higher average density than 3.98 WRP per hectare.

Of the three key management zones, the surveyed area of the Swan Coastal Plain management zone yielded the greatest estimated abundance of WRP at 9,270 individuals, the Southern Forest management zone yielded an estimate of 7,500 individuals and the South Coast management zone yielded an estimate of 3,340, WRP.

These three regional population estimates indicate a combined number in excess of 20,000 individual WRP in the surveyed area, far exceeding that for the entire State as documented in the IUCN assessment (estimated at 3,400 mature individuals) (Burbidge and Zichy-Woinarski 2017).

The methods and results of this study provide a useful framework for two major applications; to determine the potential impact of development projects upon local Western Ringtail Possum populations, and to understand the wider trends in population abundance and distribution (i.e. conservation status) of Western Ringtail Possum with these data providing a robust 2019 baseline.

By successfully applying a unified survey method (line transect distance sampling) across a variety of geographic settings and vegetation types in each of the primary WRP Management Zones, this study also addressed the key Threatening Process identified in the Western Ringtail Possum Recovery Plan (Department of Parks and Wildlife 2017) "Gaps In Knowledge". Similarly addressed were several of the Recovery Plans Objectives. This study therefore makes a significant contribution to the ongoing conservation efforts for the WRP.

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# 2.0 Introduction

This research was undertaken in response to a series of proposed developments by Main Roads, Western Australia, which will impact upon known populations of Western Ringtail Possum (*Pseudocheirus occidentalis*). This report presents the findings from surveys conducted to estimate the density of Western Ringtail Possum at over 40 study sites across the species' documented geographic range (as defined in Burbidge and Zichy-Woinarski (2017)). It Is also aimed at fulfilling the most significant of the 10 Threatening Processes affecting the conservation status of the species as defined in The Western Ringtail Possum Recovery Plan: "Gaps in Knowledge" (Department of Parks and Wildlife 2017). Gaps in Knowledge manifests in a variety of forms, constraining a unified conservation outcome for the species (Table 2.1).

Understanding local and regional context of Western Ringtail Possum population density within project areas is critical to the assessment of impact. To date, assessments have been compromised by a lack of robust methodology and geographical context, leading to the risk that future proposals may likewise be compromised.

The dearth of robustly derived abundance estimates, or even a consistent approach to estimating abundance, is recognised as a key knowledge gap and threatening processes identified in the Western Ringtail Possum Recovery Plan (the Recovery Plan; Department of Parks and Wildlife 2017). The recent (2018) elevation of the species' conservation status to Critically Endangered (Burbidge and Zichy-Woinarski 2017) emphasises the importance of developing an accurate and robust estimate of the abundance of the species across its range and throughout the variety of habitats it occupies.

Here we advocate that a consensus should be agreed on the metric used to describe populations, namely density, and that as long as a robust and repeatable technique is employed to estimate density then the actual technique is not critical. For this study we have adopted line-transect distance sampling to estimate density and present our rationale as to why this should be the preferred technique in more detail below (Section 2.3.3)

## 2.1 Report Structure

The following parts of Section 2.0 summarises the most recent assessment of the conservation status of the Western Ringtail Possum (Burbidge and Zichy-Woinarski 2017; Section 2.2). Section 2.3 describes how this study aligns with the Recovery Plan (Department of Parks and Wildlife 2017). Section 2.4 provides a synopsis of distance sampling, including robustness and repeatability, and justification for its use for Western Ringtail Possum. The stakeholder engagement undertaken during the development, implementation and reporting of the study are detailed in Section 2.5.

Section 3.0 describes our interpretation of the geographic extent of the five subpopulations identified in the most recent International Union for the Conservation of Nature (IUCN) conservation assessment (Burbidge and Zichy-Woinarski 2017), and where possible associates these with the species' Management Zones as per the Recovery Plan (Department of Parks and Wildlife 2017). Within the defined geographic extent of each of the subpopulations, the candidate study sites within which distance sampling was undertaken are identified. Section 3.1 provides a description of the field survey approach and the balance of Section 3.0 outlines the analyses using both conventional distance sampling (Section 3.3.1) and density surface modelling (Section 3.3.2).

Section 4.0 presents the results of the survey. Summary statistics including the number of transects surveyed, effort (expressed as kilometres walked), number of detection events, number of individual animals sighted and encounter rates for each of the study areas are summarised in Section 4.1. These data are described in greater detail for each study site and a frequency histogram of perpendicular distances (perpendicular distance from the transect to the sighting) and a basic plot of detection events are provided in a separate Technical Supplement (Biota 2020). Plots of detection events on high-resolution aerial imagery are similarly provided in the

Technical Supplement (Biota 2020). Results of conventional distance sampling analyses including model selection for each of the study sites or for data pooled across study sites (where appropriate) are presented along with density and abundance estimates in Section 4.2. At selected study sites density surfaces are modelled and described in Section 4.3.

Section 5.0 discusses the findings of the study in respect of the provision of local and regional abundance context and revisits the identified knowledge gaps and key recovery objectives in light of the results.

## 2.2 Conservation Status of the Western Ringtail Possum

The most recent assessment of the conservation status of the Western Ringtail Possum took place in 2014 and was published in 2017 (Burbidge and Zichy-Woinarski 2017). This re-assessment determined that the conservation ranking should be Critically Endangered under the IUCN Red List of Threatened Species. The key elements justifying the ranking were that:

- The species has an area of occupancy of <50,000 ha (area of occurrence 40,000 ha);
- The species occurs in small, severely fragmented populations;
- There was evidence of a continuing decline (threats being a drying climate, urban development, inappropriate fire regime, predation by foxes and cats);
- The Upper Warren sub-population, which was identified as the largest prior to 2002, underwent a severe decline (>95%) between 1998 and 2009 (from >10,000 individuals to near extirpation);
- Remaining fragmented populations in coastal habitats were also rapidly declining (equating to an overall population decline of >80% in the past 10 years); and
- The above factors yielded a predicted further decline of >80% within the next 10 years.

The following 2015 estimates of population size are quoted from the IUCN Red List for five subpopulations of Western Ringtail Possum with Ms B. Jones cited as the source:

- Southern Swan: 2,000;
- Cape to Cape: 500;
- Other Forest Rivers: 300;
- Upper Warren: 100; and
- Around Albany: 500.

These subpopulation estimates yield a 2015 total population number estimate of 3,400 adult Western Ringtail Possums (Burbidge and Zichy-Woinarski 2017). At the time of the IUCN assessment, the Western Ringtail Possum was considered to occur "….*patchily in coastal areas from near Bunbury to the Leeuwin-Naturaliste National Park and near Albany (B. Jones pers. comm)*." The authors go on to say that "*Most of these fragmented habitat remnants are on private land*" (Burbidge and Zichy-Woinarski 2017).

## 2.3 Alignment with the Western Ringtail Possum Recovery Plan

### 2.3.1 Threatening Processes

The Recovery Plan (Department of Parks and Wildlife 2017) identifies 10 Threatening Processes affecting the conservation status of the species. One of these ten, "Gaps in Knowledge", manifests in a variety of forms, compromising a unified conservation outcome for the species.

Initially, Gaps in Knowledge affect the basic data collection and reporting required to accurately assess the size and abundance of local populations. Shedley and Williams (2014) clearly enunciate this problem when they state:

*"However, knowledge of absolute abundance is limited because of a lack of comparable population estimates and variability in survey methods across the range of the western ringtail possum (Inions 1985, Jones et al. 1994b, de Tores 2000, de Tores et al . 2004). Techniques used to census western ringtail possums commonly include spotlighting, drey (a nest typically formed from a mass of twigs) searches, distance sampling and scat counts (Wayne et al. 2005a ; de Torres and Elscot 2010) . However, variations in survey methodology compromise comparable estimates of abundance between studies, areas and over time".*

The Recovery Plan (Department of Parks and Wildlife 2017) further emphasises the problem by stating:

*"Limited short term studies and anecdotal accounts have contributed most of the knowledge on the western ringtail possum. An understanding of the ecology and conservation status has also been constrained by the difficulty in surveying (detection of) this species (Inions et al. 1989, Jones et al. 1994b, de Tores 2000)."*

The Recovery Plan (Department of Parks and Wildlife 2017) lists eight shortfalls in knowledge, which we address in Table 2.1 with proposed mitigation measures arising from this study where relevant.

### 2.3.2 Recovery Objectives

The Recovery Plan (Department of Parks and Wildlife 2017) outlines a series of key recovery objectives that need to be met over the ten-year period. The ones pertinent to this study, and that we feel are being met by its design, are outlined in Table 2.2, along with key anticipated deliverables. These are re-visited in the Discussion based on the results of the study.

### 2.3.3 Rationale for Selecting Distance Sampling

In this study we have selected distance sampling as the preferred method to estimate Western Ringtail Possum density. This approach is a thoroughly documented and published method (Buckland et al. 2001, Buckland et al. 2004, Buckland et al. 2015) for estimating animal density and thereby abundance, across a very broad range of species, including the Western Ringtail Possum (e.g. Biota 2018a, Biota 2018b, Biota 2018c, de Tores and Elscot 2010, Finlayson et al. 2010, Zimmermann 2010).

In selecting distance sampling as the approach, we have discounted other sampling approaches whilst acknowledging that each has its uses in certain situations. Arguably the most limited are unstructured spotlight surveys, drey counts or scat counts, which are not comparable across localities, surveyors or time but which remain useful for initial habitat appraisal. Similarly, non-spatial mark-recapture studies (such as non-spatial cage trapping studies) do not yield robust density estimates (Royle et al. 2013).

While strip transects of known width and length provide density estimates, and where the assumption of complete detection is made (i.e. that all the animals within the strip are detected), they are most applicable to situations where habitat comprises small or narrow remnant vegetation strips such as road reserves or riparian belts.

Spatially explicit capture recapture (Royle et al. 2013) and distance sampling both estimate the probability of detection and provide robust density estimates. However, Western Ringtail Possums are rarely trapped, hence spotlighting (distance sampling) provides a more efficient sampling method. To obtain sufficient observations we have selected line transects as opposed to point transects.

**Table 2.1: Knowledge gaps for Western Ringtail Possums identified in the Department of Parks and Wildlife (2017) Recovery Plan and mitigation of these incorporated into the design of this study.**

| Knowledge Gaps | Mitigation |
|---|---|
| A lack of information on most populations that are small, isolated, and/or at the margins of the extant distribution, including the Waroona, Harvey, Collie, Shannon, Lower Warren and D'Entrecasteaux areas. | We selected sites at the northern (Yalgorup) and south-western (Augusta) edges of the documented distribution. |
| Robust survey methods appropriate for the various habitats that can provide reliable estimates of population density and/or abundance (as distinct from uncalibrated indices and indirect measures of abundance). | Distance sampling is one of two techniques that robustly estimates density (and hence abundance), by accounting for detectability and the area effectively sampled. |
| No strategic or co-ordinated long-term monitoring program across the species range that can quantify and track population trends over time. | Site selection was undertaken in collaboration with local experts, and survey methods are clearly described. Transect layouts are available as spatial files. These sites can be used as a foundation for future monitoring. |
| The causes for decline are not completely understood. | Covariates of density may help explain which land management practices or other factors best predict density, thus allowing inferences regarding factors causing decline to be made. |
| The relative importance and extent of threatening processes is generally not known for the species or for individual populations. | Robust density estimation at some sites provides the opportunity to test the relative impact of threatening process as inferred from covariates (see above). |
| Factors influencing population persistence in urban environments. | Significant sampling is done in peri-urban environments (and in large remnants). We have not designed this study to address this knowledge gap directly. |
| Understanding the factors that improve the success of translocations. | Collection of environmental covariates at these study sites may help explain density and could be used to help identify suitable characteristics of potential recipient sites. Two of the study sites, Yalgorup National Park and Leschanault Peninsula Conservation Park are both historical translocation sites. |
| Habitat restoration/creation parameters/prescriptions and effectiveness. | Collection of additional environmental variables at the study sites may be used to help explain density, which may inform habitat restoration. |

**Table 2.2: Recovery objectives for Department of Parks and Wildlife (2017) Western Ringtail Possums Recovery Plan and outputs from this study.**

| Recovery Objective | Outputs from this study |
|---|---|
| Habitat critical for survival for Western Ringtail Possums is identified and protected in each key management zone. | This study aims to sample a range of vegetation types and localities using a standardised approach and may identify areas of relatively high density, indicative of habitat critical for the survival of the species. |
| Threatening processes that are constraining the recovery of Western Ringtail Possums are mitigated in each key management zone. | By selecting density as the primary metric and nominating robust approaches for estimating density, this study will mitigate the Knowledge Gap Threatening Process (see Section 2.4 above). |
| An evidence-based approach is applied to the management and recovery of Western Ringtail Possums. | Distance sampling permits incorporation of variables that may assist in predicting density estimation, thereby providing a framework for an evidence based approach |
| The management of displaced, orphaned, injured and rehabilitated Western Ringtail Ppossums aids the conservation outcome for the species. | Understanding sites at which intact Western Ringtail Possum populations occur may help inform their suitability or otherwise as potential release sites. |
| Increased awareness of the status of Western Ringtail Possums and support behaviour change to mitigate anthropogenic threatening processes. | Collaboration with international experts on distance sampling and population modelling ensures a rigorous outcome. The subsequent peer reviewed publication of the study in a suitable journal should facilitate awareness. |

Line transect surveys using distance sampling protocols are a common method used to assess terrestrial mammal populations (Buckland et al. 2001, Thomas et al. 2010). They have been recommended for use in estimating the density and abundance of Western Ringtail Possums (de Tores and Elscot 2010) and applied in several studies (e.g. Biota 2018a, Biota 2018b, Biota 2018c, de Tores and Elscot 2010, Finlayson et al. 2010, Zimmermann 2010). Studies have shown that distance sampling delivers reliable results and is efficient for sampling large areas (Hounsome et al. 2005, Newson et al. 2008, Stenkewitz et al. 2010, Gottschalk and Huettmann 2011, Warren and Baines 2011, Dick and Hines 2011), making it an appropriate choice for this study.

## 2.4 Synopsis of Distance Sampling

When conducting a survey, the observer may conduct a census of all individuals of the target species present at the survey site. That is, to obtain a complete census the observer must count all the individuals within a designated plot. This is commonly called a strip transect. In the example shown in Figure 1A, the plot size (*A*) is $2w \times 10$, and the number of individuals (*N*) is 20. An estimate of density easily follows:

$$\hat{D} = N/A \qquad \text{(Eq. 1)}$$

In many circumstances censuses work well. For example, when the target species is sessile (e.g. plants, sea anemone), or if densities are high, technology can be utilised to ensure all individuals are detected (e.g. aerial photographs of seal colonies). In reality, however, it is rare that all individuals present in the survey area are actually detected. Typically, a portion of animals actually present in the survey site are missed by the observer. Without accounting for the portion of animals missed (the detectability of the target), the resulting estimate of density can be severely negatively biased.

For example, in Figure 1B, only 11 animals were actually detected (even though there were 20 present). Had *N* been taken to be 11, without accounting for detectability (as in Eq. 1), the resulting density estimate would have been 0.55 animals per km$^2$, instead of 1 animal per km$^2$. In order to account for detectability, Eq. 1 must be modified:

$$\hat{D} = \frac{N/p}{A} \qquad \text{(Eq. 2)}$$

where *p* is the probability of detection, essentially a correction factor for the proportion of animals present in the survey area but not actually detected. Distance sampling (Buckland et al. 2001) can be used to estimate *p*. Here, we only consider line-transect sampling. In line-transect sampling, the perpendicular distance between the transect and each detected animal is measured (Figure 1C).

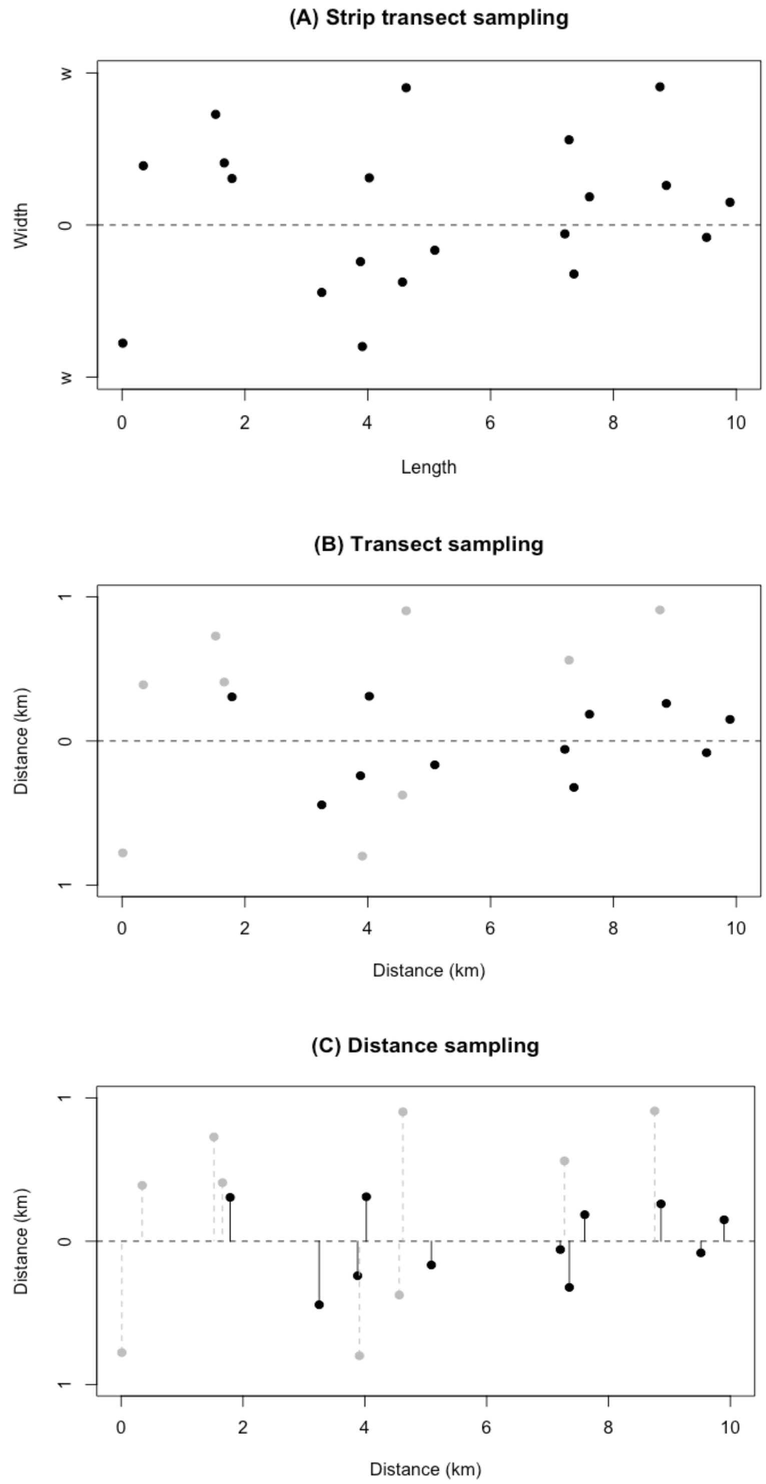


**Figure 2.1. (A) a strip transect sampling example, where all animals along the transect out to distance w are detected (black dots). (B) a transect sampling example, where only a portion of animals present in the survey region are actually detected (black dots), and some animals are missed (grey dots). (C) a distance sampling example, where the perpendicular distances between the transect line (dark grey line) of all detected animals (black dots) are measured. Some animals may be present in the survey region but not detected (grey dots), and the distances these animals are from the transect line (dotted lines) are unobserved and unknown.**

In distance sampling, it is assumed the distances between the line transect and all animals in the survey area is uniformly distributed. This is appropriate and valid if transects are placed at random and not perpendicular to a known density gradient like a road. It is easy to visualise how the ratio of animals detected compared to animals actually present in the survey region changes with increasing distance between the line transect and the animals (Figure 2A). This decline occurs due to detectability (i.e. it is harder to detect animals at greater distance from the line transect). Since animals that were not observed are assumed to follow a uniform distribution (Figure 2B), the probability of detection, *p*, is the ratio between the detected animals (i.e. the area under the red curve in Figure 2B), and the total number of animals present (i.e. the area under the black line in Figure 2B).

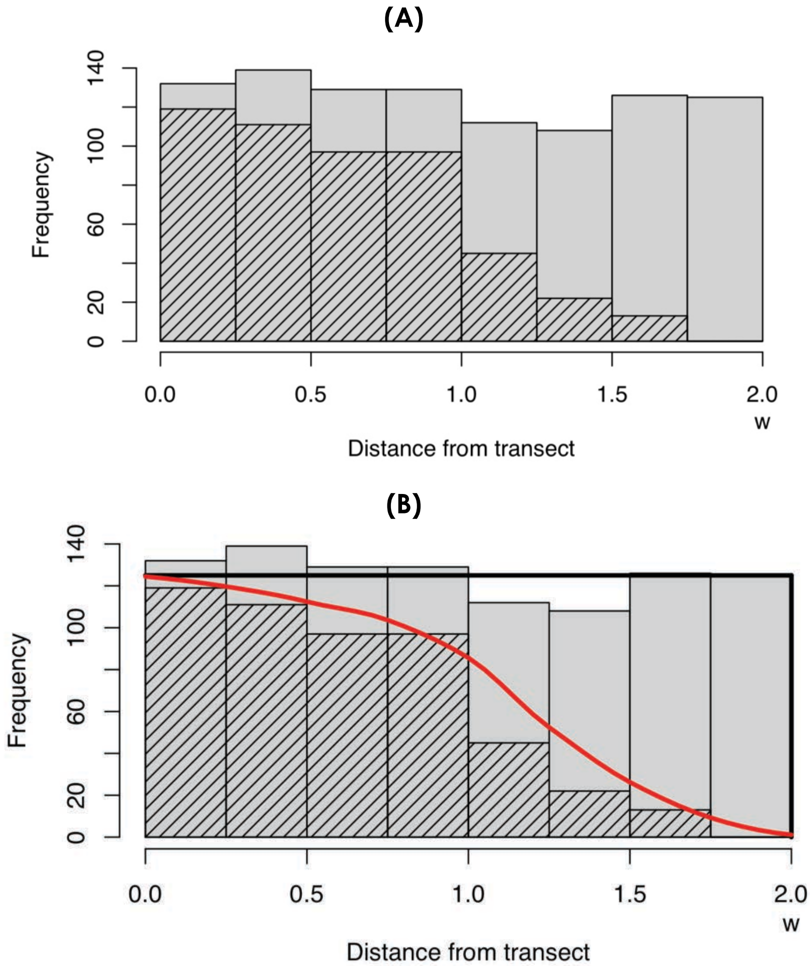


**Figure 2.2. (A) In distance sampling, the distances between the line transect and detected animals are measured. These can be plotted in a histogram of frequencies (hatched bars). That is, 120 animals were observed within a distance of 0.25w from the transect. Animals that were present in the survey region but not detected are assumed to be uniformly distributed from the line transect, and are shown as grey bars. (B) A 'line of best fit' to the distance data, shown in red, whereby as distance increases from the line transect the frequency of observations decreases, whereas the underlying distribution of distances is shown as a solid black line remains constant with increasing distance (a uniform distribution).**

The red curve in Fig. 2B is essentially a detection function, *g(x)*, i.e. what is the probability of detecting an animal given it is x m from the transect. To calculate the area under this red curve, we take the integral, and divide it by the area under the black rectangle, to obtain *p*:

$$\hat{p} = \frac{\int_0^w g(x)dx}{w} \qquad \text{(Eq. 3)}$$

Once we have estimated *p* using distance sampling, we also know how many animals we detected along our transect (*n*), we can calculate the total number of animals present ($\widehat{N}$) and estimate D using Eq. 1.

## 2.5 Stakeholder Engagement

During the site selection process, Biota presented and discussed the proposed design and approach to this study with the Western Ringtail Possum Recovery Committee. Direct contact was made with a number of committee members to assist with site selection, including:

- Ms Barbara Jones (biologist).
- Sarah Comer, Regional Ecologist, Parks and Wildlife Service, South Coast Region, Department of Biodiversity, Conservation and Attractions (DBCA).
- Deon Utber, Regional Leader Conservation, Parks and Wildlife Service, South Coast Region, DBCA.
- Kim Williams, Regional Leader Nature Conservation, Southwest Region, Parks and Wildlife Service, DBCA.
- Ian Wilson, Regional Leader, Nature Conservation, Warren Region. DBCA.
- Dr Adrian Wayne, Senior Research Scientist, Science and Conservation Directorate, DBCA.
- Dr Manda Page, Principal Zoologist, Biodiversity and Conservation Science, DBCA.

# 3.0 Methods

## 3.1 Field Sampling Methods

Line transect distance sampling surveys were undertaken at each of the 43 study sites. Based on previous Western Ringtail Possum distance sampling surveys and fitted detection functions (Biota 2018a, Biota 2018b, Biota 2018c), a minimum transect spacing of 75 m was considered optimal to maximise the effective area sampled in the survey, whilst ensuring individual possums were not detected at neighbouring transects. At some survey sites a wider inter-transect spacing of 150 m was adopted to ensure adequate coverage of large sites, given available survey effort.

Experienced observers independently walked transects using a high-powered head torch (Led Lenser XEO 19R model) to detect animals. The location of each observation was recorded using a Hemisphere R330 Differential GPS or UniStrong UT10 tablet, typically providing accuracy to within 1.5 m. The following data were recorded for each observation:

- species (Western Ringtail Possum, Common Brushtail Possum, Brush-tailed Phascogale, Fox and Cat);
- observer;
- animal location (i.e. the observer standing directly underneath the animal);
- time;
- number of individual animals;
- status of individual animals (adult / independent animal, female with joey on back, female with joey at heel);
- cue: seen (eyeshine), seen (no eyeshine) or heard; and
- tree species.

## 3.2 Study Regions

Sampling was focussed on the Western Ringtail Possum subpopulations that were identified in the IUCN assessment (Burbidge and Zichy-Woinarski 2017), with the exception of the Inland Rivers subpopulation, which was not surveyed. These subpopulations are variously overlapped by the key management zones identified in the Western Ringtail Possum Recovery Plan (Department of Parks and Wildlife 2017). The Swan Coastal Plain management zone encompasses the Swan Coastal Plain and the Cape to Cape subpopulations, the Upper Warren subpopulation is within the Manjimup management zone, and the Around Albany subpopulation is within the South Coast management zone (Figure 3.1).

Surveyed sites on the edge of the Darling Range near Boyanup do not fall into any of the IUCN identified subpopulations, though they are within the Swan Coastal Plain management zone.

Within the geographic extent of each of the IUCN subpopulations (described in further detail below), study sites were selected based on a number of criteria:

- Given the primary purpose of providing local and regional context, sites would ideally support, or once have supported, Western Ringtail Possums.
- Study sites needed to span the geographic extent of each of the subpopulations identified within the IUCN assessment (Burbidge and Zichy-Woinarski 2017).
- Study sites were readily accessible to survey. This largely precluded freehold land and meant that the majority of surveys were conducted on Crown Land.
- Study sites needed to be sufficiently large to undertake distance sampling. This required that there be space to position sufficient transects to estimate the encounter rate variance (nominally 16 (Buckland et al. 2001)) and would yield sufficient observations (typically 60 – 80 (Buckland et al. 2001)) of Western Ringtail Possums to model density without re-sampling transects or pooling data across separate sites.

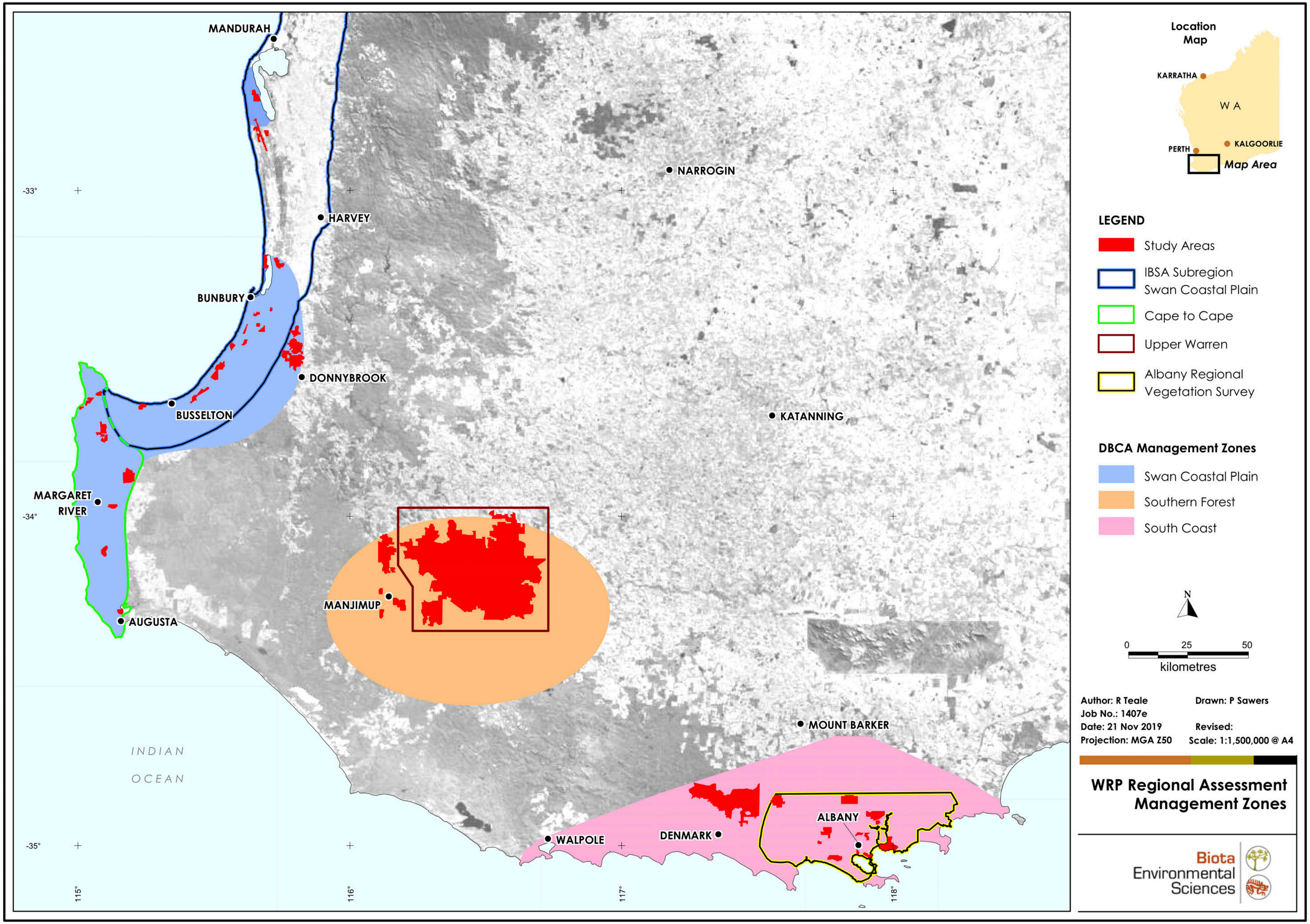


**Figure 3.1: Western Ringtail Possum key management zones and IUCN sub-populations.**

This study did not survey urban and peri-urban settings, riparian belts in agricultural settings, road reserves and smaller vegetation remnants (see criteria above), or the inland Rivers subpopulation (noted above). Some of these are known to support Western Ringtail Possums (Shedley and Williams 2014). Also excluded from survey were vegetation assemblages or habitats considered unlikely to support Western Ringtail Possums, and exceptionally densely vegetated habitats that prevented thorough sampling. Some coastal settings, including sections of the Leschenault Peninsula Conservation Park (Swan Coastal Plain), coastal scrub of the Leeuwin-Naturaliste National Park (Cape to Cape) and thickets of *Hakea* spp. Shrubland / Woodland complexes (Around Albany) are examples of densely vegetated habitats that were often impenetrable or nearly so. Also excluded were vegetation communities where vision to the upper canopy and mid storey was restricted, including Karri Hazel, *Trymalium odoratissimum,* understorey of mature Karri, *Eucalyptus diversicolor,* forest, and thickets of *Hakea* spp. Shrubland / Woodland (Around Albany). Most of the ‘difficult to sample’ vegetation types were encountered in the South Coast management zone, and the vegetation mapping of Sandiford and Barrett (2010) was used to exclude areas of unsampled vegetation from the area calculation for a given survey site.

### 3.2.1 Swan Coastal Plain Management Zone

#### 3.2.1.1 Southern Swan Coastal Plain Study Sites and Survey Timing

To estimate the area of this subpopulation we have adopted the boundary of the Swan Coastal Plain (sub-bioregion SWA02) as defined by the Interim Biogeographic Regionalisation of Australia (IBRA) (Thackway and Cresswell 1995). This sub-bioregion largely coincides with that considered by Shedley and Williams (2014), who considered sites as far north as Myalup. This study includes the Western Ringtail Possum population in the Yalgorup National Park. The species is not currently known from north of the Dawesville Channel.

Total Western Ringtail Possum habitat in the Swan Coastal Plain IBRA bioregion (south of Myalup, Shedley and Williams 2014) has been estimated at 354 $km^2$. Biota sampled approximately 35 $km^2$ (10%) of this habitat using a line-transect distance sampling approach. A further 12 $km^2$ of habitat was surveyed in Yalgorup National Park (this area is not mapped for Western Ringtail Possum habitat). A total estimate of the potential Western Ringtail Possum habitat is derived by combining the Shedley and Williams (2014) estimate with the surveyed area of Yalgorup National Park. This yields 366 $km^2$, of which 12.8 % was surveyed by this study.

As part of the regional assessment, distance sampling surveys were conducted at eight study sites on the Southern Swan Coastal Plain (Figure 3.1, Table 3.1). The three Tuart Forest National Park sections are named following Keighery and Keighery (2002).

Land tenure and the area of each study site is given in Table 3.1. In the case of the Leschenault Peninsula Conservation Park, Dardanup Conservation Park and Kemerton, the study site boundaries represent a portion of a larger extent of remnant vegetation (Figure 3.1). For the Tuart Forest (excluding recently rehabilitated blocks) and Locke Nature Reserve, the study site encompasses the entirety of the remnant (Figure 3.1).

**Table 3.1: Study sites at which distance sampling for Western Ringtail Possum was undertaken on the Southern Swan Coastal Plain.**

| Study Site | Land Tenure | Time of Survey | Area of Study Site (ha) |
|---|---|---|---|
| Yalgorup National Park | Crown Land | June 2019 | 589 |
| Yalgorup National Park - Martins Tank | Crown Land | June 2019 | 590 |
| Leschenault Peninsula Conservation Park | Crown Land | January 2019 | 257.7 |
| Kemerton | Freehold | January 2019 | 581 |
| Tuart Forest - North (Minninup block) | Crown Land | January 2019 | 265 |
| Tuart Forest - Central (North, Lime Kiln, James and Buffer blocks) | Crown Land | January 2019 | 1,080 |
| Tuart Forest - South (Old 14, Hall, Webster and Bullock blocks) | Crown Land | January 2019 | 643 |
| Locke Nature Reserve | Crown Land | January 2019 | 107.5 |
| | | **Total:** | **4,113.2** |

In addition to the findings of the current survey program, density estimates of previous distance sampling surveys in the vicinity of Bunbury, carried out in the latter half of 2018 and first half of 2019 for the proposed Bunbury Outer Ring Road project, are included. These study sites are Reserve 23,000 in the Shire of Capel, Lot 2 Boyanup – Picton Road, Lot 1 Ducane Road, various lots Ducane Road (Manea Park Bunbury) and various lots near Boyanup-West Road in the vicinity of Stratham, collectively referred to as Southern Lots (Table 3.2).

Lot 2 on the Boyanup - Picton Road and the Southern Lots are freehold land, whilst Reserve 23,000 in the Shire of Capel and Manea Park are Crown Land or Unallocated Crown Land.

The study site boundaries and hence area estimates tabulated in Table 3.2 represent the entirety of the remnant in the case of Reserve 23,000 and Lot 2 Boyanup - Picton Road, and part of the remnant in the case of Manea Park, various lots Ducane Road and the Southern Lots Boyanup West Road.

**Table 3.2: Additional study sites at which recent (2018 and 2019) distance sampling has been completed in the Southern Swan Coastal Plain (as part of Main Roads Western Australia project work) and for which results are included in this document.**

| Study Site | Land Tenure | Time of Survey | Area of Study Site (ha) |
|---|---|---|---|
| Reserve 23,000 Shire of Capel | Crown Land | August 2018 | 146.1 |
| Lot 2 Boyanup – Picton Rd | Freehold | August 2018 | 87.6 |
| Lot 1 Ducane Rd | Crown Land | August 2018 | 40.5 |
| Various Lots Ducane Rd | Freehold | July 2019 | 194 |
| Manea Park - Bunbury | Part Crown Land and Unallocated Crown Land | October 2018 | 155 |
| Southern Lots (Boyanup West Road Stratham) | Freehold | November 2018 | 188 |
| | | **Total:** | **811.2** |

### 3.2.1.2 Dardanup and Crooked Brook Study Sites and Survey Timing

The Dardanup and Crooked Brook study sites fall within the Swan Coastal Plain management zone, and within with the Southern Jarrah Forest IBRA sub-bioregion (Thackway and Cresswell 1995). Within this region two study sites were surveyed, both on Crown Land. Both of the study sites were part of much larger remnants. The area calculations presented Table 3.3 (and for which abundance has been estimated) are for the area surveyed.

**Table 3.3: Study sites at which distance sampling was undertaken between Dardanup and Crooked Brook.**

| Study Site | Land Tenure | Time of Survey | Area of Study Site (ha) |
|---|---|---|---|
| Dardanup State Forest | Crown Land | December 2018 | 330.7 |
| Crooked Brook | Crown Land | July – August 2019 | 3,044.0 |
| | | **Total:** | **3,374.7** |

### 3.2.1.3 Cape to Cape Study Sites and Survey Timing

The Cape to Cape subpopulation falls within the Swan Coastal Plain management zone and for the purpose of this study coincides with the Warren and part of the Southern Jarrah Forest IBRA sub-regions (Thackway and Cresswell 1995). Within this region eight study sites were surveyed, all on Crown Land. With the exception of Big Rock Nature Reserve, Yelverton and Augusta North each of the remaining study sites were part of much larger remnants. The area calculations presented in Table 3.4 (and for which abundance has been estimated) for these study areas is constrained to the extent surveyed.

**Table 3.4: Study sites at which distance sampling was undertaken in the Cape to Cape region.**

| Study Site | Land Tenure | Time of Survey | Area of Study Site (ha) |
|---|---|---|---|
| Big Rock Nature Reserve | Crown Land | February 2019 | 72.0 |
| Leeuwin-Naturaliste National Park (Yallingup) | Crown Land | February 2019 | 342.0 |
| Leeuwin-Naturaliste National Park (Canal Rocks) | Crown Land | February 2019 | 17.9 |
| Yelverton | Crown Land | February 2019 | 1,128 |
| North East Margaret River State Forest | Crown Land | February 2019 | 2,125 |
| Woodjtup National Park (10 Mile Brook Dam) | Crown Land | February 2019 | 323.9 |
| Boranup | Crown Land | February - March 2019 | 222.0 |
| Augusta North | Crown Land | March 2019 | 89.3 |
| | | **Total:** | **4,320.1** |

## 3.2.2 Southern Forest Management Zone

### 3.2.2.1 Upper Warren Survey Timing

The Upper Warren study site coincides with the Upper Warren subpopulation of the IUCN assessment and is entirely encompassed by the Manjimup management zone.

### 3.2.2.2 Manjimup Study Sites and Survey Timing

The Manjimup management zone also encompassed the four smaller study sites Dingup, Faunadale, Jardee and Linfarne. Faunadale and Jardee were surveyed in their entirety, whereas only small sections of the entire extent of Dingup and Faunadale were surveyed (Figure 3.5).

**Table 3.5: Study sites at which distance sampling was undertaken in the Warren management zone.**

| Study Site | Land Tenure | Time of Survey | Area of Study Site (ha) |
|---|---|---|---|
| Upper Warren | Crown Land | February - March 2019 | 9,514.0 |
| Dingup | Crown Land | July 2019 | 118.0 |
| Faunadale | Crown Land | July 2019 | 84.4 |
| Jardee | Crown Land | July 2019 | 118.0 |
| Linfarne | Crown Land | July 2019 | 980.0 |
| | | **Total:** | **10,814.4** |

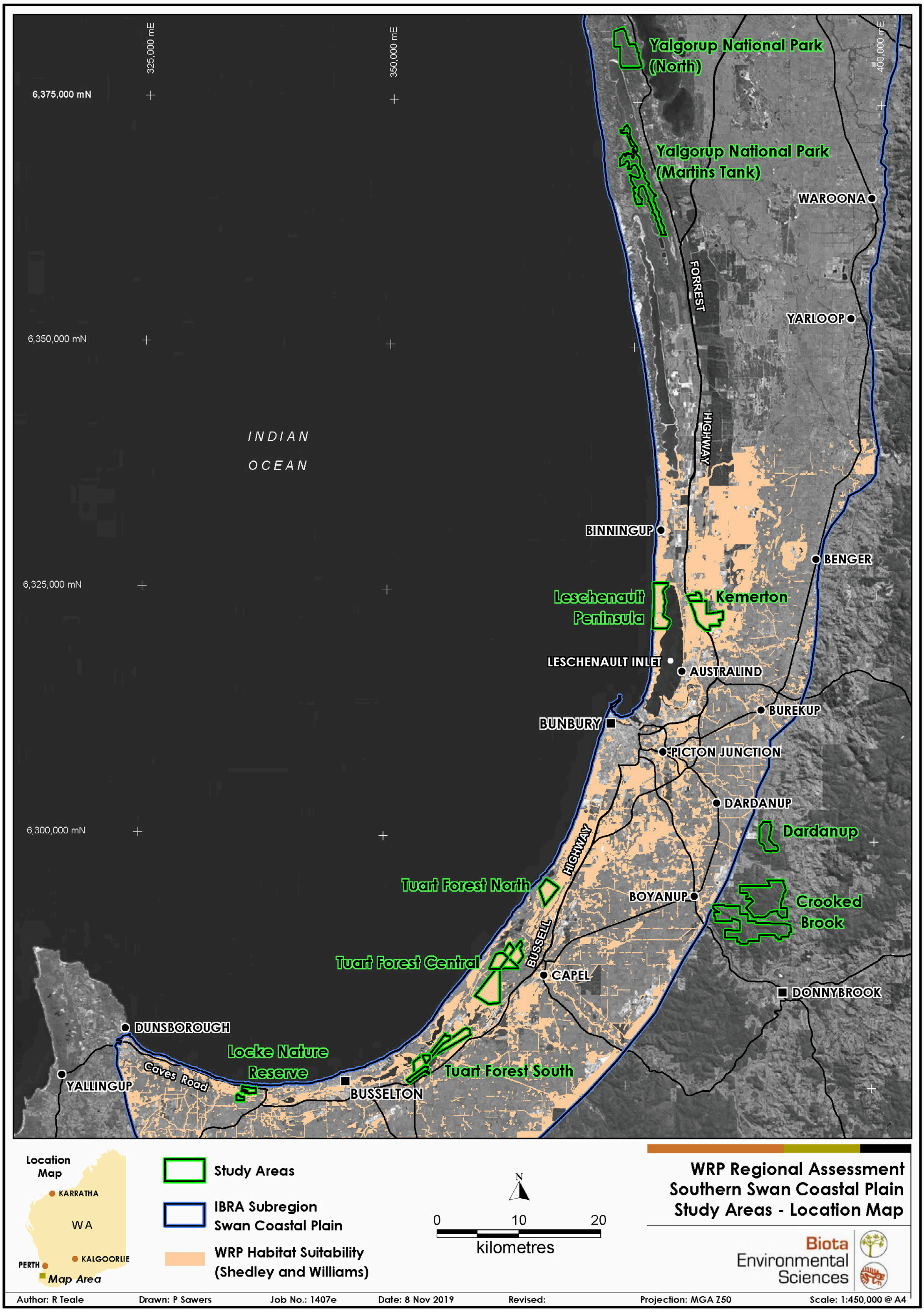


**Figure 3.2:** Study sites at which distance sampling surveys for the Western Ringtail Possum were undertaken for the Swan Coastal Plain and adjacent Dardanup and Crooked Brook locality.

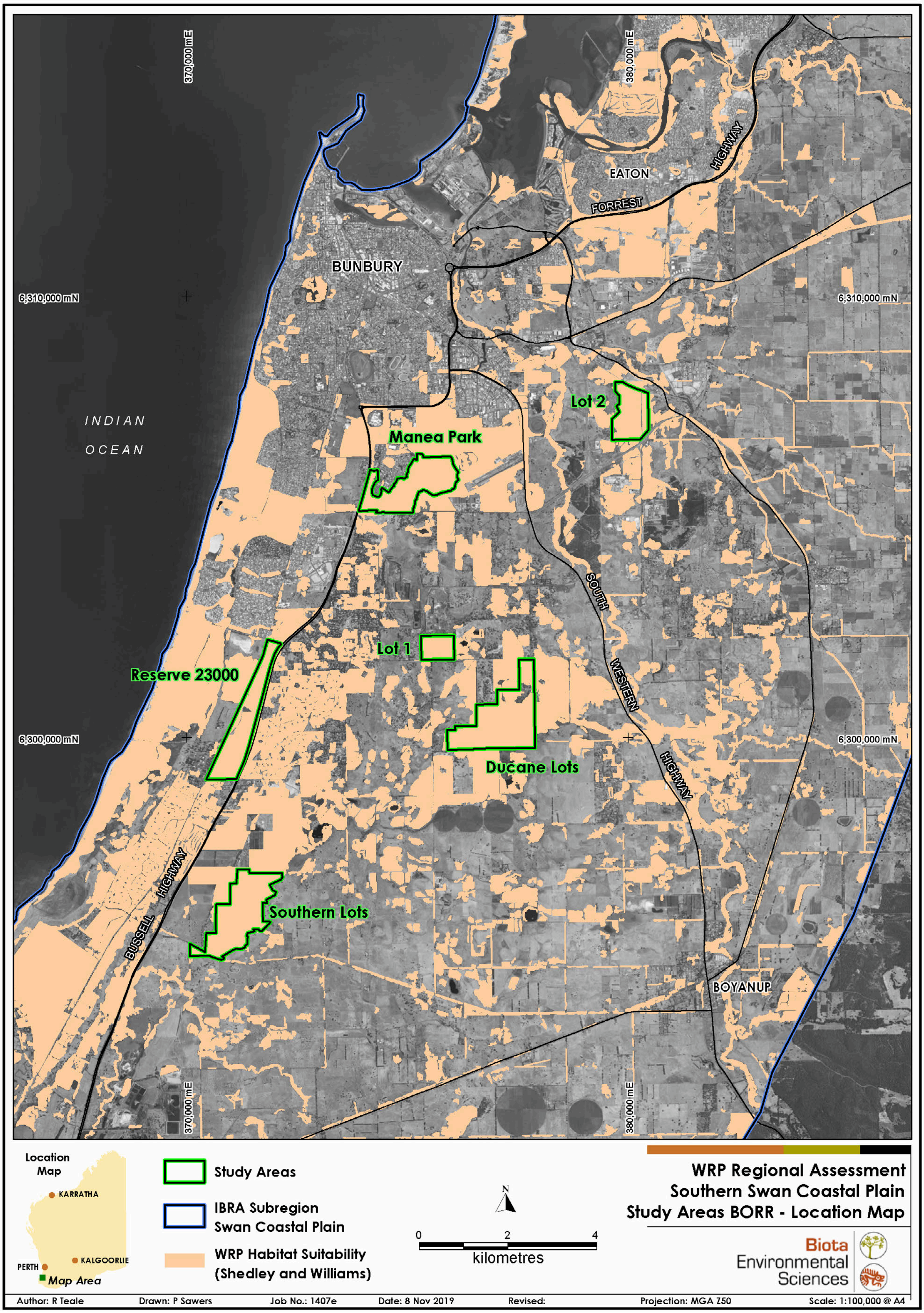


**Figure 3.3:** Study sites at which distance sampling surveys for the Western Ringtail Possum were undertaken for the Bunbury Outer Ring Road Project.

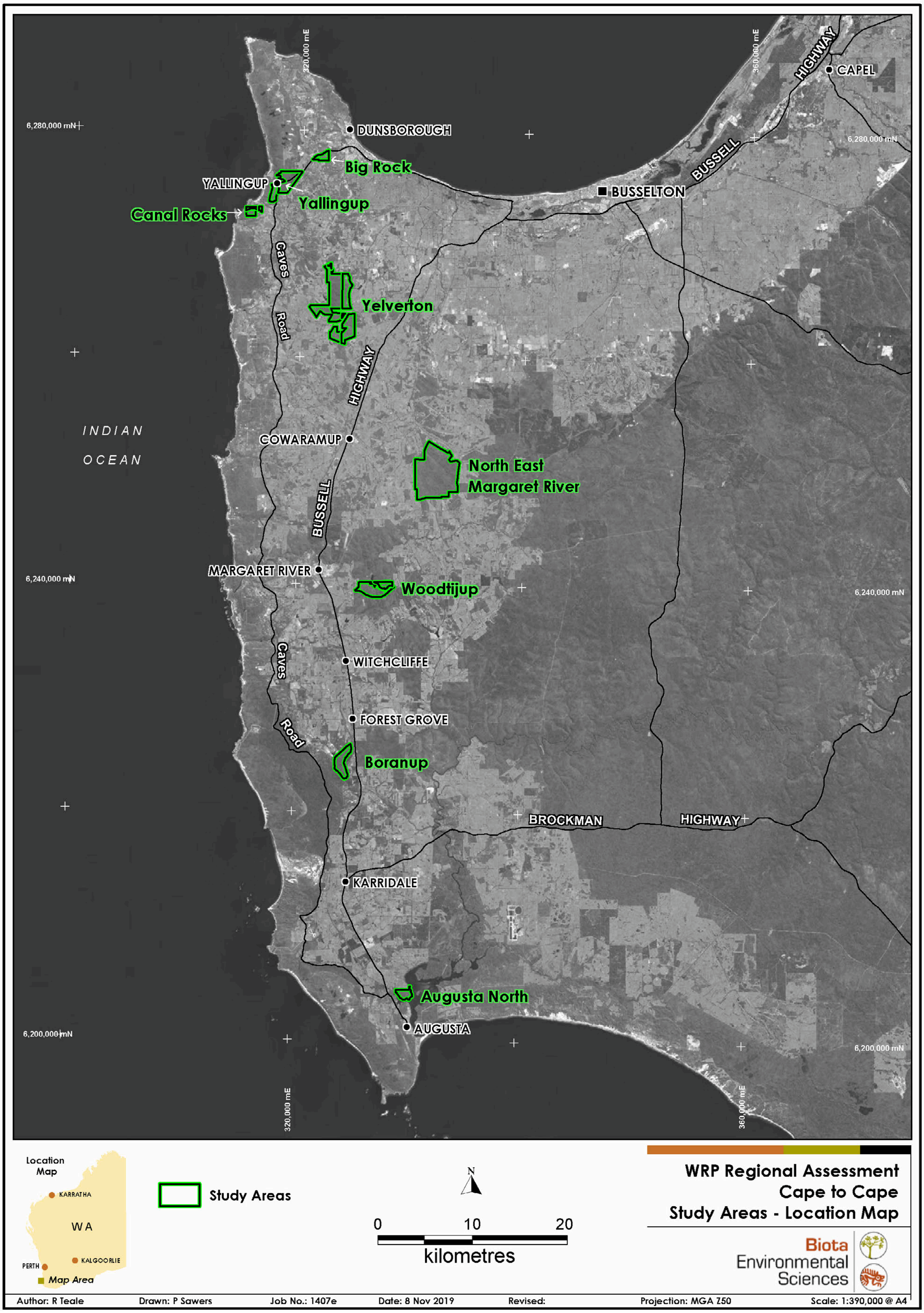


**Figure 3.4:** Study sites at which distance sampling surveys for the Western Ringtail Possum were undertaken for the Cape to Cape region.

### 3.2.3 South Coast Management Zone

#### 3.2.3.1 Around Albany Study Sites and Survey Timing

The Around Albany sub-population is within the South Coast management zone, which extends from Mt Manypeaks in the east to Walpole in the west. We have restricted study sites to an area coincident with the Albany Regional Vegetation Survey (ARVS; Sandiford and Barrett 2010). The ARVS describes and maps vegetation types totalling 124,415 ha, surrounding the Albany town site by 30 km to the east and west and 20 km to the north. The ARVS provides a thematic layer within which potential Western Ringtail Possum habitat can be identified, and for which density estimates can be examined for different vegetation types. Nine sites were surveyed (Table 3.6), with additional transects surveyed at Mt Clarence to augment effort (see below).

Most study site boundaries included the entire vegetation remnant. For Denmark Catchment State Forest and Gull Rock National Park the study area represented a portion of a larger area of remnant vegetation (Figure 3.6). Surveys were attempted within the West Cape Howe and Torbay Campsite but were abandoned due to sampling difficulties associated with dense vegetation and poor detection probability of animals on transect.

**Table 3.6: Study sites at which distance sampling for Western Ringtail Possum was undertaken in the Around Albany subpopulation.**

| Study Site | Land Tenure | Time of Survey | Area of Study Site (ha) |
|---|---|---|---|
| Cuthbert | Crown Land | July 2019 | 106.7 |
| Denmark Catchment State Forest | Crown Land | March 2019 | 1,288.0 |
| Gull Rock National Park | Crown Land | March 2019 | 2,105.0 |
| Marbelup Nature Reserve | Crown Land | June 2019 | 107.0 |
| Millbrook Nature Reserve | Crown Land | March 2019 | 1,483 |
| Simpson Road | Crown Land | July 2019 | 257.0 |
| King River | Crown Land | June 2019 | 131.0 |
| Walmsley West | Crown Land | March 2019 | 161.1 |
| Walmsley East | Crown Land | March 2019 | 176.1 |
| Walmsley South | Crown Land | June 2019 | 59.8 |
| | | **Total:** | **5,874.7** |

In addition to the above study sites, data from recently completed distance sampling in the Down Road Nature Reserve (Biota 2018d), Bakers Junction Nature Reserve (Biota 2018e) and at Mt Clarence and Mt Melville (Biota 2019) are also included. During this study additional transects were completed at Mt Clarence to develop a more robust detection function for that study site.

**Table 3.7: Additional study sites at which recent (2018 and 2019) distance sampling has been completed in the Around Albany area (as part of Main Roads Western Australia project work˘ or on behalf of the Shire of Albany*) and for which results are included in this document.**

| Study Site | Land Tenure | Time of Survey | Area of Study Site (ha) |
|---|---|---|---|
| Down Road Nature Reserve˘ | Crown Land | July 2018 | 363.0˘ |
| Bakers Junction Nature Reserve˘ | Crown Land | July 2018 | 843.0 |
| Mt Clarence* | Crown Land | April / May 2019 | 266.3 |
| Mt Melville* | Crown Land | April / May 2019 | 97.4 |
| | | **Total:** | **1569.7** |

˘ Excludes habitat that was burnt in the June 2018 fire.

#### 3.2.3.2 Frankland Study Site and Survey Timing

The Frankland Study site, situated north of Denmark lies partly outside of the indicative boundary of the South Coast management zone and extended over a substantial area. This study surveyed part of a large forest remnant.

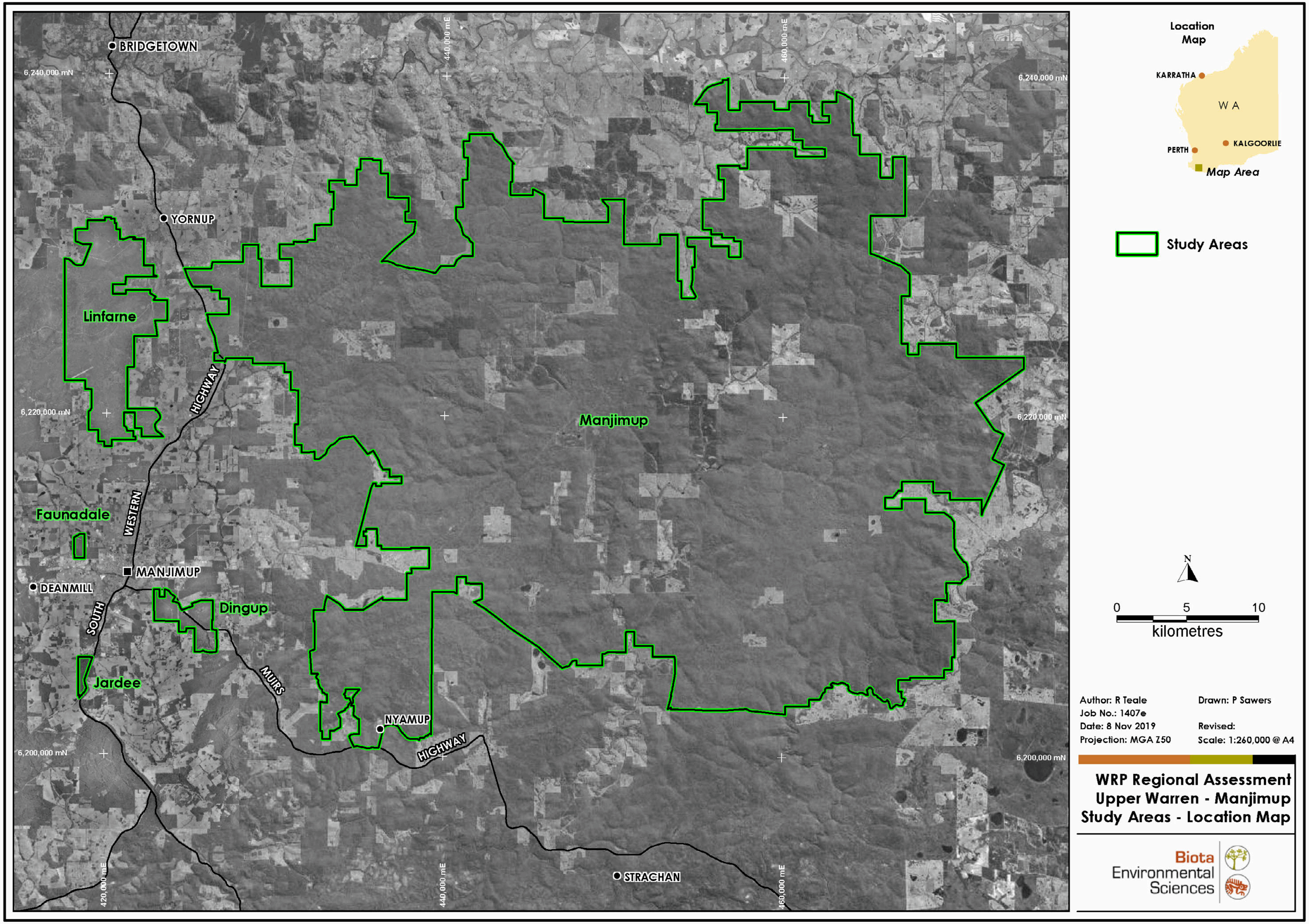


**Figure 3.5:** **Study sites at which distance sampling surveys for the Western Ringtail Possum were undertaken for the Cape to Cape region.**

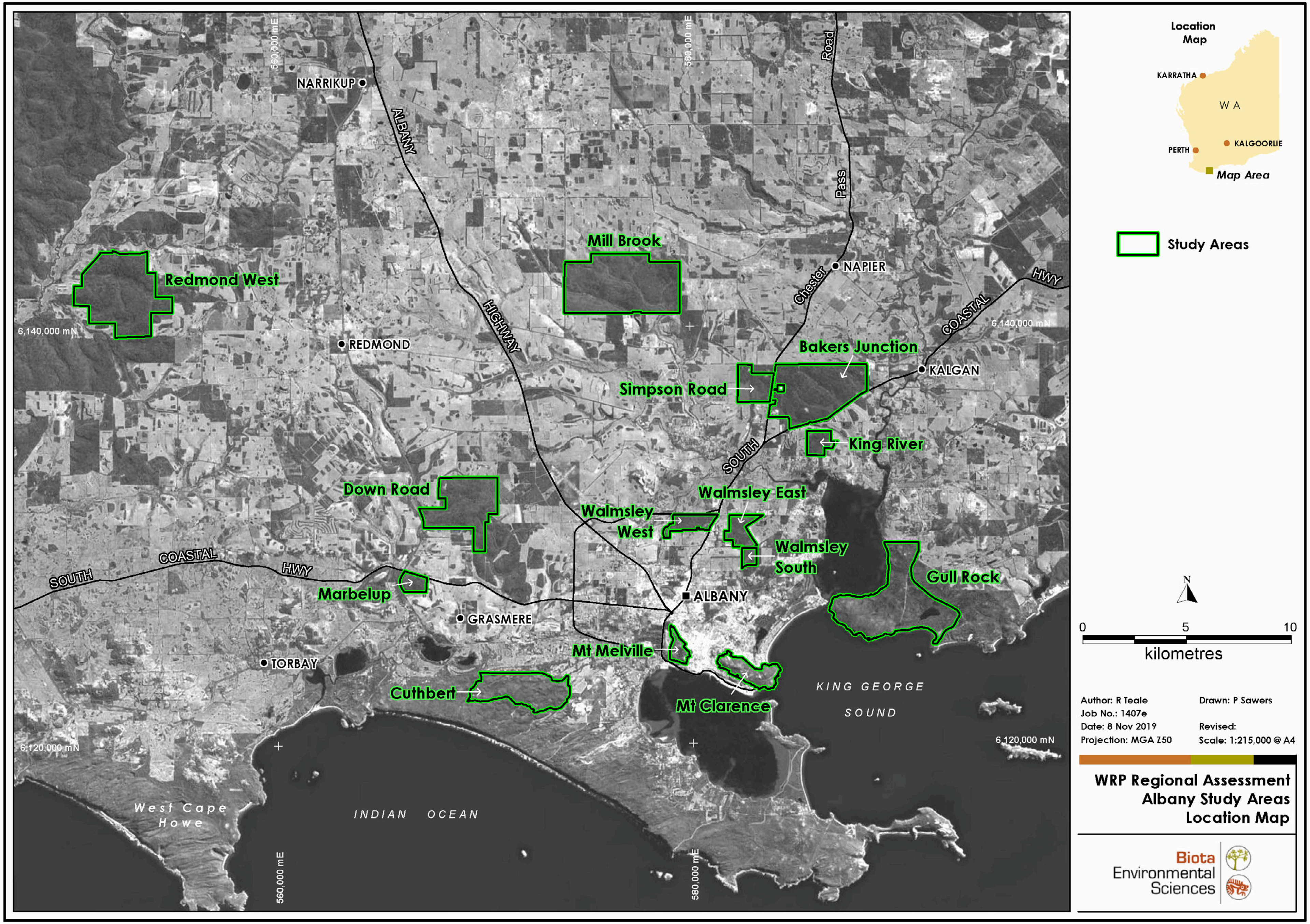


**Figure 3.6: Study sites at which distance sampling surveys for the Western Ringtail Possum were undertaken for the Around Albany region.**

## 3.3 Analyses

### 3.3.1 Analyses of Distance Sampling (DS) Data

Perpendicular distance data were analysed using the 'Distance' package (version 0.9.8, Miller 2017) in the R statistical software (v, 3.5.2, R Core Team 2018) to estimate the Probability Detection Fuction (i.e. the probability of detecting a possum, given it is x m from the transect line). Variation in the Probability Detection Function caused by observers (factor covariate: observer) and study area (factor covariate: study area) were explored. Akaike's Informative Criterion (AIC) was used to select between candidate models, such that models with a lower AIC were considered to be a *relatively* better fit to the data when compared to the candidate set of models investigated (Buckland et al. 2001). However, a given model having the lowest AIC of those models in the candidate set does not necessarily imply the model is a good fit to the data. As such, visual inspection of model fit to histograms of the observed perpendicular distances and quantile-quantile (Q-Q) plots was undertaken, and a Cramér-von Mises (CvM) test was used to formally assess goodness of fit (Buckland et al. 2004).

Within the results we provide the estimate of the encounter rate (n/L), where n was the number of observed clusters and L was the total length of the transect and the selected model was used to estimate the following parameters:

1. the average probability of detection (p);
2. a density estimate ($\widehat{D}$); and
3. an estimate of the number of animals in the specified area ($\widehat{N}$).

Two survey sites were omitted from the analysis: (1) Cuthbert (South Coast management zone), because insufficient survey effort was undertaken to effectively sample the site, and (2) Leschenault Peninsula Conservation Park (Swan Coastal Plain management zone) because of dense vegetation constraining our ability to walk transects. Summary data for these two sites, including survey effort, encounter rate and total number of observations, are still provided. In addition, during surveys at one site (Upper Warren) it became apparent to field staff the vegetation was open and consequently the detection process was different to the other surveyed sites. Consequently, this site was modelled separately.

### 3.3.2 Density Surface Modelling (DSM)

In Distance Sampling (Section 2.4), estimates of density in the total survey region are obtained by extrapolating the estimated density in the covered region upwards, by the ratio of the total survey area that was actually surveyed (i.e. it is assumed the estimated density of animals in the covered region applies to the uncovered region).

Alternatively, the spatial locations of detected animals (obtained via distance sampling) can be modelled according to a 2-dimensional spatial smooth, creating a density surface model (DSM) of the animals (Miller et al. 2013). To do this, the survey region is discretised. Line transects may have fallen within some grid cells in the discretised survey region (in which case, the encounter rate of animals within that grid cell is known, as is the survey effort, i.e. the transect length within each grid cell), or not (in which case there was no survey effort in the grid cell). The encounter rate of animals within each surveyed grid cell is corrected upwards based on distance sampling theory, to account for animals that were present but not detected.

Explanatory variables within each grid cell across the survey region are known (e.g. latitude and longitude). The relationship between the estimated density in each surveyed grid cell is modelled, accounting for survey effort, and extrapolated to grid cells that were not surveyed. This results in a spatial 'map' of where the animals are located within the survey region. The predicted abundance of the survey region can be obtained by summing the estimated abundance in each grid cell. This result differs slightly to that obtained via Distance Sampling, due to the reasons outlined above (the assumption that the estimated density in the covered region is applicable to the entire survey region); however, note that if survey coverage in the region is high, the estimates from DSM and DS will become approximately equal.

DSMs were fitted to all study sites, following Miller et al. (2013) using the 'dsm' package (v. 2.2.17, Miller et al. 2019) in the statistical program R (v. 3.5.2, R Core Team, 2018). Each survey region was discretised in to 75 m grid cells. The pooled detection function fitted to all Western Ringtail Possums observations across the three regions was used (excluding Upper Warren). A 2-dimensional smooth was used (in x and y), without any other covariates.

Since the detection function at Upper Warren was modelled separately to the other sites, a separate DSM for this site was developed. This was based on the detection function fitted to all detection events within Upper Warren. The DSM was developed in the same way as the other sites, however the influence of three other explanatory covariates (elevation, fire history and harvest history) on density estimates were explored.

The percentage deviance explained was calculated for each model, and spatial autocorrelation for each DSM was checked. The predicted density surface of Western Ringtail Possums for each study site was then generated.

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# 4.0 Results

## 4.1 Summary Statistics

The entire study surveyed 114,243 ha using 1,249 transects equating to a total effort of 1,287.2 km of transect. Across these transects 2,939 detections of 3,677 individual Western Ringtail Possum were made. These summary statistics are described for each subpopulation below and individual site descriptions are given in the Technical Supplement (Biota 2020).

### 4.1.1 Swan Coastal Plain Management Zone

#### 4.1.1.1 Southern Swan Coastal Plain

During the current distance sampling program, a total of 224 transects were surveyed for a combined total effort of 180.07 km within the Swan Coastal Plain region. Across that effort, 940 detections of 1,267 unique Western Ringtail Possum were made at an average encounter rate of 7.04 individuals per kilometre. Combining this effort with the 75.86 km across 115 transects surveyed using distance sampling as part of the Bunbury Outer Ring Road project (excluding surveys within nominal development footprints), yields a combined distance of 255.93 km and a combined total of 1,521 unique individual Western Ringtail Possum (Table 4.1). Across those same transects, a total of 715 unique Common Brushed-tail Possums was recorded.

Western Ringtail Possum were not detected at Kemerton but were recorded from all other study sites and at a relatively wide range of average encounter rates (1.18 to 15.93 individuals per kilometre) (Table 4.1). The highest average encounter rate was from Tuart Forest North (Minninup block) study site, which yielded 15.93 individuals per kilometre (Table 4.1). Higher encounter rates were yielded from some individual forest blocks within the Tuart Forest Central study site. For example, an encounter rate of 20.93 individual Western Ringtail Possum per kilometre was recorded across transects from the Bullock, Hall and Webster blocks. Still higher encounter rates were yielded from individual transects, for example, transect M_D_14 (Tuart Forest North study site) yielded 46 individual Western Ringtail Possum along its length of 2,048.1 m, resulting in an encounter rate of 22.5 individuals per kilometre, and 19 individuals were recorded from the 511.4 m of LN_D_09 (Tuart Forest Central study site) yielding an encounter rate of 37.2 individuals per kilometre.

Generally, the encounter rates from the sites near Bunbury were lower than for sites further south on the Swan Coastal Plain. The exception to this generalisation was at the Tuart Forest Central study site where the average encounter rate of 5.92 individuals per kilometre was lower than the encounter rate of 6.17 individuals per kilometre recorded from the Lot 2 Boyanup – Picton Road study site (Table 4.1). However, there was considerable variation across the individual forest blocks: North, Lime Kiln, James and Buffer comprised the Tuart Forest Central study site, but the two southern blocks (James and Buffer) yielded a relatively low encounter rate of 4.0 individuals per kilometre that was almost half that calculated for the northern two blocks in the same study site (North and Lime Kiln) at 7.9 individuals per kilometre.

Aside from differences in real abundance, the encounter rate is clearly also a function of the probability of detection for any given distance from the surveyed transect and can vary between study sites depending on a variety of factors, the most obvious (for this survey) perhaps being the thickness of vegetation. The probability of detection assessed via statistical modelling (see Section 4.0) was found to significantly change across key management zones and therefore direct comparison of encounter rates needs bear this in mind.

**Table 4.1: Key summary statistics for Western Ringtail Possum detections in Swan Coastal Plain Region study sites (raw data).**

| Study Site | No. of Transects | Effort (km) | Number of Detections | Number of Individuals | Detections Encounter Rate (per km) | Individuals Encounter Rate (per km) |
|---|---|---|---|---|---|---|
| Yalgorup National Park (North) | 52 | 49.16 | 75 | 86 | 1.53 ± 0.18 | 1.75 ± 0.21 |
| Yalgorup National Park (Martins Tank) | 73 | 32.42 | 109 | 128 | 3.36 ± 0.51 | 3.95 ± 0.63 |
| Leschenault Peninsula Conservation Park | 16 | 6.94 | 7 | 10 | 1.01 | 1.44 |
| Kemerton | 23 | 20.3 | 0 | 0 | 0 | 0 |
| Tuart Forest North | 10 | 12.18 | 157 | 194 | 12.89 ± 1.48 | 15.93 ± 1.82 |
| Tuart Forest Central | 62 | 69.88 | 293 | 414 | 4.19 ± 0.39 | 5.92 ± 0.57 |
| Tuart Forest South | 67 | 39.9 | 391 | 534 | 9.79 ± 0.83 | 13.38 ± 1.17 |
| Locke Nature Reserve | 22 | 8.58 | 80 | 98 | 9.32 ± 1.62 | 11.42 ± 0.21 |
| Reserve 23,000 Shire of Capel | 40 | 18.2 | 55 | 74 | 3.02 ± 0.54 | 4.06 ± 0.75 |
| Lot 2 Boyanup – Picton Rd | 8 | 8.87 | 52 | 58 | 5.86 ± 0.45 | 6.54 ± 0.50 |
| Lot 1 Ducane Road | 10 | 5.08 | 5 | 6 | 0.98 | 1.18 |
| Ducane Lots | 30 | 22.74 | 45 | 55 | 1.98 ± 0.34 | 2.42 ± 0.42 |
| Manea Park | 28 | 20.36 | 74 | 103 | 3.63 ± 0.49 | 5.06 ± 0,79 |
| Southern Lots | 26 | 21.51 | 24 | 32 | 1.11 ± 0.28 | 1.49 ± 0.36 |
| **Grand Total** | **467** | **336.12** | **1367** | **1792** | **4.07** | **5.33** |

#### 4.1.1.2 Dardanup and Crooked Brook

The survey of the Dardanup and Crooked Brook study sites traversed 127 kilometres across 127 transects and yielded 145 detections of 163 unique individuals (Table 4.2). No detections were made from Dardanup State Forest despite a search effort of 20.7 kilometres. The average encounter rate in Crooked Brook was relatively low at 0.99 ± 0.15 individuals per kilometre however, almost half of the transects (52 of 107) failed to yield any detections. On the remaining transects, some detection rates were relatively high, for example, along the 2.49 kilometres of transect CB_D_146A a total of 16 individuals were detected yielding a detection rate of 6.42 individuals per kilometre.

**Table 4.2: Key summary statistics for Western Ringtail Possum detections in the Dardanup and Crooked Brook study sites (raw data).**

| Study Site | Number of Transects | Effort (km) | Number of Detections | Number of Individuals | Detections Encounter Rate (per km) | Individuals Encounter Rate (per km) |
|---|---|---|---|---|---|---|
| Dardanup State Forest | 20 | 21.7 | 0 | 0 | 0 | 0 |
| Crooked Brook | 107 | 164.7 | 145 | 163 | 0.88 ± 0.13 | 0.99 ± 0.15 |
| **Grand Total** | **127** | **186.4** | **145** | **163** | | |

#### 4.1.1.3 Cape to Cape

Within the area coincident with the Cape to Cape subpopulation, a total of 220 transects were surveyed for a combined total effort of 158.6 km. Across that effort, 487 detections of 627 unique Western Ringtail Possum were made at an average encounter rate of 3.95 individuals per kilometre.

Western Ringtail Possum were not detected from the 14.5 km of transects within the Margaret River North East State Forest or from the 10.5 km of transects within the Wooditjup National Park (adjacent the 10 Mile Brook Dam). Western Ringtail Possum were recorded from all other surveyed sites with a general trend of decreasing encounter rates from the northern sites (Big Rock and Yallingup) to the southern sites (Boranup and Augusta North) (Table 5.2).

**Table 4.3: Key summary statistics for Western Ringtail Possum detections in the Cape to Cape study sites (raw data).**

| Study Site | Number of Transects | Effort (km) | Number of Detections | Number of Individuals | Detections Encounter Rate (per km) | Individuals Encounter Rate (per km) |
|---|---|---|---|---|---|---|
| Big Rock | 22 | 8.98 | 78 | 97 | 8.69 ± 0.85 | 10.81 ± 1.15 |
| Yallingup | 43 | 24.15 | 224 | 284 | 9.27 ± 0.85 | 11.56 ± 1.16 |
| Canal Rocks | 6 | 2.01 | 14 | 18 | 6.97 ± 1.85 | 8.97 ± 2.36 |
| Yelverton | 82 | 73.5 | 154 | 207 | 2.09 ± 0.24 | 2.82 ± 0.37 |
| Margaret River NE State Forest | 19 | 14.43 | 0 | 0 | 0 | 0 |
| Wooditjup National Park (part) | 12 | 10.48 | 0 | 0 | 0 | 0 |
| Boranup | 24 | 16.45 | 15 | 18 | 0.91 ± 0.34 | 1.09 ± 0.42 |
| Augusta North | 12 | 8.57 | 2 | 3 | 0.23 ± 0.16 | 0.35 ± 0.26 |
| **Grand Total** | **220** | **158.59** | **487** | **627** | | |

## 4.1.2 Southern Forest

### 4.1.2.1 Upper Warren and Manjimup

Within the Upper Warren study area and across four additional sites in the vicinity of Manjimup (Faunadale Nature Reserve, Dingup, Jardee and Linfarne) (see Figure 3.5), a total of 151 transects were surveyed for a combined total effort of 320.4 km. Across that effort, 228 detections of 260 unique Western Ringtail Possum were made (Table 4.4).

Western Ringtail Possums were recorded from all study sites within the Manjimup region, though at variable encounter rates. The highest average encounter rate (6.16 ± 0.64 individuals per kilometre) was recorded from Faunadale Nature Reserve and was over three times as high as Jardee (1.76 ± 0.37), almost an order of magnitude higher than the Upper Warren (0.70 ± 0.14) and significantly higher than Dingup (0.23 ± 0.09) and Liinfarne (0.06 ± .04) (Table 4.4). Though the average encounter rate within the 9,514 hectares of the Upper Warren was low (in comparison to Faunadale and many other study sites throughout the species range), individual encounter rates across different transects was variable ranging between nil encounters (on 44 of the 91 transects) through to 6.55 per kilometre along the 2.9 kilometres of transect MJ_76A.

**Table 4.4: Key summary statistics for Western Ringtail Possum detections in the Upper Warren, Dingup, Faunadale, Jardee and Linfarne study sites (raw data).**

| Study Site | Number of Transects | Effort (km) | Number of Detections | Number of Individuals | Detections Encounter Rate (per km) | Individuals Encounter Rate (per km) |
|---|---|---|---|---|---|---|
| Upper Warren | 91 | 251.47 | 153 | 175 | 0.61 ± 0.12 | 0.70 ± 0.14 |
| Dingup | 8 | 17.32 | 4 | 5 | 0.23 ± 0.09 | 0.29 ± 0.14 |
| Faunadale | 17 | 10.56 | 58 | 65 | 5.49 ± 0.66 | 6.16 ± 0.64 |
| Jardee | 13 | 6.83 | 11 | 12 | 1.61 ± 0.34 | 1.76 ± 0.37 |
| Linfarne | 22 | 34.20 | 2 | 3 | 0.06 ± 0.04 | 0.09 ± 0.07 |
| **Grand Total** | **151** | **320.38** | **228** | **260** | | |

## 4.1.3 South Coast

### 4.1.3.1 Around Albany

Within the area encompassed by our definition of the Around Albany subpopulation, a total of 272 transects were surveyed for a combined total effort of 269.9 km. Across that effort, a total of 685 detections were made yielding a total of 806 unique Western Ringtail Possums.

Western Ringtail Possums were not detected from the almost 16 kilometres of transects at the Redmond West study site but were recorded from all other study sites. The encounter rates of individual Western Ringtail Possums from those study sites where detections were made varied between 0.28 ± 0.28 individuals per kilometre (Cuthbert study site) to 13.08 ± 1.52 individuals per kilometre (Walmsley West study site). The encounter rate at Walmsley West was amongst the highest encounter rates recorded from any of the study sites visited by the current survey.

**Table 4.5: Key summary statistics for Western Ringtail Possum detections in the Around Albany study sites (raw data).**

| Study Site | Number of Transects | Effort (km) | Number of Detections | Number of Individuals | Detections Encounter Rate (per km) | Individuals Encounter Rate (per km) |
|---|---|---|---|---|---|---|
| Bakers Junction Nature Reserve | 18 | 31.97 | 50 | 55 | 1.56 ± 0.37 | 1.72 ± 0.43 |
| Cuthbert | 5 | 7.13 | 1 | 2 | 0.14 ± 0.14 | 0.28 ± 0.28 |
| Down Road Nature Reserve | 29 | 35.84 | 80 | 86 | 2.23 ± 0.30 | 2.34 ± 0.35 |
| Gull Rock Nature Reserve | 17 | 25.63 | 5 | 6 | 0.20 ± 0.09 | 0.23 ± 0.11 |
| King River | 13 | 13.63 | 44 | 51 | 3.23 ± 0.56 | 3.74 ± 0.60 |
| Marbelup | 15 | 12.31 | 31 | 39 | 2.52 ± 0.51 | 3.17 ± 0.66 |
| Millbrook Nature Reserve | 39 | 40.10 | 14 | 19 | 0.35 ± 0.10 | 4.74 ± 0.15 |
| Mount Clarence | 35 | 23.84 | 143 | 165 | 6.00 ± 0.58 | 6.92 ± 0.68 |
| Mount Melville | 34 | 10.44 | 58 | 74 | 5.56 ± 1.08 | 7.09 ± 1.58 |
| Redmond West | 14 | 15.86 | 0 | 0 | 0 | 0 |
| Simpson Road | 16 | 22.64 | 27 | 29 | 1.19 ± 0.20 | 1.28 ± 0.21 |
| Walmsley East | 14 | 10.80 | 65 | 80 | 6.01 ± 0.93 | 7.41 ± 0.11 |
| Walmsley South | 9 | 7.64 | 36 | 42 | 4.71 ± 0.75 | 5.50 ± 0.90 |
| Walmsley West | 19 | 12.1 | 131 | 158 | 10.84 ± 0.98 | 13.08 ± 1.52 |
| **Grand Total** | **272** | **269.9** | **685** | **806** | | |

#### 4.1.3.2 Frankland

Nine transects totalling 12.89 kilometres in length were surveyed in the Frankland study site without detecting any Western Ringtail Possums. Effort was curtailed at this site and focussed in the Crooked Brook Study Site that seemed more prospective. The site is not considered in the analyses below as it was not surveyed thoroughly.

**Table 4.6: Key summary statistics for Western Ringtail Possum detections in the Frankland study area (raw data).**

| Survey Site | Number of Transects | Effort (km) | Number of Detections | Number of Individuals | Detections Encounter Rate (per km) | Individuals Encounter Rate (per km) |
|---|---|---|---|---|---|---|
| Frankland | 9 | 12.89 | 0 | 0 | 0 | 0 |

## 4.2 Distance Sampling Analyses

### 4.2.1 All Sites

Distance data were excluded from two sites: (1) Leschenault Peninsula Conservation Park because it was not effectively sampled during the survey due to the often-impenetrable vegetation and our inability to stay consistently on transects, and (2) Cuthbert because of insufficient survey effort.

Perpendicular distance data were pooled across the remaining 43 study sites and plotted as a histogram to determine whether evasive movement of animals was occurring prior to detection. Stepped lower initial intervals that increase away from the centreline can indicate movement away from the observers, while initially high then decreasing intervals indicate potential movement towards observers and both can lead to bias in density estimation. The resulting histogram (Figure 4.1) was not suggestive of either evasive movement or movement towards the observer.

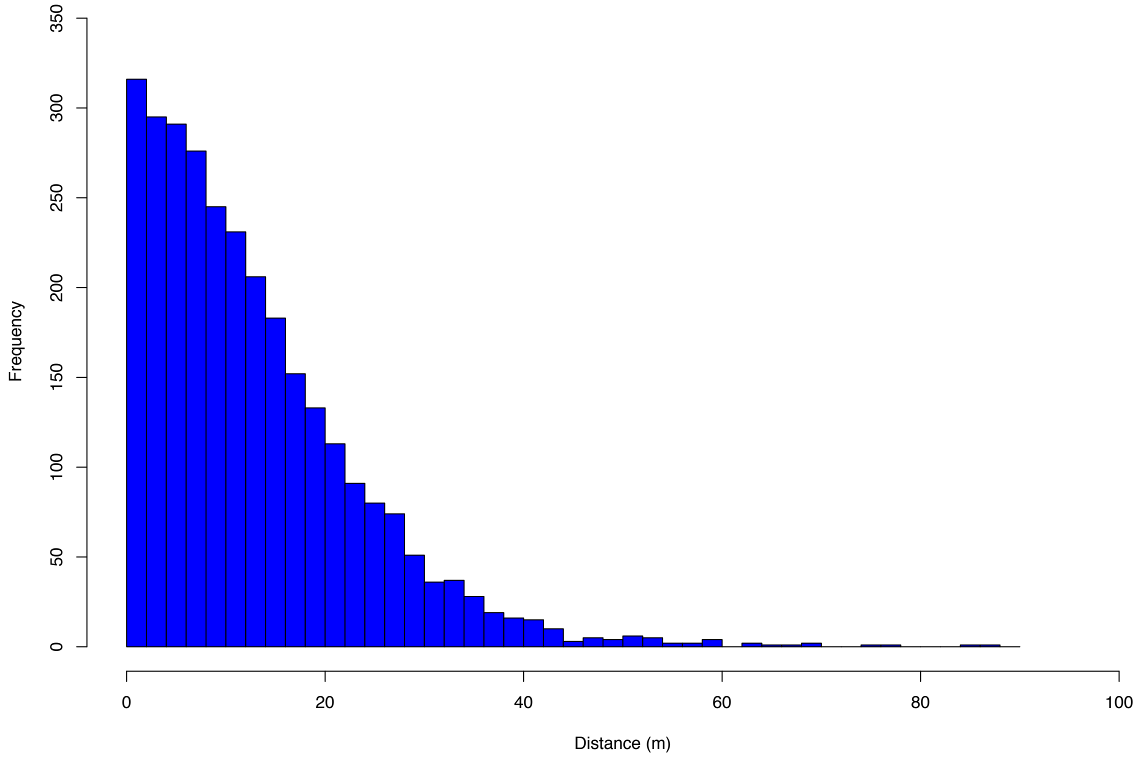



**Figure 4.1: Histogram of pooled perpendicular distances to detections of Western Ringtail Possums.**

For the analyses, truncation distance was set to 25 m. Six Study Sites, Augusta North, Cuthbert, Dingup, Gull Rock Nature Reserve, Linfarne and Lot 1 Ducane Rd at which six or fewer detections were made (following truncation) were excluded from the initial analyses that examined Study Site as an explanatory variable on the detection function.

The form of the detection function was first investigated (half normal versus hazard-rate versus uniform-cosine), and then the significance of explanatory variables (Study Site, IUCN sub-population and Management Zone) was explored. Study Sites were initially analysed separately (i.e. a different detection function was fitted to each study site) and then grouped, first based on which subpopulation they fell into and then secondly into their respective key management zone. Dardanup and Crooked Brook were assigned their own subpopulation (Whicher), as they were not associated with any of the subpopulations identified in the IUCN assessment. The rationale for grouping sites into IUCN subpopulations and key management zones ensured with-group sites were more similar (i.e. more geographically proximal to each other with similar environmental conditions) to between-group sites. These models were tested against the null model that assumed constant selection across all study sites (i.e. a single detection function pooled across all observations and sites).

Based on AIC model selection, the best fitting model was a half-normal detection function form, with detection varying by study site (i.e. probability of detecting Western Ringtail Possums was found to change between study sites; Table 4.7) However, examination of the resultant plot of study site specific detection functions (Figure 4.2), revealed that the probability of detection at the Upper Warren was markedly different from all other study sites, a view supported by observers in the field who noted that the habitat was much more open when compared to habitat at other study sites. Based on this finding, the Upper Warren data were considered separately and the remaining sites were re-analysed. The resultant AIC values are shown in Table 4.8. In this comparison, the probability of detection of the preferred model varied by key management zone rather than by study site.

**Table 4.7. AIC scores for each model fitted to the pooled Western Ringtail Possum data excluding sites with fewer than 6 detections.**

| Form | Model | AIC |
|---|---|---|
| Half normal | Varies by study site | 15906.40 |
| Half normal | Varies by key management zone | 15910.35 |
| Half normal | Varies by subpopulation | 15913.12 |
| Observer | Varies by observer | 15924.81 |
| Half normal | Null model | 15930.27 |

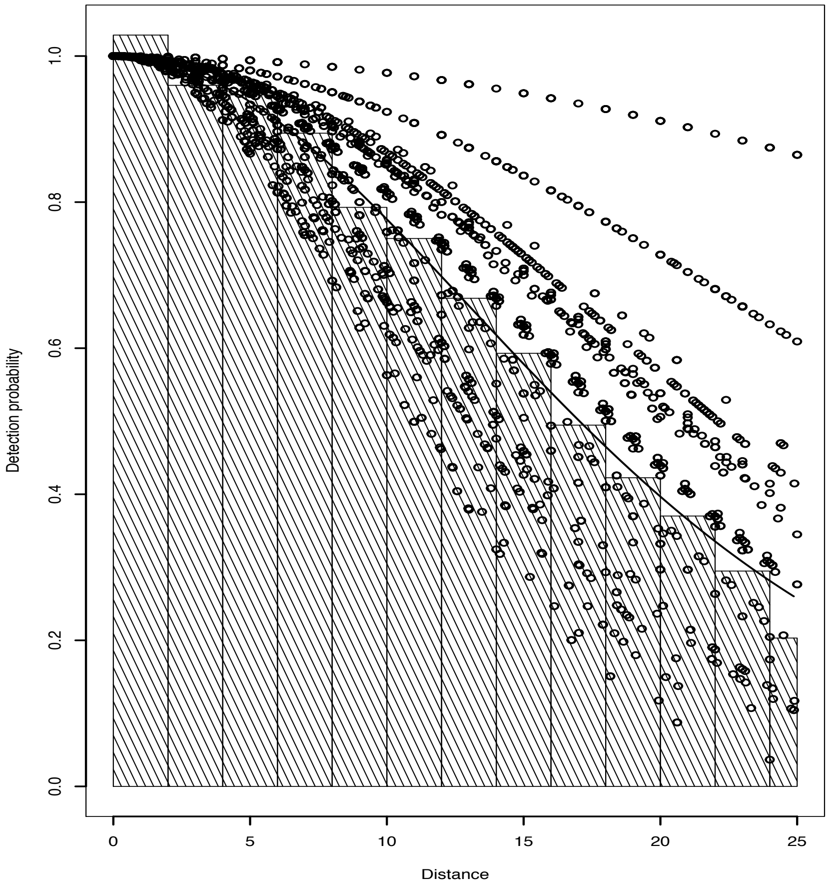



**Figure 4.2. Plot of 'best-fitting' model to the pooled Western Ringtail Possum perpendicular distance data. Upper Warren detections represented by upper series of open circles.**

**Table 4.8. AIC scores for each model fitted to the pooled Western Ringtail Possum data excluding sites with fewer than 6 detections and the Upper Warren.**

| Form | Model | AIC | dAIC |
|---|---|---|---|
| Half normal | Varies by key management zone | 15428.50 | 0 |
| Half normal | Varies by study site | 15429.36 | 0.86 |
| Half normal | Varies by subpopulation | 15431.27 | 2.77 |
| Observer | Varies by observer | 15436.72 | 8.22 |
| Half normal | Null model | 15442.45 | 13.95 |

Using a single detection function at the level of key management zone or subpopulation permitted data from the Augusta North, Cuthbert, Linfarne and Lot 1 Ducane Rd study sites to be included in the dataset and all the data were reanalysed and model selection repeated. Detection varying by key management zone was again found to be the preferred model (Table 4.9) and the resulting plot of the 'best model' fit is shown in Figure 4.3.

**Table 4.9. AIC scores for each model fitted to the pooled Western Ringtail Possum data including all study sites except the Upper Warren.**

| Form | Model | AIC | dAIC |
|---|---|---|---|
| Half normal | Varies by key management zone | 15544.83 | 0 |
| Half normal | Varies by subpopulation | 15547.62 | 2.79 |
| Half normal | Null model | 15558.77 | 13.94 |

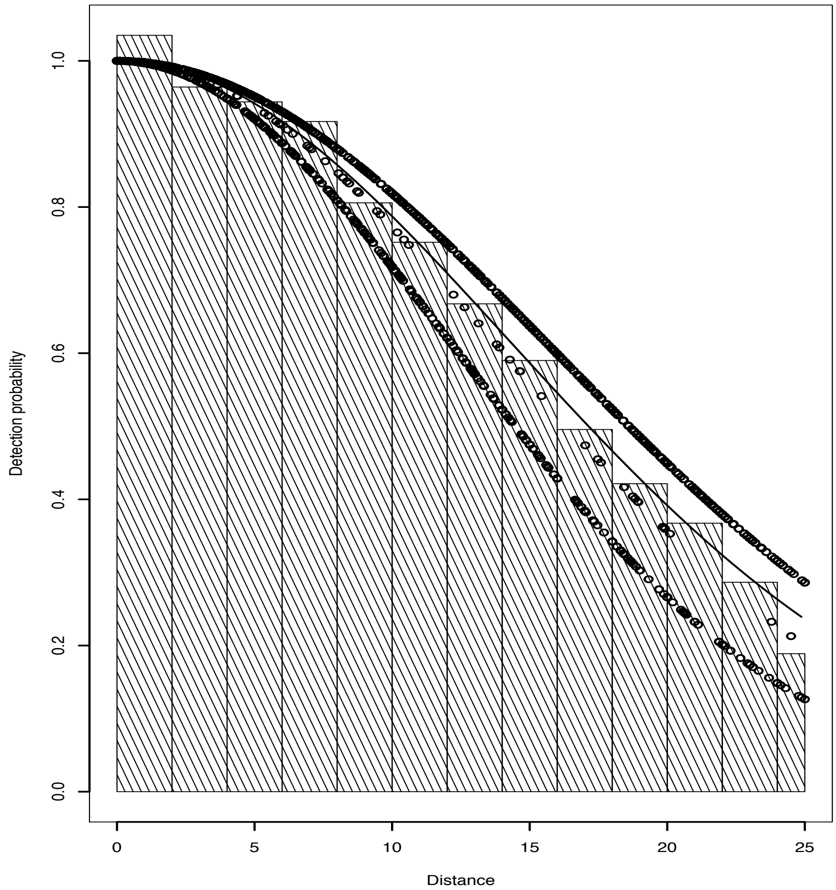



**Figure 4.3. Plot of 'best-fitting' model to the pooled (excluding the Upper Warren) Western Ringtail Possum perpendicular distance data.**

The Cramer-von Mises goodness of fit test indicated that the key management zone model was a good fit to the data (a test statistic of 0.07, p-value of 0.79).

Table 4.10 and Table 4.11 tabulate summary statistics following truncation at 25 m, as opposed to the data exploration presented above, which used raw data. Table 4.10 presents the summary for clusters, that is, each detection whether it was of one, two or three or more individuals, whilst Table 4.11 provides summary statistics at the level of the individuals.

The summary statistics for clusters include:

- Area (ha) representing the entire area of the surveyed polygon;

- Covered Area (ha) equivalent to total Effort multiplied by 50 m (i.e. 25 m (the truncation distance) either side of the transect) and represents the area surveyed after truncation;
- Effort (in metres) or the combined length of surveyed transects;
- n, the number of detections following truncation at 25 m;
- k, the number of surveyed transects;
- ER, the subsequent encounter rate (following truncation) given as the number of individuals per metre of transect;
- se ER the standard error of the Encounter Rate; and
- cv ER the coefficient of variation of the Encounter Rate.

The summary at the level of individuals (Table 4.11) includes the same elements as described above for clusters, but in addition provides Mean size were size is the number of individuals in each cluster and the se Mean, that is, the standard error of the mean cluster size.

The remaining two tables (Table 4.12 and Table 4.13) provide estimates of density at the level of individuals and then abundance also at the level of the individual. So for example, in Tuart Forest Central and from Table 4.12, estimated density $\hat{D}$ is 1.32 Western Ringtail Possums per hectare, Area is 1,079.0 ha, and so it follows that estimated abundance can be calculated as $\hat{N} = \hat{D} \times A \approx$ 1,420 individuals.

**Table 4.10. Summary of detected clusters within the pooled study sites (except the Upper Warren) (truncation at 25 m).**

| Study Site | Area | Covered Area | Effort | n | k | ER | se.ER | cv.ER |
|---|---|---|---|---|---|---|---|---|
| Augusta North | 89.3 | 42.9 | 8.57 | 2 | 12 | 0.23 | 0.16 | 0.70 |
| Bakers Junction Nature Reserve | 843.0 | 159.9 | 31.97 | 43 | 18 | 1.34 | 0.32 | 0.24 |
| Big Rock Nature Reserve | 72.0 | 44.9 | 8.98 | 70 | 22 | 7.80 | 0.98 | 0.13 |
| Boranup | 222.0 | 82.2 | 16.45 | 11 | 24 | 0.67 | 0.28 | 0.42 |
| Crooked Brook | 2,588.0 | 823.7 | 164.73 | 129 | 107 | 0.78 | 0.12 | 0.15 |
| Cuthbert | 106.7 | 35.7 | 7.13 | 1 | 5 | 0.14 | 0.15 | 1.06 |
| Dardanup State Forest | 330.7 | 108.7 | 21.75 | 0 | 20 | 0.00 | 0.00 | 0.00 |
| Dingup | 118.0 | 86.6 | 17.32 | 4 | 8 | 0.23 | 0.09 | 0.41 |
| Down Road Nature Reserve | 363.0 | 179.2 | 35.84 | 76 | 29 | 2.12 | 0.28 | 0.13 |
| Faunadale | 84.4 | 52.8 | 10.56 | 51 | 17 | 4.83 | 0.55 | 0.11 |
| Frankland | 796.1 | 64.5 | 12.90 | 0 | 9 | 0.00 | 0.00 | 0.00 |
| Gull Rock National Park | 360.0 | 128.1 | 25.63 | 5 | 17 | 0.20 | 0.09 | 0.48 |
| Jardee | 118.0 | 34.1 | 6.83 | 9 | 13 | 1.32 | 0.30 | 0.23 |
| Kemerton | 673.0 | 101.5 | 20.30 | 0 | 23 | 0.00 | 0.00 | 0.00 |
| King River | 131.0 | 68.1 | 13.63 | 41 | 13 | 3.01 | 0.55 | 0.18 |
| Leeuwin-Naturaliste National Park (Canal Rocks) | 17.9 | 10.0 | 2.01 | 14 | 6 | 6.97 | 1.85 | 0.27 |
| Leeuwin-Naturaliste National Park (Yallingup) | 342.0 | 120.8 | 24.15 | 210 | 43 | 8.69 | 0.75 | 0.09 |
| Linfarne | 980.0 | 171.0 | 34.20 | 1 | 22 | 0.03 | 0.03 | 1.02 |
| Locke Nature Reserve | 107.5 | 42.9 | 8.58 | 76 | 22 | 8.85 | 1.53 | 0.17 |
| Lot 1 Ducane Road | 40.5 | 25.4 | 5.08 | 5 | 10 | 0.98 | 0.43 | 0.43 |
| Lot 2 Boyanup - Picton Road | 87.6 | 44.4 | 8.87 | 44 | 8 | 4.96 | 0.79 | 0.16 |
| Manea Park - Bunbury | 155.0 | 101.8 | 20.36 | 61 | 28 | 3.00 | 0.48 | 0.16 |
| Marbelup Nature Reserve | 107.0 | 61.6 | 12.31 | 31 | 15 | 2.52 | 0.51 | 0.20 |
| Martins Tank | 590.0 | 178.8 | 35.77 | 100 | 73 | 2.80 | 0.46 | 0.16 |
| Millbrook Nature Reserve | 1,483.0 | 200.5 | 40.09 | 13 | 39 | 0.32 | 0.10 | 0.29 |
| Mt Clarence | 266.3 | 119.2 | 23.84 | 130 | 35 | 5.45 | 0.56 | 0.10 |
| Mt Melville | 97.4 | 52.2 | 10.44 | 54 | 34 | 5.17 | 0.96 | 0.19 |
| North East Margaret River State Forest | 2,125.0 | 72.2 | 14.43 | 0 | 19 | 0.00 | 0.00 | 0.00 |
| Redmond West | 354.0 | 79.3 | 15.86 | 0 | 14 | 0.00 | 0.00 | 0.00 |
| Reserve 23,000 Shire of Capel | 146.1 | 91.0 | 18.21 | 49 | 40 | 2.69 | 0.52 | 0.19 |
| Simpson Road | 257.0 | 113.2 | 22.64 | 50 | 16 | 2.21 | 0.37 | 0.17 |
| Southern Lots (Boyanup West Road Stratham) | 188.0 | 107.6 | 21.51 | 24 | 26 | 1.12 | 0.28 | 0.25 |
| Tuart Forest - Central | 1,079.0 | 349.4 | 69.88 | 228 | 62 | 3.26 | 0.29 | 0.09 |
| Tuart Forest North | 265.0 | 60.9 | 12.18 | 139 | 10 | 11.41 | 1.16 | 0.10 |
| Tuart Forest South | 630.0 | 199.5 | 39.90 | 351 | 67 | 8.80 | 0.77 | 0.09 |
| Various Lots Ducane Road | 194.0 | 113.7 | 22.74 | 42 | 30 | 1.85 | 0.33 | 0.18 |

| Study Site | Area | Covered Area | Effort | n | k | ER | se.ER | cv.ER |
|---|---|---|---|---|---|---|---|---|
| Walmsley East | 176.1 | 54.0 | 10.80 | 58 | 14 | 5.37 | 0.80 | 0.15 |
| Walmsley South | 59.8 | 38.2 | 7.64 | 35 | 9 | 4.58 | 0.81 | 0.18 |
| Walmsley West | 161.1 | 60.4 | 12.08 | 119 | 19 | 9.85 | 0.93 | 0.09 |
| Woodjtup National Park (10 Mile Brook Dam) | 323.9 | 52.4 | 10.48 | 0 | 12 | 0.00 | 0.00 | 0.00 |
| Yalgorup National Park | 589.0 | 245.8 | 49.16 | 66 | 52 | 1.34 | 0.17 | 0.13 |
| Yelverton | 1,128.0 | 367.5 | 73.51 | 132 | 82 | 1.80 | 0.22 | 0.13 |
| **Total** | **18,845.4** | **5146.6** | **1029.32** | **2474** | **1144** | **2.40** | **0.11** | **0.04** |

**Table 4.11. Summary of detected individuals within pooled study sites except the Upper Warren (truncation at 25 m).**

| Study Site | Area | Covered Area | Effort | n | ER | se.ER | cv.ER | mean.size | se.mean |
|---|---|---|---|---|---|---|---|---|---|
| Augusta North | 89.3 | 42.9 | 8.57 | 3 | 0.35 | 0.26 | 0.75 | 1.50 | 0.50 |
| Bakers Junction Nature Reserve | 843.0 | 159.9 | 31.97 | 46 | 1.44 | 0.35 | 0.24 | 1.07 | 0.04 |
| Big Rock Nature Reserve | 72.0 | 44.9 | 8.98 | 87 | 9.69 | 1.20 | 0.12 | 1.24 | 0.05 |
| Boranup | 222.0 | 82.2 | 16.45 | 13 | 0.79 | 0.35 | 0.45 | 1.18 | 0.12 |
| Crooked Brook | 2,588.0 | 823.7 | 164.73 | 146 | 0.89 | 0.14 | 0.16 | 1.13 | 0.03 |
| Cuthbert | 106.7 | 35.7 | 7.13 | 2 | 0.28 | 0.30 | 1.06 | 2.00 | 0.00 |
| Dardanup State Forest | 330.7 | 108.7 | 21.75 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 |
| Dingup | 118.0 | 86.6 | 17.32 | 5 | 0.29 | 0.14 | 0.47 | 1.25 | 0.25 |
| Down Road Nature Reserve | 363.0 | 179.2 | 35.84 | 81 | 2.26 | 0.33 | 0.15 | 1.07 | 0.03 |
| Faunadale | 84.4 | 52.8 | 10.56 | 58 | 5.49 | 0.55 | 0.10 | 1.14 | 0.05 |
| Frankland | 796.1 | 64.5 | 12.90 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 |
| Gull Rock National Park | 360.0 | 128.1 | 25.63 | 6 | 0.23 | 0.11 | 0.47 | 1.20 | 0.20 |
| Jardee | 118.0 | 34.1 | 6.83 | 10 | 1.47 | 0.34 | 0.23 | 1.11 | 0.11 |
| Kemerton | 673.0 | 101.5 | 20.30 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 |
| King River | 131.0 | 68.1 | 13.63 | 47 | 3.45 | 0.62 | 0.18 | 1.15 | 0.07 |
| Leeuwin-Naturaliste National Park (Canal Rocks) | 17.9 | 10.0 | 2.01 | 18 | 8.97 | 2.36 | 0.26 | 1.29 | 0.13 |
| Leeuwin-Naturaliste National Park (Yallingup) | 342.0 | 120.8 | 24.15 | 267 | 11.05 | 1.05 | 0.10 | 1.27 | 0.03 |
| Linfarne | 980.0 | 171.0 | 34.20 | 1 | 0.03 | 0.03 | 1.02 | 1.00 | 0.00 |
| Locke Nature Reserve | 107.5 | 42.9 | 8.60 | 92 | 10.70 | 1.91 | 0.18 | 1.21 | 0.06 |
| Lot 1 Ducane Road | 40.5 | 25.4 | 5.08 | 6 | 1.18 | 0.59 | 0.50 | 1.20 | 0.20 |
| Lot 2 Boyanup - Picton Road | 87.6 | 44.4 | 8.87 | 50 | 5.63 | 0.87 | 0.15 | 1.14 | 0.05 |
| Manea Park - Bunbury | 155.0 | 101.8 | 20.36 | 88 | 4.32 | 0.79 | 0.18 | 1.44 | 0.07 |
| Marbelup Nature Reserve | 107.0 | 61.6 | 12.31 | 39 | 3.17 | 0.66 | 0.21 | 1.26 | 0.08 |
| Martins Tank | 590.0 | 178.8 | 35.77 | 119 | 3.33 | 0.58 | 0.17 | 1.19 | 0.04 |
| Millbrook Nature Reserve | 1,483.0 | 200.5 | 40.09 | 17 | 0.42 | 0.13 | 0.32 | 1.31 | 0.17 |
| Mt Clarence | 266.3 | 119.2 | 23.84 | 150 | 6.29 | 0.67 | 0.11 | 1.15 | 0.03 |

| Study Site | Area | Covered Area | Effort | n | ER | se.ER | cv.ER | mean.size | se.mean |
|---|---|---|---|---|---|---|---|---|---|
| Mt Melville | 97.4 | 52.2 | 10.44 | 67 | 6.42 | 1.31 | 0.20 | 1.24 | 0.06 |
| North East Margaret River State Forest | 2,125.0 | 72.2 | 14.43 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 |
| Redmond West | 354.0 | 79.3 | 15.86 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 |
| Reserve 23,000 Shire of Capel | 146.1 | 91.0 | 18.21 | 66 | 3.62 | 0.73 | 0.20 | 1.35 | 0.07 |
| Simpson Road | 257.0 | 113.2 | 22.64 | 54 | 2.39 | 0.41 | 0.17 | 1.08 | 0.04 |
| Southern Lots (Boyanup West Road Stratham) | 188.0 | 107.6 | 21.51 | 32 | 1.49 | 0.36 | 0.24 | 1.33 | 0.10 |
| Tuart Forest - Central | 1,079.0 | 349.4 | 69.88 | 323 | 4.62 | 0.43 | 0.09 | 1.42 | 0.04 |
| Tuart Forest North | 265.0 | 60.9 | 12.18 | 170 | 13.96 | 1.42 | 0.10 | 1.22 | 0.04 |
| Tuart Forest South | 630.0 | 199.5 | 39.90 | 477 | 11.95 | 1.06 | 0.09 | 1.36 | 0.03 |
| Various Lots Ducane Road | 194.0 | 113.7 | 22.74 | 52 | 2.29 | 0.41 | 0.18 | 1.24 | 0.07 |
| Walmsley East | 176.1 | 54.0 | 10.80 | 72 | 6.67 | 1.04 | 0.16 | 1.24 | 0.06 |
| Walmsley South | 59.8 | 38.2 | 7.64 | 40 | 5.24 | 0.99 | 0.19 | 1.14 | 0.06 |
| Walmsley West | 161.1 | 60.4 | 12.08 | 142 | 11.75 | 1.37 | 0.12 | 1.19 | 0.04 |
| Woodjtup National Park (10 Mile Brook Dam) | 323.9 | 52.4 | 10.48 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 |
| Yalgorup National Park | 589.0 | 245.8 | 49.16 | 76 | 1.55 | 0.20 | 0.13 | 1.15 | 0.05 |
| Yelverton | 1,128.0 | 367.5 | 73.51 | 176 | 2.39 | 0.33 | 0.14 | 1.33 | 0.04 |
| **Total** | **18,845.4** | **5,146.6** | **1,029.32** | **3,098** | **3.01** | **0.14** | **0.05** | **1.25** | **0.01** |

**Table 4.12. Summary of estimated density of Western Ringtail Possum individuals within each of the study sites (except the Upper Warren).**

| Study Site | Estimate | se | cv | lcl | ucl | df |
|---|---|---|---|---|---|---|
| Augusta North | 0.10 | 0.08 | 0.75 | 0.02 | 0.44 | 11.02 |
| Bakers Junction Nature Reserve | 0.49 | 0.12 | 0.24 | 0.29 | 0.81 | 17.63 |
| Big Rock Nature Reserve | 2.76 | 0.35 | 0.13 | 2.13 | 3.58 | 22.40 |
| Boranup | 0.23 | 0.10 | 0.44 | 0.09 | 0.54 | 23.12 |
| Crooked Brook | 0.25 | 0.04 | 0.16 | 0.18 | 0.35 | 110.28 |
| Cuthbert | 0.10 | 0.10 | 1.06 | 0.01 | 1.05 | 4.01 |
| Dardanup State Forest | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dingup | 0.09 | 0.04 | 0.49 | 0.03 | 0.26 | 7.78 |
| Down Road Nature Reserve | 0.77 | 0.12 | 0.15 | 0.56 | 1.04 | 30.88 |
| Faunadale | 1.70 | 0.25 | 0.15 | 1.26 | 2.28 | 78.29 |
| Frankland | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Gull Rock National Park | 0.08 | 0.04 | 0.47 | 0.03 | 0.21 | 16.16 |
| Jardee | 0.45 | 0.12 | 0.26 | 0.26 | 0.77 | 17.86 |
| Kemerton | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| King River | 1.17 | 0.22 | 0.18 | 0.79 | 1.73 | 12.81 |
| Leeuwin-Naturaliste National Park (Canal Rocks) | 2.55 | 0.68 | 0.26 | 1.31 | 4.97 | 5.07 |
| Leeuwin-Naturaliste National Park (Yallingup) | 3.15 | 0.31 | 0.10 | 2.59 | 3.83 | 46.81 |
| Linfarne | 0.01 | 0.01 | 1.02 | 0.00 | 0.05 | 21.49 |
| Locke Nature Reserve | 3.05 | 0.55 | 0.18 | 2.11 | 4.42 | 21.67 |
| Lot 1 Ducane Road | 0.34 | 0.17 | 0.50 | 0.12 | 0.97 | 9.04 |
| Lot 2 Boyanup - Picton Road | 1.60 | 0.25 | 0.16 | 1.12 | 2.31 | 7.30 |
| Manea Park - Bunbury | 1.23 | 0.23 | 0.19 | 0.85 | 1.79 | 27.81 |
| Marbelup Nature Reserve | 1.07 | 0.23 | 0.21 | 0.69 | 1.67 | 14.71 |
| Martins Tank | 0.95 | 0.17 | 0.18 | 0.67 | 1.34 | 74.43 |
| Millbrook Nature Reserve | 0.14 | 0.05 | 0.32 | 0.08 | 0.27 | 38.83 |
| Mt Clarence | 2.13 | 0.24 | 0.11 | 1.70 | 2.67 | 40.78 |
| Mt Melville | 2.17 | 0.45 | 0.21 | 1.44 | 3.29 | 34.74 |
| North East Margaret River State Forest | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Redmond West | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Reserve 23,000 Shire of Capel | 1.03 | 0.21 | 0.20 | 0.69 | 1.55 | 39.99 |
| Simpson Road | 0.81 | 0.14 | 0.17 | 0.56 | 1.17 | 16.13 |
| Southern Lots (Boyanup West Road Stratham) | 0.42 | 0.10 | 0.24 | 0.26 | 0.70 | 25.43 |
| Tuart Forest - Central | 1.32 | 0.13 | 0.10 | 1.09 | 1.60 | 68.16 |
| Tuart Forest North | 3.98 | 0.41 | 0.10 | 3.15 | 5.01 | 9.90 |
| Tuart Forest South | 3.40 | 0.31 | 0.09 | 2.84 | 4.08 | 74.81 |
| Various Lots Ducane Road | 0.65 | 0.12 | 0.18 | 0.45 | 0.94 | 29.93 |
| Walmsley East | 2.26 | 0.36 | 0.16 | 1.61 | 3.17 | 14.19 |
| Walmsley South | 1.77 | 0.34 | 0.19 | 1.15 | 2.74 | 8.49 |
| Walmsley West | 3.98 | 0.48 | 0.12 | 3.10 | 5.12 | 20.97 |
| Woodjtup National Park (10 Mile Brook Dam) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Yalgorup National Park | 0.44 | 0.06 | 0.13 | 0.34 | 0.57 | 54.12 |
| Yelverton | 0.68 | 0.09 | 0.14 | 0.52 | 0.90 | 85.48 |
| **Total** | **0.68** | **0.02** | **0.04** | **0.63** | **0.73** | **742.01** |

**Table 4.13. Summary of estimated abundance of Western Ringtail Possum individuals within the study sites (except Upper Warren).**

| Study Site | Estimate | se | cv | lcl | ucl | df |
|---|---|---|---|---|---|---|
| Augusta North | 8.90 | 6.71 | 0.75 | 2.03 | 38.96 | 11.02 |
| Bakers Junction Nature Reserve | 410.87 | 100.44 | 0.24 | 247.49 | 682.09 | 17.63 |
| Big Rock Nature Reserve | 198.75 | 25.02 | 0.13 | 153.27 | 257.71 | 22.40 |
| Boranup | 49.97 | 22.22 | 0.44 | 20.76 | 120.30 | 23.12 |
| Crooked Brook | 653.26 | 104.80 | 0.16 | 476.31 | 895.94 | 110.28 |
| Cuthbert | 10.14 | 10.70 | 1.06 | 0.92 | 111.83 | 4.01 |
| Dardanup State Forest | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dingup | 10.52 | 5.10 | 0.49 | 3.63 | 30.52 | 7.78 |
| Down Road Nature Reserve | 277.91 | 41.88 | 0.15 | 204.71 | 377.27 | 30.88 |
| Faunadale | 143.21 | 21.26 | 0.15 | 106.75 | 192.13 | 78.29 |
| Frankland | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Gull Rock National Park | 28.55 | 13.56 | 0.47 | 10.99 | 74.20 | 16.16 |
| Jardee | 53.40 | 13.84 | 0.26 | 31.24 | 91.27 | 17.86 |
| Kemerton | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| King River | 153.06 | 28.18 | 0.18 | 103.11 | 227.21 | 12.81 |
| Leeuwin-Naturaliste National Park (Canal Rocks) | 45.71 | 12.08 | 0.26 | 23.50 | 88.90 | 5.07 |
| Leeuwin-Naturaliste National Park (Yallingup) | 1,076.74 | 105.26 | 0.10 | 884.91 | 1310.16 | 46.81 |
| Linfarne | 8.85 | 9.06 | 1.02 | 1.53 | 51.33 | 21.49 |
| Locke Nature Reserve | 328.15 | 59.04 | 0.18 | 226.56 | 475.29 | 21.67 |
| Lot 1 Ducane Road | 13.62 | 6.78 | 0.50 | 4.70 | 39.48 | 9.04 |
| Lot 2 Boyanup - Picton Road | 140.57 | 21.90 | 0.16 | 97.77 | 202.11 | 7.30 |
| Manea Park - Bunbury | 190.83 | 35.34 | 0.19 | 130.98 | 278.02 | 27.81 |
| Marbelup Nature Reserve | 114.84 | 24.12 | 0.21 | 73.70 | 178.96 | 14.71 |
| Martins Tank | 559.02 | 97.86 | 0.18 | 395.45 | 790.25 | 74.43 |
| Millbrook Nature Reserve | 213.03 | 67.52 | 0.32 | 113.93 | 398.35 | 38.83 |
| Mt Clarence | 567.68 | 63.41 | 0.11 | 453.34 | 710.86 | 40.78 |
| Mt Melville | 211.72 | 43.74 | 0.21 | 139.79 | 320.66 | 34.74 |
| North East Margaret River State Forest | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Redmond West | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Reserve 23,000 Shire of Capel | 150.81 | 30.41 | 0.20 | 100.74 | 225.77 | 39.99 |
| Simpson Road | 207.70 | 36.20 | 0.17 | 143.97 | 299.65 | 16.13 |
| Southern Lots (Boyanup West Road Stratham) | 79.65 | 19.47 | 0.24 | 48.52 | 130.74 | 25.43 |
| Tuart Forest - Central | 1,420.46 | 137.25 | 0.10 | 1171.90 | 1721.75 | 68.16 |
| Tuart Forest North | 1,053.39 | 109.66 | 0.10 | 835.57 | 1327.99 | 9.90 |
| Tuart Forest South | 2,144.84 | 195.39 | 0.09 | 1,789.54 | 2570.68 | 74.81 |
| Various Lots Ducane Road | 126.37 | 22.63 | 0.18 | 87.91 | 181.67 | 29.93 |
| Walmsley East | 397.63 | 63.20 | 0.16 | 283.48 | 557.73 | 14.19 |
| Walmsley South | 106.09 | 20.44 | 0.19 | 68.61 | 164.05 | 8.49 |
| Walmsley West | 641.52 | 77.87 | 0.12 | 498.86 | 824.97 | 20.97 |
| Woodjtup National Park (10 Mile Brook Dam) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Yalgorup National Park | 259.35 | 34.07 | 0.13 | 199.53 | 337.12 | 54.12 |
| Yelverton | 769.20 | 105.99 | 0.14 | 585.64 | 1010.30 | 85.48 |
| **Total** | **12,826.32** | **454.93** | **0.04** | **11,963.87** | **13,750.94** | **742.01** |

### 4.2.2 Upper Warren Only

During data collection, it became apparent to field personnel that the vegetation at Upper Warren was very open and consequently the detection process was different to the other surveyed sites. This was demonstrated above, whereby the detection function for the Upper Warren was markedly different to all other sites (Figure 4.2). Consequently, this site was modelled separately. Here, the truncation distance was set to 55 m. Based on AIC model selection, the half-normal and hazard rate were considered equivalent (i.e. the AIC of each was within 2 dAIC), and the half-normal detection function was selected (Table 4.14). Based on the Cramer-von Mises goodness of fit test, the selected model was a good fit to the data (i.e. a test statistic of 0.05, p-value of 0.9).

**Table 4.14: AIC scores for each model fitted to the Upper Warren Western Ringtail Possum data.**

| Form | Model | AIC | dAIC |
|---|---|---|---|
| Hazard rate | Null model | 944.73 | 0 |
| Half normal | Null model | 945.14 | 0.41 |

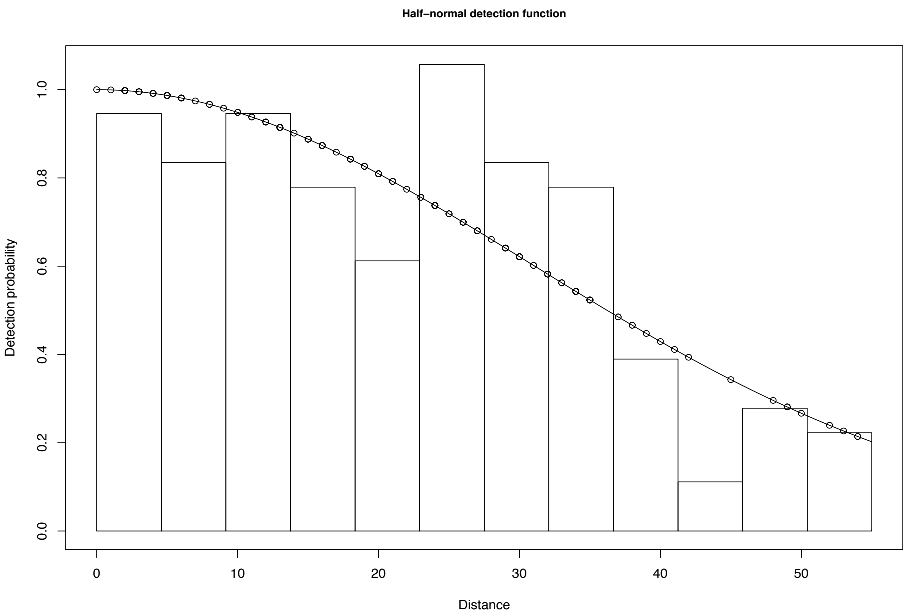



**Figure 4.4. Plot of 'best-fitting' model to the Upper Warren Western Ringtail Possum perpendicular distance data.**

Table 4.15 and Table 4.16 tabulate summary statistics following truncation of the Western Ringtail Possum perpendicular distance data at 55 m, as opposed to the data exploration presented above, which used raw data (Table 4.4

**Table 4.15. Summary of detected clusters within the Upper Warren (truncation at 55 m).**

| Study Site | Area | Covered Area | Effort | n | k | ER | se.ER | cv.ER |
|---|---|---|---|---|---|---|---|---|
| Upper Warren | 95,142.7 | 2,766.2 | 251.47 | 140 | 91 | 0.56 | 0.1 | 0.2024 |

**Table 4.16. Summary of detected individuals within the Upper Warren (truncation at 55 m).**

| Study Site | Area | Covered Area | Effort | n | ER | se.ER | cv.ER | mean.size | se.mean |
|---|---|---|---|---|---|---|---|---|---|
| Upper Warren | 95,142.7 | 2,766.2 | 251.47 | 159 | 6e-04 | 1e-04 | 0.2056 | 1.1357 | 0.029 |

**Table 4.17. Summary of estimated density of Western Ringtail Possum individuals within the Upper Warren.**

| Study Site | Estimate | se | cv | lcl | ucl | df |
|---|---|---|---|---|---|---|
| Total | 9e-06 | 2e-06 | 0.22 | 6e-06 | 1.4e-05 | 117.1382 |

A summary of estimated abundance (of individuals) is given below (i.e. in Upper Warren, $\hat{D}$ is 8. 8.853372e-06, A is 951427223, and it follows that $\hat{N} = \hat{D} \times A \approx$ 8,423 individuals) (Table 4.18).

**Table 4.18. Summary of estimated abundance of Western Ringtail Possum individuals within the Upper Warren.**

| Region | Estimate | se | cv | lcl | ucl | df |
|---|---|---|---|---|---|---|
| Total | 8,423.339 | 1,856.536 | 0.22 | 5,472.19 | 12,966.03 | 117.14 |

# 4.3 Density Surface Modelling

## 4.3.1 All Sites

DMSs were fitted to all sites, using only x and y coordinates in the spatial smooth. Results are presented in the Technical Supplement (Biota 2020).

## 4.3.2 Upper Warren Only

Three covariates were explored in the Upper Warren: fire history, elevation and harvest history (Figure 4.5 a, c and e). All covariates were representatively sampled in the survey (Figure 4.5 b, d and f). Model selection was based on deviance, so the model with the lowest deviance (the elevation model, Table 4.19) was deemed the best fitting model of those fitted. Please note, the absence of finding an effect of fire history and harvesting history on the distribution of Western Ringtail Possums in the Upper Warren does not mean there is no effect, especially given the paucity of the data (especially harvest history, Figure 4.5c and Figure 4.6c).

For each model, the deviance, percentage deviance explained, and the estimated abundance are provided in Table 4.19. Depending on the model, abundance estimates ranged between 6,389 (under a fire covariate) compared to 7,354 (under the null model), whereas under standard distance sampling, the estimated abundance was 8,423 (Table 4.18).

Spatial maps for each model are provided in Figure 4.6 in order of deviance.

**Table 4.19. Model deviances.**

| Model | Deviance | %devExplained | Nhat | 95%CI |
|---|---|---|---|---|
| Elevation | 301.2735 | 59 | 7,292 | (5,805, 9,161) |
| Null | 303.3703 | 50 | 7,354 | (6,022, 8,980) |
| Harvest | 318.345 | 56 | 6,830 | (5,615, 8,309) |
| Fire | 318.3368 | 56 | 6,389 | (5,271, 7,744) |

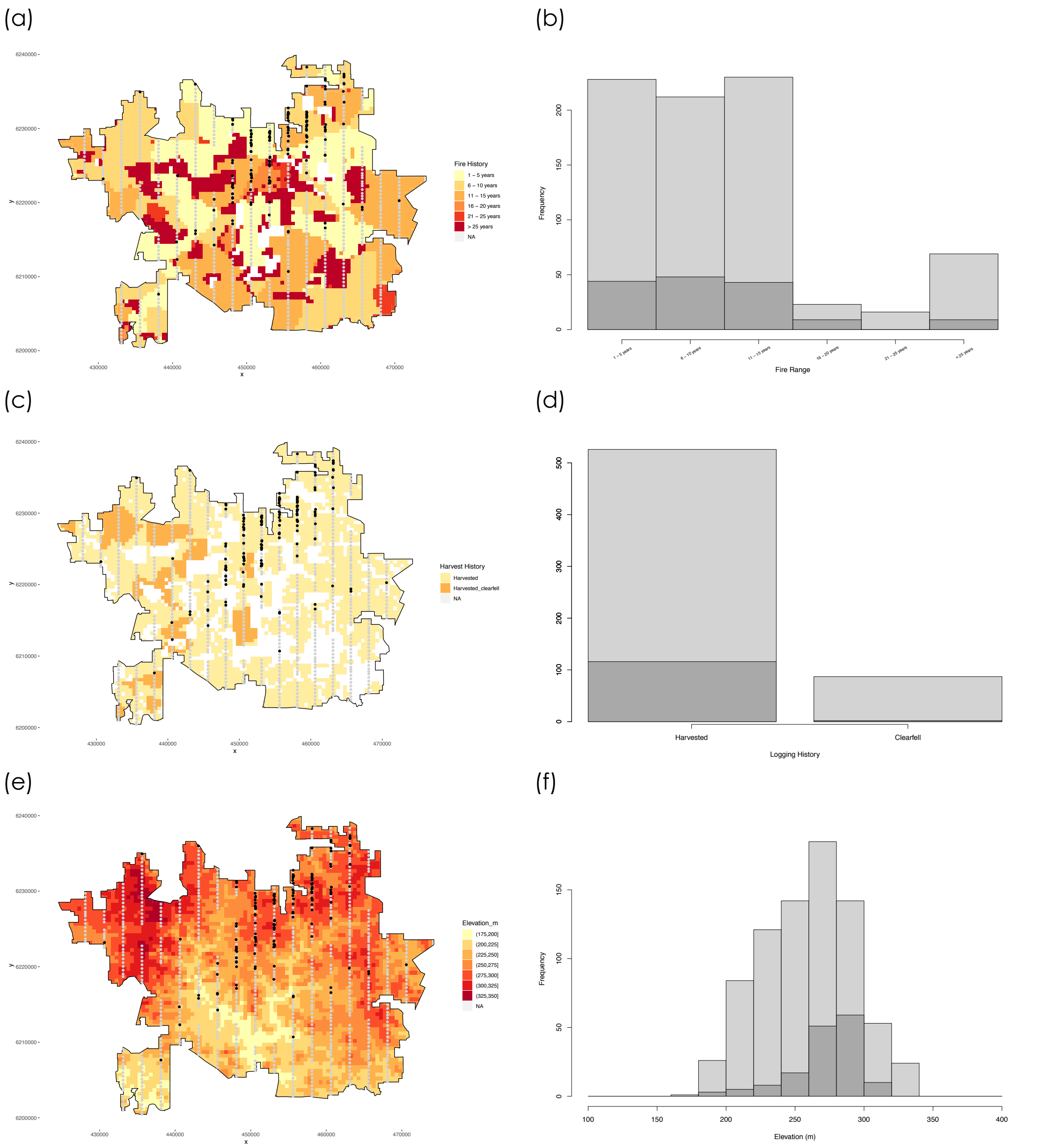
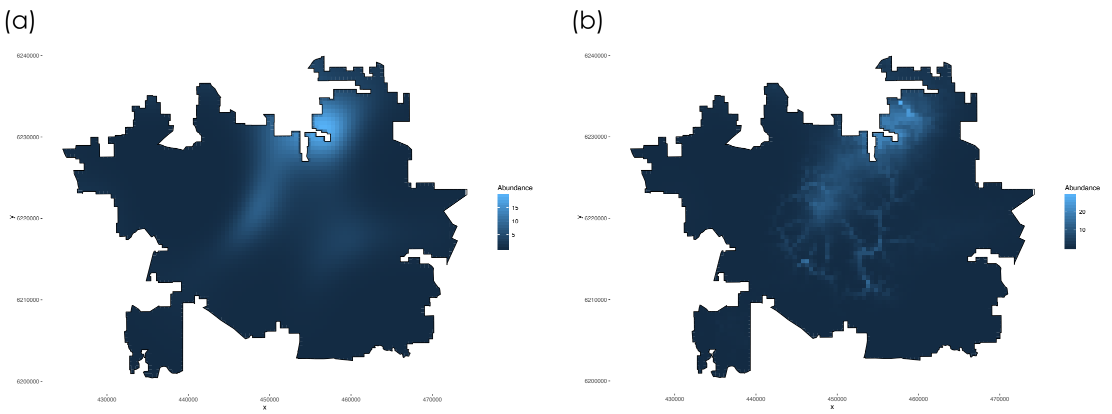
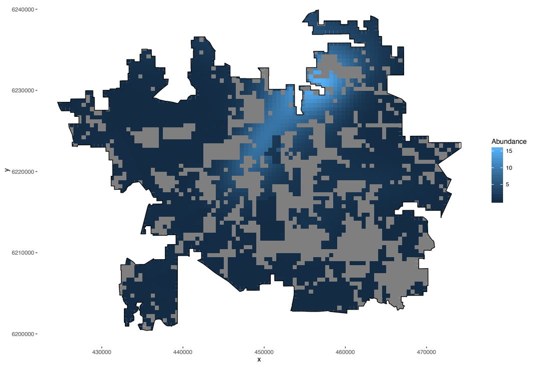



**Figure 4.5** **Plot of Upper Warren survey site discretised in to 75 m grid cells, with fire history (a), harvest history (c) and elevation (e) overlaid with transect locations when a possum was detected (black grid cell) or not (grey grid cell). Often, explanatory variable information was missing, especially for harvest history (c), noting high number of cells recorded as NA, and also fire history (a). Corresponding explanatory variables shown with amount available for sampling (grey bars) and that which was actually sampled (dark grey bars) (b, d and f, respectively).**



(c)



(d)

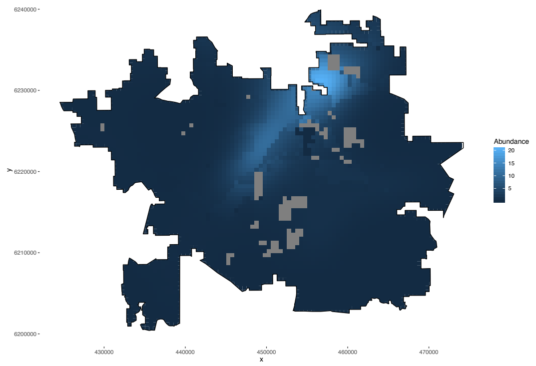


**Figure 4.6. Predicted spatial density map of WRTP based on (a) the null model (i.e., a simple x and y spatial smooth), (b) elevation, (c) harvest history and (d) fire history. All models consistently predict a 'hot spot' of WRTP in the top central-NE. Harvest history (c) and fire history (d) were data depauperate, hence the high number of grid cells with no prediction (shown as grey cells). The absence of finding a significant effect of either of these two variables does not mean there is no effect, and is likely caused by a paucity of input data.**

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# 5.0 Discussion

This study considered Western Ringtail Possum density and abundance estimates, using Distance Sampling, a proven robust and repeatable methodology (Buckland et al 2001, Buckland et al 2014, Buckland et al 2015, Miller et al 2013, Thomas et al 2010). The population estimate from this study indicated in excess of 20,000 individual Western Ringtail Possum occurred in the surveyed area across the Western Ringtail Possum Recovery Plan's three management zones (Department of Parks and Wildlife 2017) (see also Figure 3.1). This is a significant increase over the 2014 estimate of 3,400 individuals published in the most recent IUCN estimate (Burbidge and Zichy-Woinarski 2017).

The Western Ringtail Possum abundance estimates increased in each of the three management zones delineated in the Western Ringtail Possum Recovery Plan (Department of Parks and Wildlife 2017). The surveyed footprint of the Swan Coastal Plain management zone yielded the greatest estimated abundance of Western Ringtail Possum at 9,270 individuals, with the majority (around 6,500) occurring in the Swan Coastal Plain IBRA region. The well-documented stronghold for the species, the Tuart forests between Busselton and Bunbury (Shedley and Williams 2014, Jones et al. 1994; de Tores et al., 2005), yielded some of the highest estimated densities (3.40 –3.98 individuals/ha (at the study site level)) and the relatively large remnants sampled support some of the largest populations of the species.

A relatively large estimated population of Western Ringtail Possum was found to occur in the Southern Forest management zone, principally in the expansive Upper Warren study site. A combined estimate of approximately 7,500 individuals far exceeds that documented in the IUCN assessment (estimated at 100 mature individuals (Burbidge and Zichy-Woinarski 2017)).

The South Coast management zone yielded an estimate of 3,340 individuals within a 30 km around the Albany townsite. This is the least well surveyed of the three key management zones and has the potential to have a much larger population in the event that a larger area be surveyed.

The population estimate of greater than 20,000 Western Ringtail Possums from this study is likely to be an underestimate as urban and peri-urban settings were excluded from the study even though these can be strongholds for the species (Van Helden et al. 2018, references in Shedley and Williams 2014). In addition, the management zone 'Other Forest Rivers' was also not surveyed due to logistical constraints.

Clearly, natural population processes and changing environmental conditions will result in abundances fluctuations over time. Therefore, when citing the results of this study, authors should explicitly state that these estimates were derived for 2019. It is also important to note that the abundance estimates include all individuals and not just adults, as is the case for the IUCN conservation assessment. Most importantly, the abundance estimate reported here should not be referred to as the 'total population' or as the 'population size' of the Western Ringtail Possum in Western Australia, since this study surveyed only a portion (approximately 114,243 ha) of the available habitat.

The 2019 survey data and methods provide a strong population baseline and a means of directly assessing the effectiveness of management actions (such as fire management, logging, predator control, re-vegetation etc.). The 2019 survey data also permits impact assessment on population abundance as well as appraising environmental trends, such as rainfall, groundwater levels, and habitat structure and composition (e.g. dieback disease, tree senescence) on species persistence.

In addition to estimating abundance, the robust methods utilised here developed density surface models that can be used to monitor changes in local (within survey sites) possum distribution following environmental management interventions or impacts, and in responses to both seasonal and long-term environmental changes. For instance, high-resolution density surface models can be applied to test the effect of burning, re-vegetation or tree senescence upon local Western Ringtail Possum distributions. This level of data interrogation can be applied to high-value areas where habitat for the species is subjected to planned, or unplanned, disturbance or change.

The Western Ringtail Possum Recovery Plan identifies "Gaps In Knowledge" as a primary Threatening Process. The Recovery Plan identified two main factors contributing to knowledge gaps; a lack of comparable survey methods previously used to estimate abundance (see also Shedley and Williams 2014), and general difficulties encountered when surveying and detecting the species (Department of Parks and Wildlife 2017).

This study successfully applied a unified survey method (line transect distance sampling) across a variety of geographic settings and vegetation types in each of the key management zones. Distance sampling is considered a best practice method to obtain spatially robust estimates of density, because it accounts for uncertainty in detectability. Therefore, this approach also addressed the second key gap identified by the Recovery Plan: difficulty in detecting species, clearly demonstrating that distance sampling is a feasible method for estimating density and abundance of the Western Ringtail Possum. This supports previous publications that have advocated the use of distance sampling (Finlayson et al. 2010, references in Department of Parks and Wildlife 2014), however this current study extends these earlier appraisals by applying it to 42 study sites across the geographic range of the species.

Line transect distance sampling is not suitable for every setting or proposal where abundance estimates of Western Ringtail Possums are required. Our initial site selection process excluded sites that were considered too small or poorly shaped (narrow riparian zones and road reserves) for effective line transect distance sampling. General guidance around the number of transects required to estimate the encounter rate variance and the number of detection events required to model a detection function (Buckland et al. 2001) were followed to exclude unsuitable sites. Additionally, urban settings were excluded even though these can be strongholds for the species (Van Helden et al. 2018, references in Shedley and Williams 2014). Other approaches are better suited for these settings. Some sites were excluded where site conditions precluded distance sampling or gave us considerable doubt as to whether key underlying assumptions were likely to be met. For example, vegetation of near coastal sand dunes within Leschenault Peninsula Conservation Park and some parts of the Canal Rocks study site were extremely thick and precluded walking transects. Within the Karri Forest of West Cape Howe National Park, the understorey of Karri Hazel obscured a clear view along the transect and thus reduced certainty that detections could be made directly on the transect (a critical assumption of single observer distance sampling, Buckland et al. 2001). The geographic scale and remoteness of parts of the contiguous forest of the Upper Warren study site (9,500 ha) necessitated additional planning to accommodate the range of variation in some environmental variables (including logging and fire history), and to overcome logistical constraints (including the safety of observers). Larger inter-transect spacing and careful planning and coordination with local authorities enabled this expansive study site to be surveyed.

The use of robust density estimation as the common reporting metric when describing Western Ringtail Possum populations will allow direct comparisons of density estimates from different localities and/or different times. In addition, practitioners can select from a toolbox of methods to overcome methodological limitations imposed by site conditions. Some of these approaches and the settings in which they might be appropriate are tabulated below (Table 5.1).

**Table 5.1. Sampling methods available to document Western Ringtail Possum populations.**

| Approach | Metric | Pros | Cons | Example settings |
|---|---|---|---|---|
| Distance Sampling (either line- transect or point transect) | Spatially robust density estimate | • Accounts for uncertainty of detection.<br>• Pooling robustness.<br>• Yields density estimation.<br>• Doesn't require trapping.<br>• Improved accuracy of hand-help GPS units negates requirement for physically measuring perpendicular distance with either laser-range finders (problematic in dense vegetation) or tape measures. | • Impracticable when study sites are narrow strips e.g. road reserves or riparian belts, or when vegetation is difficult to traverse.<br>• Typically requires 60 – 80 observations to model detection<br>• Requires formal analyses.<br>• Field techniques requires people familiar with distance sampling protocols.<br>• Typically requires probability of detection on transect be 1 (unless compensatory approaches are used) | Larger remnants where sufficient transects can be surveyed.<br><br>Repeat sampling can overcome insufficient numbers of observations to model a detection function. |
| Spatially Explicit Capture Recapture | Spatially robust density estimate | • Animals can be marked using a number of techniques (e.g. traditional marking methods like ear tags or PIT tags, and modern approaches utilising genetic identification from hair samples or scats) or their pelage identified from camera trapping.<br>• Rapidly evolving field with development of statistical models that don't require uniquely marking individuals.<br>• Collection of genetic material enhances other studies. | • Western Ringtail Possums generally considered to be trap shy.<br>• Genetic identification (e.g., from scats) adds additional cost to the field program | The same sites at which distance sampling occurs.<br><br>Where spotlighting is undesirable such as in the urban or peri-urban setting. Assumes structured surveys for scats or deployment of hair snares etc can be undertaken. |
| Strip Transects | Density when detection is perfect | • Suitable for small areas of habitat or where habitat is narrow such as in Riparian belts or road reserves a few tens of metres in width.<br>• Simple statistical analyses | • Requires that the probability of detection all individuals within the strip be 1<br>• | Narrow Road Reserves, riparian belts. Agricultural land with scattered large paddock trees. |

| **Approach** | **Metric** | **Pros** | **Cons** | **Example settings** |
|---|---|---|---|---|
| Scat counts | Indice | • Rapid confirmation of species presence<br>• Suitable for assessing habitat use especially in small patches of habitat<br>• Suitable for occupancy modelling, if repeat visits to a site are conducted *and* scats are removed between visits. | • Requires familiarity with detecting scats and identification to the species-level<br>• Difficult to undertake when undergrowth is very dense or considerable leaf fall makes detection of scats problematic<br>• Estimate of scat decay and deposition rates is problematic, so translating scat-indice in to an estimate of abundance can be dubious<br>• Cannot confirm absence | |
| Drey counts | Indice | • Rapid confirmation of species presence<br>• Can be translated into a minimum estimated population size if the ratio of the number of possums per drey is known | • Cannot confirm absence | Narrow Road Reserves, riparian belts. Agricultural land with scattered large paddock trees. |
| Unstructured spotlight | Confirmed presence and assumed (or unconfirmed) absence | • Rapid confirmation of species presence<br>• Suitable for occupancy modelling, if repeat visits to a site are conducted *and* survey effort is even across the survey area | • Cannot estimate abundance or density as often the surveyed area is difficult to estimate | Used as a precursor to structured surveys. |

Other methods used to estimate density (cue counts (scat and drey) and simple presence estimators) are also assessed, as these are commonly used techniques. Wayne et al. (2005) suggested that scat counts might represent a suitable way to estimate abundance. However, when using scat counts to estimate abundance, both production and decay rates are required to calibrate the observed counts (Wayne et al. 2005). These rates may change in response to different environmental conditions. Arguably as possum scats are small in dimension (10 mm by 5 mm), an estimation of probability of detection would also be desirable. An advantage to the use of scat counts is they indicate habitat usage that may not be evident from single observational counts. For example, if animals forage on seasonally available Banksia flowers, then counts outside of the flowering season may not detect Western Ringtail Possum in this habitat. Thorough searching may indicate that Western Ringtail Possums have used an area, and high densities of scats may indicate a high level of use. Though this information will not in itself provide data on the size of the population in the area.

There is a perception from some stakeholders that distance sampling is a time consuming process and that structured nocturnal surveys present increased occupational health and safety risks for observers. However, during this study no injuries were sustained by any of the observers after walking in excess of 1,280 km of linear transects. In terms of rapidity of assessments an experienced and trained observer (such as used in this survey) walked an average of approximately six kilometres of linear transect per night, this allows a study site the size of Tuart Forest Central (North, Lime Kiln, James and Buffer blocks of the Tuart Forest National Park) at 1080 ha and surveyed with 62 transects at a spacing of 150 m and total effort of 70 km to be completed in approximately six nights by a team of two. Generally, this walking pace was not sustained in the Around Albany study sites where, at some sites, observers were more likely to traverse 3 kilometres of linear transect in approximately six hours. The thickness of vegetation is a consideration when estimating the required survey duration for budgeting purposes.

Some monitoring programs utilise existing track networks to conduct spotlight surveys with the rationale that cleared tracks provide a safer environment for observers during surveying. Whilst this is likely to be the case, edge-effects caused by tracks may introduce biases, and the data obtained from these areas may be likewise biased. For example, animals could be attracted to, or repelled from the track, and detection rates will be biased high and low, respectively. This practice is strongly discouraged (Buckland et al. 2010).

This study investigated two recipient translocation sites at Leschenault Peninsula Conservation Park and Yalgorup National Park. Western Ringtail Possums were released into these sites between 1991 and 2008 (Clarke 2011), and the success of these translocations has not been recently assessed. A strikingly positive result emerged from the survey effort within the Yalgorup National Park (including Martins Tank), where the translocated population within the surveyed area was estimated to be in excess of 800 individuals and is now clearly another important stronghold for the species. The 6.9 kilometres of transect within the Leschenault Conservation Park yielded seven detection events of 10 individuals, with the individuals potentially originating from the original translocated individuals or alternatively from animals that moved down the coast from Binningup.

The majority of sites investigated by this study fell within the conservation estate and are thus already afforded some level of protection. However, differences in density estimates across study sites may assist in ranking sites in significance to the species, informing the allocation of resources toward conservation operations. Similarly, within each study site, density surface models highlight hotspots that may help identify habitat critical to the persistence of the species locally. This study may provide inferences and a baseline for experimental testing. So for example, sites where no detections of Western Ringtail Possum were made may provide clues as to potential causal factors that can then be experimentally tested. For instance, the effects of fire, water table changes, forest regeneration through plantings and predator control can all be experimentally tested using these data. Additionally, this study also identified several sites at which Western Ringtail Possum were not detected and these may represent suitable repository sites where a long-term conservation gain may potentially be achieved.

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