An assessment of habitat for

Western Ringtail Possum (*Pseudocheirus occidentalis*)

on the

southern Swan Coastal Plain
(Binningup to Dunsborough)

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Department of Parks and Wildlife

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Executive Summary

The western ringtail possum (WRP) (*Pseudocheirus occidentalis*) is an arboreal mammal endemic to the south-west of Western Australia. The species has declined or become locally extinct over much of its former inland range with some fragmented populations remaining in coastal areas. Its current IUCN conservation status is Vulnerable at both the state and commonwealth level.

Populations occurring in inland eucalypt forests have seriously declined in numbers since 1998, while those on the coastal strip near Busselton have higher population densities and reproduction rates than recorded elsewhere. Much of the occupied coastal habitat is in a restricted and fragmented vegetation type that supports dense stands of peppermint (*Agonis flexuosa*), a preferred food resource in coastal settings that also provides shade and shelter from predators. However, this occupied habitat coincides with an area of rapid urban development that results in many land-use conflicts and costly environmental impact assessments.

This report assesses the habitat for WRP in the southern Swan Coastal Plain between Binningup and Dunsborough and provides a habitat classification and GIS mapping dataset that can be used for prioritising habitat. Specifically it seeks to provide information on habitat patches that are most important to support a viable population of WRP in this area.

An extensive review of the literature was undertaken to identify habitat variables affecting possum persistence, some of which were suitable for use in landscape-scale spatial modelling. Survey data for WRP were obtained for a range of sample sites in the region and were used to examine relationships between the habitat variables and WRP abundance.

The main variables associated with suitable habitat were indicators of habitat quality (a score derived from soil and vegetation attributes), presence and dominance of peppermint, area of patch, area of other habitat within its neighbourhood and distance to the nearest other high quality patch. Canopy cover, canopy trend over the last 10 years, vegetation condition and fuel age were not statistically useful indicators of suitable habitat for the sample sites used in this analysis, but these attributes warrant further investigation.

A revised habitat quality variable was used to develop the spatial classification of habitat suitability. From these data, five habitat classes were constructed and these were mapped for five WRP management zones from Binningup to Dunsborough.

Habitat mapping provides a qualitative view of habitat quality and distribution but should not be used to predict or determine likely carrying capacities of particular habitat. There were many map units without any survey data and there was unexplained variation in WRP density, even within the well surveyed highest quality habitat type. Further surveys are needed across a broader range of vegetation types and sites to build a more reliable model and provide more robust predictions of habitat quality and carrying capacity. These surveys need to be conducted using a consistent methodology appropriate to the site type and with greater attention given to defining the area/extent actually surveyed. In the interim, field assessments by experienced surveyors will still be required to assess the finer scale habitat attributes and to conduct surveys for WRP to meet environmental assessment protocols.

The information in this habitat assessment provides a broad context for WRP management and is one component of a decision support system to conserve WRP in the southern Swan Coastal Plain. It is not intended or of sufficient detail to meet requirements for environmental impact assessment for particular applications or proposed sites of disturbance.

It is desirable that ongoing work by the Department of Parks and Wildlife will develop the landscape connectivity aspects of habitat suitability to provide a basis for more informed decisions on the value of individual linkage patches. These tools would assist in testing scenarios about the conservation cost of removing certain habitat patches, or the conservation gain from revegetating others, and their contribution to overall landscape connectivity and WRP conservation. The cost effectiveness of various habitat management options could also be considered.

CONTENTS

1.0 Introduction

The western ringtail possum (WRP) (*Pseudocheirus occidentalis*) is a nocturnal arboreal mammal endemic to the south-west of Western Australia. Its conservation status is currently listed as Vulnerable under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and as rare or likely to become extinct under the Western *Australian Wildlife Conservation Act 1950*. The management and recovery of the WRP is guided by a species recovery plan (Department of Parks and Wildlife, 2014).

WRP populations have declined or become locally extinct over much of the former range in the south-west due probably to clearing and fragmentation of habitat during agricultural development (Jones *et al.,* 1994a; DSEWPaC, 2012). However, even in the intact forested regions of the south-west populations have declined significantly, particularly since 1998 (Wayne *et al*., 2011; Wayne *et al*., 2012). Threatening processes including logging intensity, inappropriate fire regimes, jarrah dieback disease (*Phytophthora cinnamomi*), drought and a drying climate may have all contributed to the degradation of WRP habitat, and increased the exposure of WRP to predation by foxes (*Vulpes vulpes*) and feral cats (*Felis catus*) or to heat stress (Jones *et al*., 1994a; Wayne *et al*., 2000; Burrows *et al*., 2002; Jones *et al*., 2004; Wayne *et al*., 2006; de Tores, 2009; Wayne *et al*., 2011; DSEWPaC, 2012; Woinarski *et al*., 2012).

Once patchily found throughout forests and woodlands in the south-west, the distribution of WRP has more recently contracted to wetter coastal and near coastal habitats and in close proximity to creeks, swamps and rivers (Jones *et al*., 2004a; de Tores, 2009). The current known distribution comprises intermittent occurrences along the south coast (from east of Albany to west of Walpole), the west coast (from Bunbury to Augusta), and inland populations in the lower Collie River Valley, at Harvey and in the Upper Warren forest near Manjimup.

The greatest population density of WRP is now found around the Bunbury (Binningup) to Dunsborough coastal strip, which coincides with an area of rapid urban development and loss of prime habitat. This coastal strip is considered to be a stronghold for WRP and is therefore a focus for recovery and conservation of the species (Jones *et al.,* 2004a; Jones *et al*., 2007; Harewood, 2008). High WRP population densities have been recorded in some urban settings, where mature peppermint trees (*Agonis flexuosa*) with large, dense and overlapping canopies have been retained (Harewood, 2008). This habitat type is thought to provide high quality shelter and food. High population densities may indicate that WRP have benefited from some forms of development and adapted to the urban setting, or alternatively have been displaced from the broader setting by vegetation clearing and are confined to smaller pockets of retained habitat.

Spatial and temporal differences in habitat quality and associated relative abundance of WRP provide important information for developing management strategies for their conservation. Earlier studies identified a number of spatial habitat variables in the Busselton coastal area that were associated with higher abundance of WRP including foliar nitrogen concentration, canopy connectivity, abundance of tree hollows, proximity to waterways, absence of intense fire regimes and abundance of mature peppermint trees (Jones *et al*., 1994a, Jones and Hillcox, 1995). These variables can be manipulated to some degree to improve habitat values.

More recent hypotheses suggest that temporal patterns of cattle grazing and fire impacts at Locke Nature Reserve, near Busselton, and surrounding areas may have affected the growth and form of peppermints and understorey components (Jones *et al*., 2004; Jones *et al.,* 2007). These studies hypothesized that increased browse quality in ten-year-old regrowth following patchy burns may have encouraged a female-biased sex ratio and rapid expansion of the local population.

The increasing incidence of drought in the last decade may be driving the decline of local WRP populations (B. Jones, unpublished data) and causing them to contract even further into coastal habitats. However, drought also affects these habitats by reducing the growth of peppermint foliage for possum browse and canopy protection (B. Jones, unpublished data). At one development site where mature peppermint trees were thinned and the area replanted, fertilised and watered, the number of young WRP recovered to pre-thinning levels despite an overall reduction in the number of adults (B. Jones, unpublished data). That study indicates that management strategies may be employed in existing habitat to overcome drought impacts and manipulate the browse quality to improve the reproductive output of WRP.

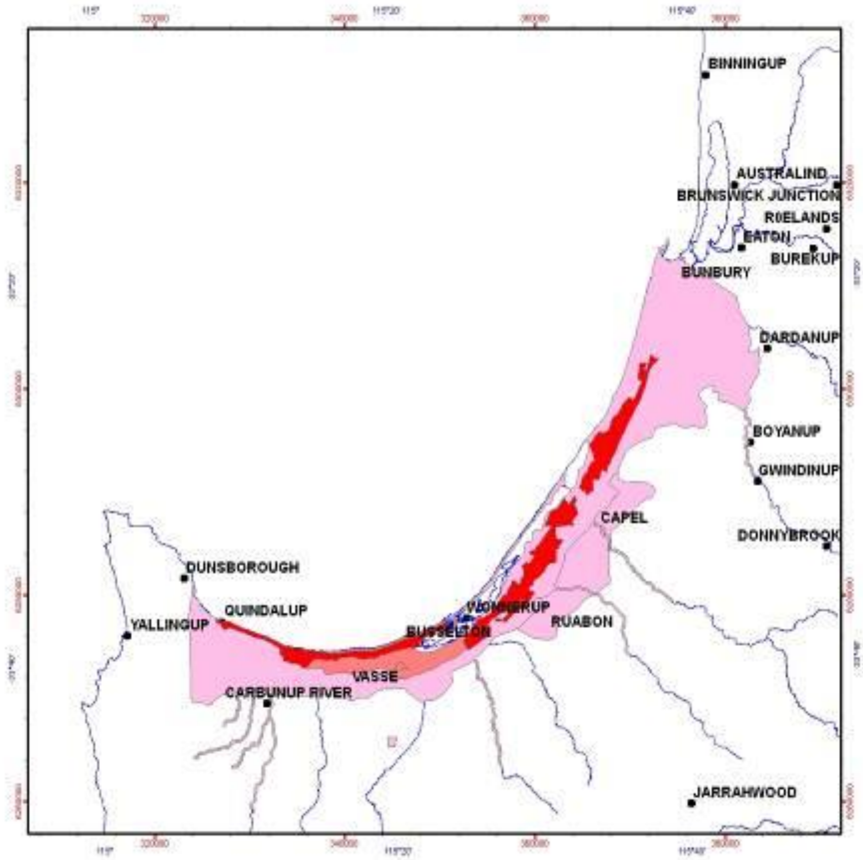
WRP are particularly susceptible to heat stress with many observations by wildlife rehabilitators of animals that were affected by dehydration during heat wave conditions recovering after drinking water (Jones *et al*., 1994b). Stream flows have reduced by more than 50% in recent years in inland forested catchments due to reduced rainfall (Kinal and Stoneman, 2012; Silberstein *et al*., 2012), and this lack of surface water during summer may be contributing to the decline in WRP in these areas. The level of heat stress for WRP may also be greater in inland areas where maximum temperatures during summer are higher than coastal areas, which benefit from the cooling oceanic influences. Ensuring safe access to drinking water and encouraging denser canopy growth to reduce heat stress may help to ameliorate the impacts of climate change on this species.

Over the last decade or so a number of land developments have been assessed under the EPBC Act and proponents required to enter into management agreements and contribute financially to WRP population monitoring and research and/or secure offset land with suitable WRP habitat for inclusion into the conservation estate.

Several studies have been undertaken by DEC to define local WRP habitat variables and to identify areas of remnant vegetation that contained suitable habitat in the Busselton to Dunsborough coastal strip. One study in 2006–07 identified and mapped 147 habitat polygons greater than 1ha from high resolution aerial photography and analysed them according to land tenure and vegetation complex. This analysis determined that only 6.6% of the pre-European extent of WRP habitat remained and of that 0.86% was contained in secure conservation reserves (K. Williams, unpublished data). These results were presented to various stakeholders via a series of workshops.

A second study was conducted in 2009–10 to characterise habitat patches in 37 sites in the Bunbury to Dunsborough area and identify variables that may influence occupancy and population density of WRP (Molloy *et al*., unpublished data). These study sites extended around Bunbury where there were similar urban development pressures, albeit with lower WRP population densities than the Busselton to Dunsborough area. This study attempted to relate site habitat variables to relative abundance of WRP based on scat scores but spatial coverage, replication and sampling intensity were not sufficient to provide a robust habitat model.

In 2009, DEWHA with advice from DEC and others, developed policy guidelines for the protection and enhancement of WRP habitat and habitat connections on the southern Swan Coastal Plain in which criteria for significant impacts were defined so that proponents could determine if a referral under the EPBC Act was required (DEWHA, 2009a, b). This document recognised and mapped three habitat categories, namely core habitat, primary corridors and supporting habitat from Bunbury to Dunsborough based on broad vegetation complex mapping and current expert knowledge (Map 1).



Map 1. Three habitat categories determined by the Australian Government for WRP in the southern Swan Coastal Plain (DEWHA, 2009a). Core habitat is red, primary corridor is dark pink and supporting habitat is light pink.

At the same time, the then Shire of Busselton worked with consultants and DEC to prepare their own habitat protection plan for WRP (NGH Environmental and Ecosystem Solutions, 2009). That report provided recommendations that the shire used in conjunction with the DEWHA guidelines to formulate Amendment No. 146 to their District Town Planning Scheme No. 20. This amendment seeks to regulate the clearing of existing individual and/or groups of peppermint habitat trees not protected under existing legislation, offer incentives to encourage retention and enhancement of existing habitat and provide a system for offset plantings where clearing is approved (Shire of Busselton, 2012).

The Department of Parks and Wildlife, and its predecessor the former Department of Environment and Conservation (DEC), coordinated a review of key habitat in the Busselton area. This report reviews the factors influencing WRP habitat quality, provides a classification of habitat suitability and maps of suitable habitat in the southern Swan Coastal Plain. The area covered by this habitat assessment (Map 2) incorporates all known and predicted habitat and connecting corridors occupied by WRP from Binningup to Dunsborough and east to the Whicher Range. GIS mapping products accompany this report.

Map 2. Area of interest (hatched) in the southern Swan Coastal Plain covered by the present WRP habitat assessment and mapping.

2.0 Context and objectives

This habitat assessment was undertaken within the broader context of a conservation goal to maintain coastal populations of WRP on the southern Swan Coastal Plain. Maintaining these coastal populations is seen as an achievable target and one which would underpin the conservation of the entire species across the south-west of Western Australia.

The aim of this study was to identify and classify habitat that would support viable populations of WRP. To assist management of the species and for practical mapping considerations, the region was divided into five management zones.

A hypothetical target was established, based on IUCN criteria, of identifying and maintaining sufficient habitat to support a minimum of 2,500 WRP per management zone and in doing so at least maintain the existing area of occupancy and area of extent.

The study objectives were:

1) identify through a review of literature the factors which were likely to influence habitat quality and thus habitat use and distribution of WRP in the southern Swan Coastal Plain,

2) investigate the relationships and interactions between the habitat factors and their influence on the distribution of WRP, and

3) develop a habitat classification system to quantify and map areas of remnant vegetation in the southern Swan Coastal Plain suitable for WRP use.

3.0 Approach and methodology

The general approach undertaken was to review existing knowledge about WRP biological and ecological requirements and habitat characteristics in this region and relate these to spatial information to develop a landscape-based GIS habitat suitability model across the southern Swan Coastal Plain.

WRP survey data were used to investigate relationships between WRP abundance and various habitat variables using linear regression methods. However, given the limitations of the available survey data, the modelling approach was more exploratory in nature and was used to inform and refine the habitat classes and understand interactions between habitat variables. It was not intended that this approach would generate a predictive model to be used to determine the likely carrying capacity of individual remnants of vegetation.

The habitat review and GIS mapping was conducted on the broader area of interest from Binningup in the north to Dunsborough in the south and out to the Whicher range. The spatial mapping dataset was subsequently divided into five WRP management zones within 10km of the coastline to provide a more detailed assessment of habitat availability within the areas of greatest pressure for land development.

4.0 Description of species

The WRP is a medium-sized nocturnal, arboreal, folivorous marsupial endemic to south-western Australia. It has dark brown or occasionally dark grey fur above with cream or grey fur below. Its ears are short and rounded compared with the larger species, the common brushtail possum (*Trichosurus vulpecular*), and it has a slender strongly prehensile tail with a terminal white tip, rather than a brushtail. The WRP weighs up to 1.3kg with a body length of 40cm and tail length of 41cm (Van Dyck and Strahan, 2008). Average mature adult weights for both sexes are about 1000g and they attain sexual maturity at about 830–1000g (Ellis and Jones, 1992; Jones *et al*., 1994b).

The aboriginal name for this species is 'ngwayir' (Abbott, 2001a).

- ❖ The WRP is a nocturnal, arboreal possum that is endemic to the south-west of Western Australia.

5.0 Distribution of species

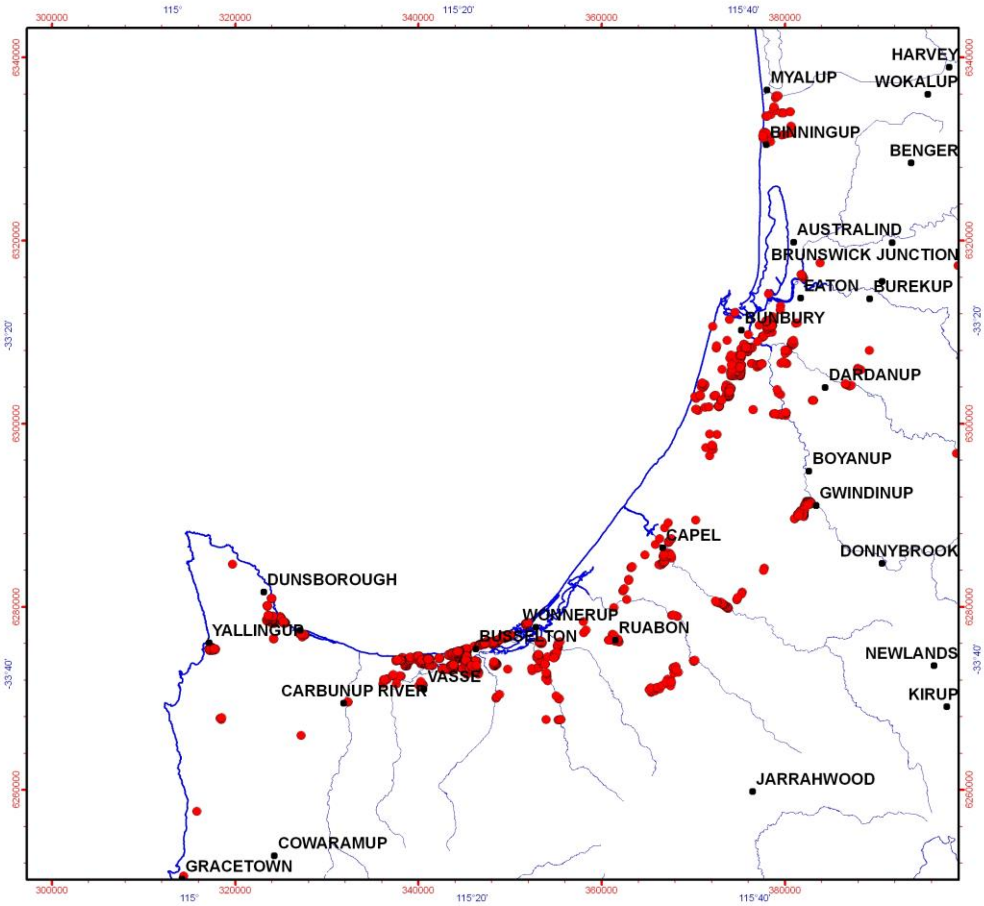
The WRP once occurred throughout much of south-western Western Australia in a patchy distribution (Shortridge, 1909; Maxwell *et al*., 1996). Early WA Museum records indicate its presence from north of Perth to around Cranbrook and the Pallinup River in the south-east (Burbidge and de Tores, 1998; de Tores *et al.*, 2005a). It was regularly recorded in Tutanning Nature Reserve near Pingelly in the 1970s (de Tores *et al*., 2005a) but is now mostly extinct from the northern and inland majority of its range. The distribution contracted to the wetter parts of the south-west and by the early 1980s it was considered that about 80% of its former range was no longer occupied (Jones, 2004; de Tores *et al.*, 2005a; Woinarski *et al*., in prep).

Using post 1995 records, the extent of occurrence of WRP was estimated to be 7155km^2 while the area of occupancy was estimated to be 3700 km^2 (DSEWPaC, 2012).

Two main populations remain – Albany and Bunbury to Dunsborough. The Upper Warren population, which previously supported the largest extant inland population of the species, has declined to near extirpation since 1998 with greater than 95% reduction in sightings from spotlight surveys (Wayne *et al*., 2011; Wayne *et al*., 2012; Woinarski *et al*., in prep). Smaller scattered occurrences are found around Augusta, Margaret River, Yallingup, Dawesville, Harvey and Collie (Jones *et al.,* 1994a; Jones, 2004; DEC 2007; Swinburn, 2008; Wilson, 2009; DSEWPaC, 2012; G. Harewood, unpublished data). There were also several translocated populations in Leschenault Peninsular Conservation Park, Yalgorup National Park, Lane Poole Conservation Park and Karakamia Sanctuary near Chidlow (owned by the Australian Wildlife Conservancy), but only the ones at Karakamia and a small group near Dawesville in the Yalgorup National Park remain (Woinarski *et al*., in prep).

By 1994, extant populations of WRP were closely associated with creeks, swamps, rivers or drainage lines in the south-west, or were within 2km of the coastline (Jones *et al*., 1994a). The densest population is in the Bunbury to Dunsborough area and is most commonly associated with peppermint (*A. flexuosa*) and tuart (*Eucalyptus gomphocephala*) woodland, whereas the lower density populations in the Upper Warren areas are associated with jarrah (*E. marginata*) and marri (*Corymbia calophylla*) forest (Jones *et al*., 1994a; de Tores *et al*., 2005a). Its former inland distribution included wandoo (*E. wandoo*) and sheoak (*Allocasuarina huegeliana*) woodlands (Maxwell *et al*., 1996).

In the Bunbury to Dunsborough region, populations are frequently associated with urban or semi-urban environments (Map 3, G. Harewood, unpublished data). This distribution may reflect the greater survey effort in these urban areas associated with proposed land developments and subdivisions where fauna surveys have been conducted as part of the environmental impact assessment process. Other surveys conducted in areas proposed for sand mining and other non-urban disturbances have shown that WRP are also patchily distributed in remnant vegetation across the inland coastal plain, particularly along the connecting vegetated river systems out to the Whicher Scarp foothills (Map 3).



Map 3. Distribution of WRP in the southern Swan Coastal Plain from spotlight survey records, including multiple surveys of the same location, conducted between 1986 and 2013 within the area of interest (G. Harewood, unpublished data).
[Note: Map 3 is generated from limited data sets. Other survey data either was not available in digital format, used other survey methods or was not made available for this review. For example, extensive survey data in the Tuart Forest National Park, Ludlow Nature Reserve, Leschenault Peninsular Conservation Park, and Siesta Park–Kealy localities are not shown on this map (Jones *et al.,* 1994b; Jones and Hillcox, 1995; Jones *et al*., 2007; Clarke, 2011).]

- ❖ The distribution of WRP has contracted significantly since the 1970s and is now largely concentrated in cooler south-west coastal regions. Many populations are found in urban and semi-urban areas.

6.0 Conservation status and population size

6.1 Conservation status

The western ringtail possum is accepted as a separate species to its congener in the eastern states, the common ringtail possum (*Pseudocheirus peregrinus*) (Murray *et al.*, 1980; McKay*,* 1984; Maxwell *et al.,* 1996; Wilson, 2009).

WRP is currently listed as a Vulnerable species under the IUCN Red List of threatened species classification (IUCN, 2012), and listed as Vulnerable under the EPBC Act. It was listed in 1983 as 'fauna that is rare or likely to become extinct' under the Wildlife Conservation Act, and is ranked as Vulnerable using IUCN criteria, including that its extent is less than 20,000km^2, it has a severely fragmented distribution, and there is a continuing decline in the area of occupancy, the extent and quality of its habitat and in the number of mature individuals (IUCN, 2012).

Due to its recent rapid decline, especially in the Upper Warren region but also elsewhere, it has been recommended that the conservation status of WRP be reviewed with a likely recommendation for upgrading (A. Burbidge, personal communication; Woinarski *et al*., in prep).

WRP in the southern Swan Coastal Plain are also subject to EPBC Act policy statement 3.10 *Significant impact guidelines for the vulnerable western ringtail possum (Pseudocheirus occidentalis) in the southern Swan Coastal Plain, Western Australia* (DEWHA, 2009a), which provides guidance to whether a proposed action is likely to have a 'significant impact' on this species. The policy statement and background paper (DEWHA, 2009b) define different assessment criteria for three habitat areas – core habitat, primary corridors and supporting habitat – to determine if an action should be referred to the federal Environment Minister.

- ❖ WRP is a threatened species and is protected by Commonwealth and State legislation.

6.2 Population size

The population extent of WRP in the south-west of Western Australia has been declining since about 1900 particularly in the drier inland parts of it range (Jones *et al.,* 1994a; Jones, 2004; Wayne *et al*., unpublished data). However, there are no reliable estimates of the current total population size, or of the minimum viable WRP population in Western Australia (Burbidge and de Tores, 1998; DSEWPaC, 2012; Department of Parks and Wildlife, 2014). This situation arises because the species is elusive and difficult to survey in a cost effective manner, with predominately low detection rates that vary in different vegetation types (Wayne *et al*., 2005a; de Tores and Elscot, 2010). On the basis of limited existing survey data, the population in the Bunbury to Dunsborough region has been estimated to be between 2,000 and 5,000 animals (Wilson, 2009; B. Jones and G. Harewood, personal communications).

- ❖ There are no reliable estimates of the total WRP population in Western Australia.

6.3 Population monitoring

There have been few long term monitoring studies in the Bunbury to Dunsborough region to determine population trends and future habitat requirements. Some have shown a general decline in population in line with increasing drought effects in the last decade, but there are other examples of increasing populations. There has been a small increase in the number of WRP reported to the DPaW in the Bunbury area over recent years where none had been previously recorded, suggesting a possible expansion of WRP into unoccupied habitat, or a greater level of community awareness/intolerance, or both (C. Fleay, personal communication). Generally, surveys have been sporadic and often imprecise so that the true status (stable/increasing/decreasing) of the population is unknown (Clarke, 2011).

Reduced rainfall has been strongly associated with attrition of fauna populations (Burbidge and McKenzie, 1989) and may explain the recent contraction of the distribution of WRP to the wetter coastal areas but many other factors are implicated (Clarke, 2011). For example, in the inland Upper Warren region (Perup and Kingston areas) long-term population monitoring indicates that there has been a substantial and extensive decline since 1998 (Wayne *et al*., 2011; Wayne *et al*., 2012) (Fig 2).

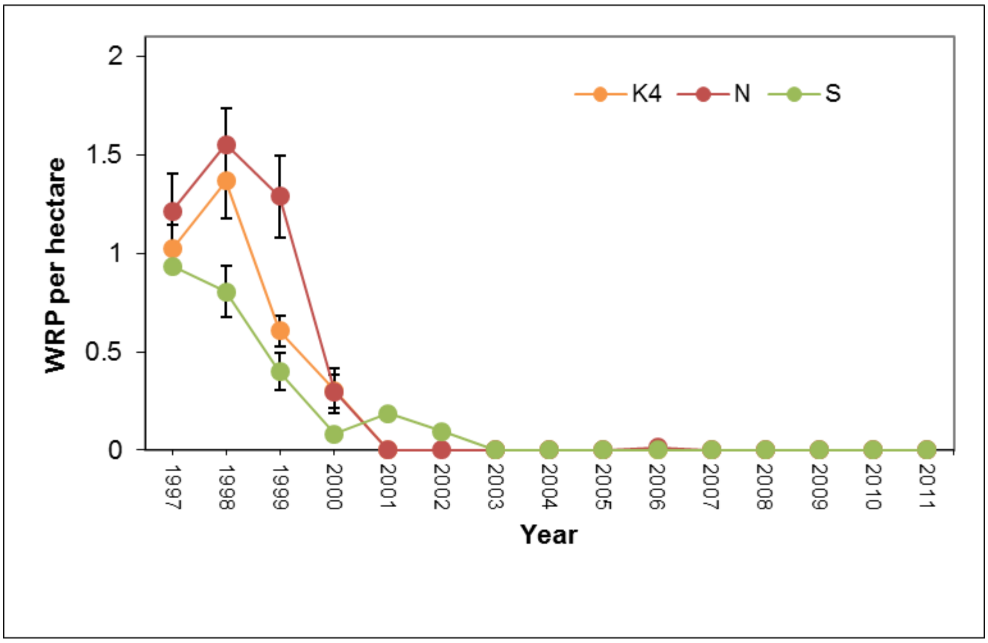


Figure 2. Annual spotlight detection rates (individuals per km, +/- SE) for WRP along three transects (K4, N and S) in the greater Kingston area. The number of surveys conducted each year varied (1997–99, 12–15 surveys/year; 2000, 8 surveys/year; 2001–03, 1 survey/year; 2004–11, 6 surveys/year) (Data provided by A. Wayne, Kingston Study and Wayne *et al.,* 2012).

Population monitoring at the Tuart Forest National Park near Busselton indicated a decline of one-third to two-thirds during 2002–08 compared with the population in the early 1990s, particularly after the 2001 and 2006 drought years where average rainfall was about 30% lower than the long term average (B. Jones, unpublished data). The 2006 drought year was also associated with a “collapse” or dieback of the peppermint canopy (B. Jones, personal communication). There is also evidence of a local population recovery in the early 1990s, about ten years after patchy burns at Locke Nature Reserve (Jones *et al*., 2004), which was attributed to the availability of high quality browse in the post-burn peppermint regrowth and an observed female-biased sex ratio enabling rapid population expansion.

Other long term monitoring has been associated with translocated populations north of Bunbury since 1991. In that area, hundreds of WRP have been translocated into potentially suitable habitat to compensate for the loss of habitat due to urban development and as an outlet to release animals rehabilitated by wildlife carers (de Tores *et al.,* 1998; de Tores *et al.,* 2005a). Monitoring of translocated WRP in the Leschenault Peninsular Conservation Park showed that the population was increasing and by 1998 there were 100 spotlight sightings, which included second and third generation young (de Tores *et al*., 2005a). By 2002, this declined significantly to only two sightings whereas at other release sites at Yalgorup National Park, the number of sightings was still increasing (de Tores *et al*., 2005a). Additional releases into the Leschenault Peninsular Conservation Park during 2004–05 and 2006–08 were monitored closely and these studies found that the high mortality rates were mostly due to predation by foxes and cats, and also by pythons, raptors and chuditch (*Dasyurus geoffroii*), although other causes were implicated including poor habitat quality and competition from common brushtail possums (de Tores *et al*., 2005a, 2005b; Clarke 2011).

Although there has been some monitoring of WRP populations in the Swan Coastal Plain, it has been for specific locations or research purposes and there has been no comprehensive long term monitoring at representative sites to determine the overall population trends. Similarly, there has been no long term monitoring of foxes or feral cats in this region to determine trends in predator populations (de Tores *et al*., 2004), and no long term monitoring of habitat loss from clearing of vegetation or decline in vegetation health.

❖ Monitoring shows that WRP populations have declined significantly in inland forests since 1998, and decreased in some coastal areas during drought years or where there are high levels of predation.

6.4 Site-based population density

Density of WRPs in small habitat patches in the Bunbury to Dunsborough region appears to be significantly greater than currently found in the drier inland region, (Appendix 1), but these density values are difficult to compare owing to the different methods used to derive them. WRP are difficult to trap as they rarely come to ground so most density estimates have been derived from spotlight transects (Wayne *et al*., 2005a; Jones *et al*., 2007; de Tores and Elscot, 2010). Relative abundance of WRP using scat scores were highly correlated with spotlight counts (Wayne *et al*., 2005a). However, detection of scats in dense understorey or heavy litter can make comparisons of relative abundance difficult and may only be useful in open bushland with consistent site conditions (de Tores and Elscot, 2010; B. Jones, personal communication).

Density estimates depend on the area in question and this is often loosely defined. In some cases, density is expressed in terms of area either of the whole remnant, peppermint canopy, total canopy or 'suitable habitat'. In other cases the detection rate of the number of possums per km of spotlighting transect, which may be one or two sided transects is expressed as a density measure. In smaller remnants, all animals present can be observed, but in larger habitat patches, the most reliable estimate of WRP abundance and density is determined using line-transect distance sampling (de Tores and Elscot, 2010).

Population density estimates in the Bunbury to Dunsborough region range from around 0.2/ha to over 20/ha in smaller urban parks and holiday villages with large mature peppermint trees (Appendix 1). In one study in a Busselton tourist resort development site, the maximum number of mature possums (>700g weight) appeared to be tightly regulated to about 39 per hectare of peppermint canopy, or about nine mature peppermint trees per possum (B. Jones, unpublished data). This tree-based density was maintained over a four year period during which 33% of the trees were removed from the site resulting in a 38% reduction in the number of mature possums present. This apparent regulation of maximum carrying capacity could be related to social behaviour of the dominant possums to reduce overcrowding (B. Jones, personal communication). It is not known if these higher concentrations of WRP in small patches of habitat around Busselton can be sustained over the longer term.

Density of WRP varies within remnants due to variations in vegetation structure and composition, proximity to creeklines or wetlands and is likely to be associated with social groupings. Using Capture-Mark-Release (CMR) studies over the summer of 1991–92, the density of WRP in 40ha of the Locke Nature Reserve west of Busselton was 2.4/ha. However, 87% of these captures were in one section of the reserve (12ha) where dreys were most abundant and density was 7.0/ha (Jones *et al*., 1994b). In the western half of this reserve, population density was only 0.2/ha. At the Abba site within the Tuart Forest National Park north-east of Busselton, WRP density in 12ha was 4.0/ha. At the nearby Geographe Bay site, density was 0.6/ha for the 22ha judged to be suitable habitat, but averaged 0.26/ha for the 50ha site. By comparison at Emu Point near Albany, density was 0.35/ha in 20ha that included all dreys and sightings, but was 0.08/ha for the whole area of 85ha, including parks and gardens (Jones *et al*., 1994b). At Frenchman's Bay near Albany in peppermint dominated vegetation, WRP density varied from 0.05/ha at one site (19.8ha) to 0.5/ha at another site (10.5ha) (Gilfillan, 2008).

- Density estimates for WRP vary considerably from 0.2 to 20 per hectare but are generally greater in the Bunbury to Dunsborough region than in other areas in the south-west.

7.0 Biology and ecology of relevance to habitat assessment

7.1 Nutrition and food resources

7.1.1 Plant species preferences

Western ringtail possums are more specialised in their diet selection than the common brushtail possum, and feed mainly on leaves with occasional flowers, fruit and buds (de Tores, 2008; Jones *et al.*, 1994a). Coastal populations of WRP occupy peppermint (*A. flexuosa*) dominated sites and peppermint leaves comprise the major component of their diet (Jones and Hillcox, 1995; Jones *et al*., 1994b). Inland populations are found within jarrah (*E. marginata*) and marri (*C. calophylla*) dominated forests sites in the upper Warren region and previously occupied wandoo (*E. wandoo*) and sheoak (*A. huegeliana*) sites in the wheatbelt.

However, observations in the Bunbury to Dunsborough region have shown that WRP also feed on new shoots, flowers, leaves and/or fruiting bodies from a range of flora including *Nuytsia floribunda, Acacia saligna, Hardenbergia comptoniana, Allocasuarina fraseriana, E. gomphocephala, E. rudis, Melaleuca viminea, M. cuticularis, M. rhaphiophylla, Kunzea glabrescens* and *Xylomelum occidentale* (G. Harewood, personal communication; A. Webb, personal communication; Molloy *et al.,* unpublished data; Clarke, 2011). Other species in which WRP have been sighted, but may not have been feeding on, include karri (*E. diversifolia*), bullich (*E. megacarpa*), blackbutt (*E. patens*) and pine (*Pinus radiata*) (Gilfillan, 2008; G. Harewood, personal communication). In urban areas, WRP are known to feed on a variety of garden shrubs including roses, New Zealand christmas tree (*Metrosideros excelsa*), lilly-pilly (*Acmena smithii*), wisteria (*Wisteria sinensis*) and various fruit trees (Burbidge and de Tores, 1998; Gilfillan, 2008; G. Harewood, personal communication).

Highest relative abundances of WRP in the Bunbury to Dunsborough area from scat surveys were in wetlands without peppermint and browsing appeared to be confined to mature *M. cuticularis, M. viminea* and to a lesser extent *M. rhaphiophylla* (Molloy *et al*., unpublished data). *K. glabrescens* was the main food source in other areas in the absence of peppermint. Abundant scats were also found beneath *N. floribunda* and *X. occidentale* during the flowering period leading to the hypothesis that WRP used these flowers as a seasonal supplementary food resource (Molloy *et al*., unpublished data).

In captivity, WRP show a preference for young fresh green leaves rather than young leaves with red colouring or older leaves (Ellis and Jones, 1992). Based on faecal pellet analysis, peppermint was the major component (79–100%) of the diet across all study sites in the south-west, other than the two inland sites near Perup where peppermint was absent and jarrah and marri were the major dietary components (Jones *et al*., 1994b).

These observations match those for the common ringtail possum (*Pseudocheirus peregrinus*) in eastern Australia. For this species, eucalypt foliage is the major food source and young foliage is preferred to older foliage, but because of the limited availability of young foliage, mature foliage is consumed for most of the year (Pahl, 1984). Understorey shrubs also provided a supplementary food source where the preferred *Eucalyptus* species was not present (Pahl, 1984).

- ❖ WRP are specialised arboreal browsers that prefer a diet of mainly young myrtaceous leaves, but will feed on garden species.

7.1.2 Nitrogen and diet selectivity

Myrtaceous leaves are generally low in nutrients and high in tannins but ringtail possums are well adapted to this diet. They have low metabolic rates and low feed intakes, and are hindgut fermenters with an enlarged caecum and re-ingest their faeces (coprophagy) which increases their ability to extract nutrients, in particular nitrogen and vitamins, from a poor quality diet (Hume *et al*., 1984). However, availability of nitrogen is likely to be the most limiting factor for nutrition and growth (White, 1978; Mattson, 1980) and an important determinant of browse quality and habitat suitability for possums.

Nitrogen concentration of the dominant tree foliage was found to be strongly correlated with WRP relative abundance across nine sites in the south-west (Jones *et al.,* 1994a). Occupied sites tended to have higher foliar nitrogen levels in late summer (February) than unoccupied sites (Jones *et al.,* 1994a) at a time when nitrogen levels are generally at their lowest due to seasonal drought and low soil moisture and nitrogen availability. Highest foliar nitrogen levels were found in October when leaves were mature and trees were in flower. These results are consistent with earlier work in the eastern states where the density of possums was highly correlated with foliar nitrogen and potassium levels (Braithwaite *et al*., 1983).

Higher foliar nitrogen concentrations are generally associated with more rapid plant growth where there is increased availability of soil moisture and nitrogen, which vary between sites and seasons. Trees growing in moist environments, such as creeklines, swales and near wetlands are likely to be able to maintain nitrogen uptake throughout the summer months and provide a more continuous supply of higher foliar nitrogen than those growing in drier areas. These areas can therefore provide higher quality food over the critical late summer-autumn period when possums would otherwise be forced onto a very low protein diet.

Young eucalypt shoots which regenerate after fire have higher levels of nitrogen than the slower growing older foliage (Landsberg, 1990; Radho-Toly *et al.,* 2001), so there may be some improvement in WRP carrying capacity after fire (Friend and Wayne, 1993; Pausas *et al*., 1995; Braithwaite, 1996; Jones *et al*., 2004).

- ❖ WRP prefer foliage with higher nitrogen levels and these are generally found in lush vegetation growing in wetter areas, in higher fertility soils or in young regrowth foliage after fires.

7.1.3 Phenolic compounds as feeding deterrents

Other factors that may affect browse quality and diet selectivity of arboreal marsupials have been investigated. Young eucalypt leaves have higher nitrogen and lower lignin levels than older foliage but they also have higher levels of tannins and other phenolic compounds which can interfere with the digestion of proteins (Cork and Pahl, 1984). A particular group of phenolic compounds (formylated phloroglucinol compounds or FPCs) were shown to inhibit browsing of certain eucalypt species by ringtail possums in the eastern states (Lawler *et al.,* 1998; Pass *et al*., 1998). Ringtail possums have also been shown to use a closely related terpene, an essential oil called cineole, as a cue to toxic properties of leaves through learned associations of the cineole smell with the toxic effects of the FPCs (Foley *et al*., 2004). WRP have been observed to smell peppermint foliage thoroughly before either consuming the leaves or moving on to another tree (Clarke, 2011).

Individual eucalypt trees vary widely in the levels of phenolic compounds even within sites (Lawler *et al*., 2000; Wiggins *et al*., 2006), which may explain the spatial heterogeneity in site utilization, carrying capacity and home ranges in some sites. Lawler *et al*. (2000) found that more than half the potential food trees within a 0.5ha site could not sustain a ringtail possum due to reduced intake of leaves with higher concentrations of the leaf chemical sideroxylonal, one of the FPC compounds. This negative relationship between dry matter intake and sideroxylonal concentration suggested that ringtail possums were able to regulate their intake of sideroxylonal by using a slower ingestion rate to allow more time for detoxification and elimination of wastes (Wiggins *et al*., 2006). Possums may also choose to mix their diet with other plants with lower levels of sideroxylonal but this behavioural strategy may increase the energetic costs of foraging and increase the predation risk (Wiggins *et al*., 2006). The foliar level of sideroxylonal and the spatial heterogeneity of alternative foraging plant species may therefore determine the suitability of various habitats.

A similar variation in phenolic compounds is likely to exist in peppermints, which are in the Myrtaceae family and which have essential oils, including 1,8 cineole (Robinson, 2006) that is known to be strongly correlated with sideroxylonal in eucalypts (Lawler *et al*., 2000). Cineole is reported to have anti-microbial and anti-inflammatory properties and it is possible that while higher levels of these phenolic compounds are toxic and cause nausea, low levels are tolerated and may be important for maintaining the health of possums.

Variations in phenolic compounds may be related to site and seasonal conditions as drought and increased nutrient stress have been related to increased leaf toxicity (Gershenzon, 1984). As plants become more depleted in nitrogen, a greater proportion of carbon produced is directed to producing secondary defence compounds (Mattson, 1980). Increasing soil nitrogen levels through fertilisation has reduced the level of phenolic compounds in a wide variety of plants (Mattson, 1980). Possums selectively browsed on eucalypt seedlings that had been irrigated with a fertiliser solution rather than those which had been irrigated with water alone (Landsberg, 1987). It is likely that peppermints growing in well watered and fertilised urban parks and gardens in the Bunbury to Dunsborough region are producing both higher foliar nitrogen levels and lower foliar levels of browsing deterrent chemicals than those in natural settings which could explain the high abundances observed in these areas.

- ❖ Ringtail possums use smell as a cue to detect and avoid foliage with higher levels of phenolic compounds that cause nausea.

7.2 Moisture requirements and heat stress

Most ringtail species are traditionally associated with higher rainfall areas and more mesic habitats and rainforest environments (Van Dyck and Strahan, 2008). Ringtail possums obtain most of their water requirements from their foliage diet, but will drink water when affected by heat stress. They appear to be particularly susceptible to heat stress and die during periods of high daytime temperatures (Pahl, 1987; Jones *et al*., 1994b).

The recent significant decline in WRP population in the inland areas and apparent contraction to the coastal areas may be a response to climate change over the last thirty to forty years that has seen a decrease in annual rainfall of 30% and a warming trend. While WRP are likely to be responding to changes across a range of interrelated bioclimatic factors, attributes of moisture and temperature and the interactions between these factors are expected to be among the most important. WRP may benefit from the cooler, moist environment that is available during the critical summer period on the coastal plain and the shady micro-climate provided within the dense canopy of peppermints and shrubs to maintain their body temperature. Thermoregulation and maintenance of body temperature within the thermoneutral zone are important for survival and this is achieved by behavioural or physiological mechanisms (Frappell and Mortola, 2000).

Ringtail possums without access to water and at temperatures above 30ºC lick their forearms to enhance evaporative cooling but are intolerant of ambient temperatures above 35ºC with constant licking and high evaporative water loss (Pahl, 1987; Yin, 2006). During a period of very hot weather in 1991, an unusually high number of WRP were presented to wildlife carers in the Busselton area (Jones *et al*., 1994b). Many of these animals had been observed trying to access water and all drank water at first offering and most recovered within 12 hours. Ellis and Jones (1992) provided water to captive WRP in their studies and reported that some possums drank regularly while others did not appear to drink.

Body temperature (Fig. 3), thermal conductance and evaporative water loss in WRP are known to increase with increasing ambient temperature while metabolic rate decreases to reduce overheating (Yin, 2006). At low ambient temperatures, WRP increase their metabolic rate to increase body temperature. There was a significant increase in evaporative water loss (licking of fur and panting) between 25°C and 32.5°C at a time when water produced through food oxidation decreased (lower metabolic rate), leading to an unfavourable water balance. At temperatures above 35°C, animals were not extracting enough oxygen from the air, possibly due to excessive panting (Yin, 2006). These studies indicate that although WRP appear to have a relatively broad thermoneutral zone, they are unable to cope with high temperatures at or above 35°C.

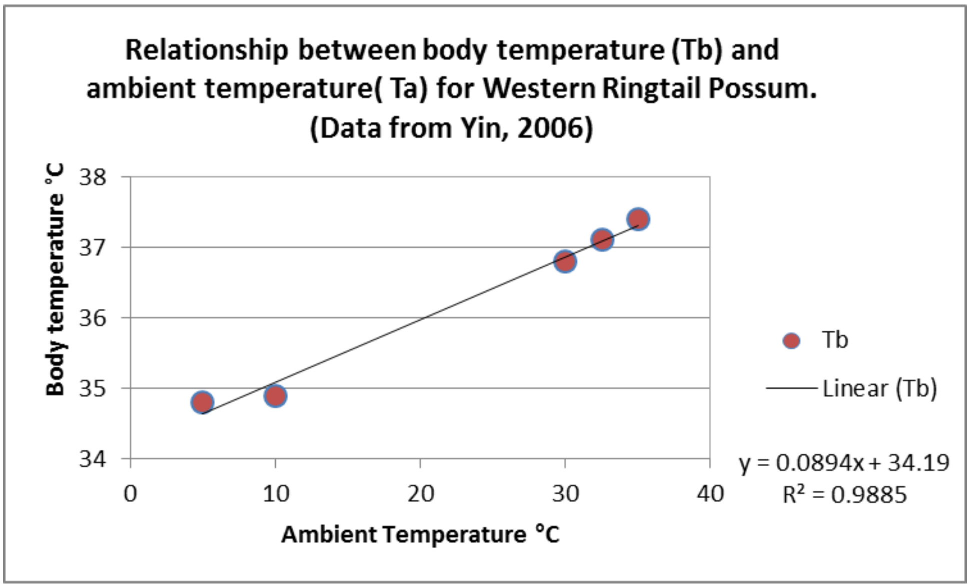


Figure 3. Graph showing the relationship between ambient temperature and body temperature in western ringtail possums in controlled temperature metabolic chambers (data taken from Yin, 2006).

Consideration should be given to these physiological requirements of the WRP when identifying suitable habitat for the species. They may only be important for a couple of weeks each year but with increasing temperatures and aridity in the south-west of Western Australia with climate change (BOM, 2013) it is likely that the availability of suitable habitat may contract even further. From the available WA Bureau of Meteorology records, the number of days with maximum temperature equal to or above 35°C during 2000 to 2013, varied from 10 at Cape Leeuwin to 255 in Donnybrook (Table 1). These data suggest that the coastal and more southerly areas have fewer hot days.

Table 1. Data from the Western Australian Bureau of meteorology website for weather stations in the south-west showing the total number of days at, or above 35°C during the period January 2000 to March 2013, and the mean annual number of these days.

Weather Station	Station Number	Total No. days ≥ 35°C	Mean annual No. days ≥ 35°C
Cape Leeuwin	9518	10	0.8
Cape Naturalist	9519	45	3.5
Manjimup	9573	118	9.1
Bunbury	9965	152	11.7
Busselton Aero	9603	172	13.2
Bridgetown	9617	183	14.1
Donnybrook	9534	255	19.6

These data suggest that Busselton (the Aero site is about 8km inland) has more hot days than Manjimup which may be due to Manjimup being elevated (about 300m above sea level) and having greater cloud cover and a cooling influence from the southern ocean. Manjimup also has a higher mean annual rainfall (1002mm) than Busselton (815mm). Although Perup Nature Reserve, which is 40km east of Manjimup, has a lower rainfall (700mm) and lower elevation (220–280m) than Manjimup, it seems unlikely that climatic factors alone have caused the massive decline in populations in the upper Warren region. The fact that WRP are doing well in the Busselton area despite having more than 13 days per year over 35°C (Table 1) indicates that other factors are allowing them to survive and attain high population densities. This climate data also suggests that the Cape Naturaliste to Cape Leeuwin region may be more suitable for future translocations than areas north of Bunbury.

During hot weather, WRP will either need to have safe access to drinking water, confine themselves to thick canopy with shade or find well insulated hollows or other protection to sleep or rest in during the hottest part of the day.

A hotter and drier climate will also affect the availability and quality of browse for possums as plants grow more slowly and produce fewer young shoots with more open canopies. Streams are also drying up earlier in the season resulting in less surface water being available during times of heat stress (Kinal and Stoneman, 2012; Silberstein *et al*., 2012). A more comprehensive assessment of climate change and the implications for the conservation of WRP across the species range would be beneficial.

- ❖ WRP are affected by heat stress when the temperature is above 35°C and require access to water and dense shade or hollows to rest. A drying, warming climate is also likely to alter the habitat on which they depend.

7.3 Reproduction and genetics

7.3.1 Breeding parameters

Western ringtail possums reach maturity at about 830–1000g body weight (Ellis and Jones, 1992; Jones *et al*., 1994b). Young possums were found to spend about three months in the pouch and emerge at 130–150g body weight, and lactation ceased after six to seven months when young weighed 550–650g (Jones *et al*., 1994b). Most young are born during winter (April–June) with a second peak in spring (October–November) but some populations breed all year around (Jones *et al*., 1994b; Wayne *et al*., 2005b). Breeding in inland areas is more seasonal and most young are born during May–June (Wayne *et al*., 2005b). Detection rates are greatest during spring (Oct–Apr) with an October peak in the Kingston area coinciding with weaning and maturation of young (Wayne *et al*., 2005c).

Births are usually single but twins are not uncommon in the Busselton area. At Locke Nature Reserve, 17% of females captured with pouch young had twins, and three other pairs of dependent young twins were observed, but none of the females captured at Abba River had twins (Jones *et al.,* 1994b). In populations north of Bunbury, offspring productivity was highest in July with 88% of females having pouch young (Clarke, 2011). Two females examined had pouch young and an accompanying juvenile at the same time, while 15% of females carried twin pouch young. Annual productivity in this population was 1.04 pouch young per female examined (Clarke, 2011).

Weaning of young in inland areas coincides with emergence of young jarrah leaves (Wayne *et al*., 2005b) while weaning coincides with higher foliar nitrogen concentrations in peppermints in coastal areas (Jones *et al*., 1994a). These growth flushes in the preferred diets may also stimulate breeding in the adult females. In captivity on a varied and nutritious diet, one female raised four single young in rapid succession within the first two years of maturity (Ellis and Jones, 1992), a breeding rate closer to the fecundity of the common ringtail possum (Pahl and Lee, 1988). These observations suggest that fecundity, as well as seasonality of breeding may be limited by nutrition (Wayne *et al*., 2005b), particularly in inland areas where WRP have lower quality browse and larger home ranges. This may also explain variations in abundance and habitat preferences in coastal areas.

The sex ratio of pouch young is mostly 1:1 (Ellis and Jones, 1992; Jones *et al*., 1994b; Wayne *et al*., 2005b) but at Locke Nature Reserve in the early 1990s there was a female bias in young and adult age classes (Jones *et al*., 1994b; Jones *et al*., 2004). Regrowth of peppermint trees ten years after fires in the early 1980s was thought to have contributed to the higher proportion of females at this reserve due to the presumed higher quality browse. The female sex bias was suggested to be indicative of an expanding population while a male bias may indicate a declining population or marginal habitat conditions (Jones *et al*., 2004). Growth rates of young were also higher at Locke Nature Reserve than at Abba River (Jones *et al*., 2004). However, there was no sex bias evident in young born to well-fed captive WRP, which had a similar growth rate to those at Locke Nature Reserve (Ellis and Jones, 1992; Jones *et al*., 1994b).

Body condition index of adult WRP in inland populations was found to be poorest in autumn and winter, when young are born, and greatest in late spring and summer when most young are weaned, and may be synchronised with environmental seasonality, including jarrah leaf growth (Wayne *et al*., 2005b). However, coat condition was better in autumn and winter during the coldest months and the main breeding season, than in spring and summer.

The oldest age observed for WRP in jarrah forest was estimated to be four years old from tooth wear scores and it is assumed that the average age is three years, rarely exceeding four to five years (Wayne *et al*., 2005b). However, the species has been recorded to live more than six years (de Tores, 2008; van Dyck and Strahan, 2008).

Mortality rates of wild and translocated WRP are high and are mainly attributed to fox predation (Jones *et al*., 1994b; Wayne *et al*., 2005b; Clarke, 2011) although other predators (cats, pythons, chuditch, raptors) can have a large impact (de Tores *et al*., 2005b; Wayne *et al*., 2005b; Clarke, 2011). In the Perup Nature Reserve, the annual adult mortality rate was 46% with 84% of deaths between April and September, often in pulses where multiple mortalities were observed over one or two weeks (Wayne *et al*., 2005b). Most of these deaths (81%) were due to predation with most being killed by foxes or cats, but some were attributed to raptors and chuditch. However, seasonal periods of high mortality and poor body condition coincided with periods of low or no leaf growth of jarrah and may be related to a loss of fat reserves during autumn (Wayne *et al*., 2005b).

In a translocation trial north of Bunbury, survival of WRP at three sites was lower than found in inland areas with models indicating that annual survival rates were 9–16% (mortality rates of 84–91%) (Clarke, 2011). Most deaths were attributed to predation (56–60%) but the identity of the predator species, other than python, was not clear. It was also difficult to differentiate between primary predation and secondary scavenging. These survival rates were considered to be too low to maintain a stable population given the three to five year life expectancy of this species (Clarke, 2011).

Wayne *et al*. (2005b) proposed that anything less than 100% survival of WRP young through to maturity in the jarrah forest may be profound given the annual fecundity rate of one young per mature female and a relatively short life span. A female needs a minimum of two successful reproductive seasons (i.e. reach three years of age) and 100% survival of offspring to maturity to maintain population size (Wayne *et al*., 2005b). Anything that reduces offspring survival or female life expectancy may threaten the viability of a population.

- ❖ WRP have a short life span with a low reproductive output. High mortality rates, mainly due to predation, can lead to a declining population trend. Mortality is higher in lower quality habitats and when possums are stressed.

7.3.2 Habitat fragmentation and genetic differentiation

The area of remnant vegetation available for WRP habitat in the southern Swan Coastal Plain has been greatly reduced due to clearing for agriculture, mining and urban development. This has reduced the overall carrying capacity for WRP and limited connectivity between individuals, groups and sub-populations and the opportunities for sustaining a demographically and genetically viable population in the short to long term.

Reducing patch size and increasing isolation between patches can have immediate effects by reducing the effective population size and the movement between populations (Frankham, 1996, 1997). Fragmentation of the habitat can also lead to isolation of populations and reduced gene flow leading to a decline in genetic diversity and inbreeding which can threaten the long term survival of a species. Variations in genetic structure are related to the social structure, dispersal characteristics and spatial structure of the species. Translocation of WRP within the coastal populations may possibly have reduced the impact of habitat fragmentation through artificial gene flow (Wilson, 2009).

- ❖ Fragmentation of habitat can lead to isolation of populations, reduced population size and genetic decline. Maintenance of effective meta-population size through retention of adequate habitat area and connectivity is important for maintaining WRP genetic diversity and population viability.

7.4 Hollows, dreys and rest sites

7.4.1 The use of hollows and dreys

Western ringtail possums are active at night and need to shelter during the day. They use a variety of shelters including tree hollows and forks, dreys, grass trees (*Xanthorrhoea* spp.), hollow logs, rabbit burrows and forest debris (de Tores *et al*., 2005a; Wayne, 2005; Clarke, 2011). In inland areas, tree hollows are more commonly used while in coastal areas, hollows may be used in tuart forest and dreys in peppermint woodland (Ellis and Jones, 1992; Inions *et al*., 1989; Jones *et al*., 1994a; Jones and Hillcox, 1995). However, dreys are used in some dense habitats in jarrah forest (Wayne, 2005), indicating that vegetation structure may determine the different shelter types used by WRP.

Dreys are constructed from flexible twigs and foliage and are attached to branches of trees or shrubs in usually dense vegetation (Ellis and Jones, 1992). Nest materials include peppermint foliage, bracken fern fronds, creepers and sedge leaves. The average height of dreys varied from 1.6m at Two Peoples Bay where they were built in shrubs in the understorey, to 5.4m at east Augusta where they were built in trees with sedge and bracken understorey (Ellis and Jones, 1992). Dreys break down over time or are abandoned but have been known to persist from 6 to 38 months, although a new drey may be re-built in the same position as an old one. WRP may occupy around 40–46% of dreys present, usually by a single male or female, or a female and her young (Ellis and Jones, 1992).

Shelters and nest sites need to provide protection from the effects of high ambient temperatures and from a variety of predators, both introduced and native, and attacking either from the ground or air. Tree hollows have an advantage in providing better insulation against excessive heat than dreys (Pahl, 1984), but possums may be more prone to attack from pythons and large goannas in hollows. Dreys built in thin branches can vibrate easily when disturbed and this may give resident possums early warning of approaching predators (Russell *et al*., 2003). Dreys built in open or recently burnt vegetation would be more exposed to heat than those built in dense vegetation (Russell *et al*., 2003) and would be more visible to predators. The common ringtail possum appears to be dependent on eucalypt hollows in cold environments (e.g. snow gum) in the eastern states and this may also be a factor in nest site selection for the WRP in inland areas in Western Australia.

Across a range of sites in the south-west, relative abundance of WRP was best described by a model that included foliar nitrogen concentration and a measure of hollow abundance (Jones *et al*., 1994a). In that study, dreys were abundant only in coastal peppermint forest and were rare or absent in more inland sites. At Ludlow, in the Tuart Forest National Park north of Busselton, the rate of sighting of WRP was correlated with the abundance of peppermint trees and with the presence of hollow-bearing trees (Jones and Hillcox, 1995) although peppermint trees rarely have hollows (Jones *et al*., 1994a). It appears that in tuart forest, WRP will use eucalypt hollows whereas in peppermint dominated forest, they build dreys due to the absence of hollows.

At Yalgorup National Park, dreys and branch forks were used more frequently in areas dominated by peppermint, whereas grass trees (*Xanthorrhoea preissii*) were used where this species was most common (de Tores *et al.,* 2005a; Clarke, 2011). However, at one site, where large individual tuart trees were scattered throughout the peppermint dominated forest and grass trees were common in the understorey, WRP commonly used tree hollows and grass trees as rest sites rather than dreys. Other refuges included forks in *M. rhaphiophylla* and *Banksia* spp*,* and 'witches brooms' in *Spyridium globulosum.* There was a preference for larger diameter (0.8–1.1m diameter at breast height) peppermint trees where these were used for resting and foraging (Clarke, 2011). Overall, rest site usage was dynamic with 3 to 15 different rest sites used per possum over time (Clarke, 2011). Dreys were built and used more by females than males in three of four locations, suggesting that drey building may be associated with the rearing of young (Clarke, 2011).

WRP also used grass trees in the Perup Nature Reserve (Wayne *et al.*, 2000). Most of the grass trees occupied were greater than 2m tall with multiple heads and long thick skirts of dead leaves in which the possums nested. The concealed forks between heads were also used for resting. Grass trees have similar insulation properties as hollows used by WRP. It was estimated that ambient temperatures would need to reach 53ºC or 47ºC before a WRP became heat stressed inside a grasstree or a tree hollow, respectively (Driscoll, 2000).

It seems likely that the choice of shelter sites is determined not only by the vegetation structure present but by the physiological requirements of the possums and by the type and abundance of predators. Other factors such as fire regimes and drought may also affect the availability of shelter sites.

- ❖ WRP use a range of nest and shelter sites to avoid predators and exposure to the weather. Dreys are constructed in the canopy if hollows are not available. Adequate nest and shelter sites are necessary components of good quality habitat.

7.4.2 Impacts of fire on hollows and dreys

Fire regime can have a significant impact on habitat value, mainly during and for some time after the event until the vegetation recovers. Tree hollows, dreys and grasstree skirts are often destroyed by bushfires although fire can also increase the number of available hollows for possums (Inions *et al*., 1989). The impact of fire can be on immediate survival of possums during the fire as well as in the period after the fire until food resources, vegetation structure and protection from predators are restored (Russell *et al*., 2003).

Low to mild intensity fire within a habitat patch that results in a patchy mosaic of burnt and unburnt vegetation with minimal crown scorch may have less impact on habitat value. Tree hollows may provide protection for possums during lower intensity bushfires and prescribed burns in eucalypt forests, however, dreys built in lower spindly branches and shrubs are usually consumed by most fires (Russell *et al*., 2003). In the inland Kingston area, relative abundance of WRP was positively associated with sites subject to very low fire intensity or those that had not experienced fire for at least 20 years (Wayne, 2005; Wayne *et al*., 2006).

Another study of 37 sites in the Busselton area, using WRP scat scores to estimate relative abundance, found similar results (Molloy *et al*., unpublished data). They found that relative abundance of WRP was around 60% (n=19) in sites with fuel age greater than 20 years compared with around 37% (n=17) in sites with fuel age less than 20 years. These fuel ages were estimated from bark scorch, charcoal and litter depth rather than spatially captured fire scar mapping.

Few fires have been experienced in the peppermint dominated forests along the coastal urban fringe in the Busselton area in the last 50 years so the impact of fire may have been avoided in this habitat. Fire-scarred trees were much less common in coastal areas (0.05% of trees scarred) where the forest was dominated by peppermint, than in inland forests where peppermint was a minor component or was absent (70% of trees scarred) (Jones *et al*., 1994a).

- Fire has short-term and long-term impacts on possums through direct mortality, increased predation and loss of suitable habitat for foraging and building nests or shelters. Areas that are protected from high fire intensity for at least 20 years are required to provide high quality habitat for WRP.

These findings show that tree hollows are important for WRP, but that dreys and other rest and nest sites may suffice where they can be built in dense vegetation and where threats of predation and fire are reduced. Synergistic effects of climate, predation and fire as well as habitat fragmentation can alter the suitability of various habitats and these interactions need to be considered together for the management and conservation of this species.

7.5 Predators

Widespread presence of introduced foxes and cats has been linked to marsupial declines and active suppression in many populations of small to medium sized fauna species (Burbidge and McKenzie, 1989; Abbott, 2001b, 2002; Short *et al*., 2005; Johnson, 2006).

Fox predation is one of the main threats and causes of mortality to WRP, which have been reported as being particularly naive to predators (de Tores *et al*., 2004; Wayne, 2005). Predation may also be greater for WRP if they are hungry, stressed and weakened due to hot and dry weather conditions, sub-optimal habitat conditions, when dispersing over long distances (Clarke, 2011) or following fire, logging or translocation disturbances. Predation of WRP in coastal areas is also attributed to native south-west carpet pythons during summer months and raptors (Clarke, 2011), while chuditch and wedge-tailed eagles accounted for a significant number of WRP in the Upper Warren (Wayne, 2005).

Fox control is known to increase the abundance of common brushtail possum which may compete with WRP for foraging areas and nesting hollows. Control of foxes may also lead to an increase in the abundance of feral cats and pythons due to meso-predator release (Christensen and Burrows, 1994; de Tores *et al*., 2008). Cat predation was a significant cause of mortality in translocated WRP north of Bunbury, particularly at Leschenault Peninsular Conservation Park; however it was often difficult to distinguish between fox and cat predation (Clarke, 2011). This area was identified as a priority site for control of feral cats using newly developed cat bait Eradicat® (de Tores *et al*., 2008). Decreased rabbit control has been associated with an increased abundance of foxes (King *et al*., 1981). On the other hand, increased rabbit control by baiting, myxomatosis or calicivirus may also lead to increased predation of WRP due to prey switching by foxes (Clarke, 2011).

At Locke Nature Reserve west of Busselton foxes were abundant in the 1980s and early 1990s (Lambert, 1985) and were baited during this time (Jones *et al*., 2004). However, fox predation in this reserve was considered to have a limited impact on WRP due to the continuity of the dense peppermint canopy (Jones *et al*., 2004). Dense canopies allow WRP to forage within the canopy for a greater proportion of time without having to cross the ground where they are more prone to predation from foxes, cats and other predators (Jones and Hillcox, 1995; Wayne *et al*., 2006; Clarke, 2011). Dense canopy may also provide greater protection from raptors and owls when WRP are foraging or resting in dreys.

The survival of threatened fauna species in some inland reserves, including Perup Nature Reserve, and the Upper Warren is thought to be due in part to the abundance of heart-leaf poison (*Gastrolobium bilobum*) which contains the same chemical (sodium mono-fluoroacetate or 1080) that is used in fox baits (Christensen, 1980; Short *et al*., 2005). Higher relative abundance of WRP in this area was also associated with a high level of fox control; however other factors were involved, including fire intensity, logging age and aspects of fragmentation (Wayne *et al*., 2006).

In urban areas, predation by dogs can also be significant. Many of the injured WRP taken to vets in the Busselton area have been attacked by domestic dogs (B. Masters, personal communication). To reduce this impact, the City of Busselton has recently changed its regulations for backyard fences in some new subdivisions to be built to 2.1m tall so that large dogs cannot reach up and take WRP that are using the fences as linkages between habitat patches. Other special restrictions on cat and dog ownership in areas adjoining certain reserves or areas of known habitat have been considered to encourage more responsible dog and cat ownership (NGH Environmental and Ecosystem Solutions, 2009).

There has been little focus on monitoring fox or cat abundance, or their interactions, until recently. Monitoring is required in baited and unbaited areas to determine the effectiveness of baiting programs and to assess seasonal and long term trends in predator abundance (de Tores *et al.,* 2004).

Similarly there has been little focus on assessing the attributes of different vegetation types that facilitate protection to native fauna from introduced predators. Methods for assessing the protective value of different vegetation types need to be developed and tested.

- ❖ Predation by foxes and cats is a major threat to WRP, the impact being greater when possums are stressed and in habitat types that provide inadequate protection.

7.6 Home range and dispersal

WRP home ranges for established animals in the Busselton area are small and vary from around 0.5 to around 5ha, being smaller in high quality habitat and larger in the drier inland forests (Jones *et al*., 1994b). Home ranges are likely to reflect resource availability and could vary with vegetation density, nutrient quality and floristic diversity but other factors such as social interactions and inter- and intra-specific competition are indicated (Clarke, 2011).

WRP are relatively solitary animals, except during mating or when accompanied by a juvenile. In one study in the Busselton area, no excursions were made from the home range by adults while sub-adults made short excursions from the natal range (Jones *et al*., 1994b). Most overlap in home ranges was between mother-daughter pairs. Female home ranges averaged 0.44ha (0.07–1.0ha) at Abba River and 0.28ha at Locke Nature Reserve, compared with 2.4ha at Yendicup in the inland Perup Nature Reserve (Jones *et al*., 1994b). By comparison, male home ranges at Abba River averaged 0.28ha (0.16–1.9ha). In an urban area near Busselton, home ranges were estimated to be 0.36ha for females and 1.12ha for males (Love, 2011).

In a translocation trial north of Bunbury, using animals displaced or rehabilitated from the Busselton area, home ranges (estimated from kernel-derived areas enclosed by the 90% isopleth) for translocated female WRP ranged from 0.2–4.8ha at Leschenault Peninsular Conservation Park, and 0.5–2.2ha at Martin's Tank in the Yalgorup National Park, with an overall mean of 0.5ha (Clarke, 2011). By comparison, the home range for translocated males ranged from 4.7–16.5ha at Leschenault Peninsular Conservation Park and 0.4–14.9ha at Yalgorup National Park, with an overall mean of 5.0ha. Male-female overlap was greater than male-male or female-female overlap in this study (Clarke, 2011). These are much larger home ranges than estimated for the Busselton area. This difference may have been due to the lower quality habitat in this northern area, but it may have also been due to released animals moving around the landscape to find more suitable habitat, find a mate or avoid interactions with other established possums.

After translocation, some radio-collared adult male and female animals moved long distances from their release sites, possibly to find better quality habitat or a mate (Clarke, 2011). One female released in Leschenault Peninsular Conservation Park travelled 2.5km over a 24 hour period, while a male released at Martin's Tank in Yalgorup National Park travelled 6.5km south and spent six weeks at an isolated farmhouse near a dam surrounded by peppermint and tuart trees before moving again (Clarke, 2011). Another female stayed 4.5 months near her release site, then moved 2.3km away after the loss of her juvenile offspring, possibly to find another mate.

Some established resident adults may also move significant distances to establish new territories elsewhere, although the reasons for these movement may not always be clear. For example, in a radio-telemetry study involving 29 radio-collared individuals in the Kingston area (Wayne *et al.* 2000), two adults independently moved through contiguous native habitat to relocate 3–5 km from their original territory (A. Wayne, unpublished data).

The total area of habitat required to sustain a population of WRP will depend on the carrying capacity of the habitat patches. It is not known if the fragmentation of suitable habitat has caused higher concentrations of possums within small patches around Busselton due to limitations on dispersal, or if other factors associated with urban and semi-urban development allow higher densities and smaller home ranges to be sustained, such as artificial linkages along fences and access to fertilised and watered parks and gardens with improved nutritional value of browse. However, WRP appear to reach a maximum carrying capacity above which animals disperse, possibly to avoid over utilising the resources (B. Jones, unpublished data).

- ❖ Home ranges for WRP are smaller in resource rich areas and are smaller for females than males. WRP are usually sedentary but can disperse several kilometres to find better habitat or a mate. This has implications for optimal minimum patch size and connectivity.

7.7 Connectivity of vegetation

Dense vegetation provides some physical protection and a refuge from predators and has been shown to be important for the persistence of a number of mammal species in the south-west of Western Australia including quokka, brown bandicoot and tammar wallabies (Christensen, 1980; Sinclair and Morris, 1995; Short *et al*., 2005). Fire, logging and grazing can dramatically reduce the understorey cover and result in increased fox predation (Christensen, 1980; Jones *et al.,* 2004; Wayne *et al.*, 2006).

Density of vegetation and connectivity between trees or clumps of trees can be important habitat factors when predators are threatening WRP. Attributes such as canopy connectivity, mid-storey height and cover, tree diameter, crown senescence and species can all affect refuge selection in jarrah forest (Wayne, 2005). Changes in vegetation structure following logging in jarrah forests resulted in WRP travelling and denning more frequently on or near the ground where they were more vulnerable to fox and cat predation (A. Wayne, unpublished data).

Jones *et al.* (1994a) found that inland forests without peppermints present and occupied by WRP had low continuity of the upper canopy and mid-strata with an average of 1.3 canopy connections per tree, whereas coastal forests with peppermint as the dominant species had relatively continuous canopies or mid-strata with an average of 3.3 canopy connections per tree. The higher level of canopy continuity combined with higher foliar nitrogen concentrations in the peppermint forests, were associated with higher abundance of WRP (Jones *et al.* (1994a).

Coastal peppermint forests have been grazed and degraded by cattle since early settlement and this has impacted on the level of understorey present, with shrubs often being replaced by grasses or sedges. However, many remnants of dense peppermint forest around the Busselton area with a degraded understorey of coastal sword sedge (*Lepidosperma gladiatum*) or arum lily (*Zantedeschia aethiopica*) are occupied by WRP. In fact, the highest densities of WRP are found around Busselton in small urban parks with short mown grass as the understorey (G. Harewood, unpublished data). This suggests that the presence of dense understorey may not be so important to WRP where the upper canopy is continuous and provides adequate food resources and protection.

In an earlier assessment of habitat suitability in the Bunbury to Dunsborough area, relative abundance of WRP (assessed from scat scores) was unrelated to canopy cover of trees (<10m or 10–30m tall) and was negatively related to canopy cover of shrubs <1m tall, with highest scat scores found where there was no shrub canopy

(Molloy *et al*., unpublished data). Canopy cover in this study was based on simple quadrat-based scoring of cover (0–4) of the different vegetation strata. This suggests that either WRP do not favour vegetation types with a shrub layer in the Busselton area, or that scats were possibly less visible in areas with greater canopy cover.

Vegetation density, canopy cover and canopy connectivity in these studies measure different attributes of vegetation that may not be comparable. In addition, spatial scales and methods used for measuring these attributes varied among studies. Clearly, different vegetation structural attributes are associated with habitat suitability in different vegetation types and locations.

During other surveys, active dreys were found in isolated paddock trees up to 300m from the nearest patch of remnant vegetation near Busselton, suggesting that the possums had traversed open paddocks to reach these habitat trees (K. Williams, personal communication). In these studies there was no assessment of the predator population so it is not known if the possums moved more freely across open ground because they were under low threat from predation, or if the habitat trees were highly sought after and this outweighed the potential risk of predation. Other examples of WRP traversing significant patches of open ground have been observed north of Bunbury at translocation sites where possums were attempting to establish new territories, but these were associated with high levels of predation (Clark, 2011).

It appears from the above studies and observations that canopy connectivity may be a more important attribute of suitable WRP habitat than vegetation density or canopy cover in the Bunbury to Dunsborough area, but this is likely to depend on the quality of the browse on offer, the need to disperse and the level of predation.

- ❖ Canopy connectivity, canopy cover and vegetation density are important aspects of habitat suitability for the WRP but their relative importance may vary with vegetation type and predation pressure. Where possums need to disperse to access alternative habitat, they will travel over open ground but this greatly increases the risk of predation.

7.8 Diseases

Sudden declines in WRP populations have been recorded in the Upper Warren since about 1998 (Wayne *et al*., 2005, 2012) and in a translocated population at Leschenault Peninsular Conservation Park between 1998 and 2000 (de Tores *et al*., 2004; de Tores *et al*., 2005b). Although there is no direct evidence of disease being a limiting factor, there is anecdotal evidence of widespread disease-like mortality following European colonisation (Abbott, 2006; 2008).

Health screening of WRP pre-and post-translocation found no evidence of infectious diseases (toxoplasmosis, leptospirosis, salmonellosis and chlamydiosis), that have been reported in other wild marsupials in Australia and that are capable of causing reductions in survival and reproductive capacity, particularly when associated with stress (Clarke, 2011). Body condition in WRP was negatively correlated with endoparasite levels (nematode and tapeworm eggs) but not with ectoparasite levels (mites, fleas and ticks). Differences were found between a number of pre- and post-translocation haematological values suggesting that the habitat quality or nutrient intake was lower at the translocation sites than at the original sites (Clarke, 2011). These differences indicated that translocation to poorer quality habitats, or the stress of translocation itself, may have reduced the possums' health status and possibly affected their survival, or made them more predisposed to predation.

- Disease occurrence in WRP can be related to stress from occupation of poor quality habitat. Optimal habitat needs to be identified for retention of existing populations and potential translocation sites.

7.9 Interactions with common brushtail possums

The south-western subspecies of common brushtail possum (CBP) (*Trichosurus vulpecular hypoleucus*) and the western ringtail possum (WRP) are the only arboreal browsing marsupials in the south-west of Western Australia. The two species share many habitats and have a similar distribution (Van Dyck and Strahan, 2008). However, CBP are larger (2–3 kg) and more aggressive and may limit the ability of WRP to occupy some habitats, particularly when food and shelter resources are spatially or temporally limited.

The digestive tract of the CBP is not as specialised as the WRP and they require a more varied diet to obtain adequate nutrition. CBP mostly eat leaves, but flowers and fruits can make up 50% of their diet (Van Dyck and Strahan, 2008). They have been observed feeding on leaves of peppermint, tuart and acacia (Clarke, 2011) which are the main diet of the WRP in coastal areas. Some overlap in habitat usage was also found in the Tuart Forest National Park north of Busselton, where 90% of all sightings of WRP were in peppermint and 5% in marri, whereas 43% of all CBP sightings were in peppermint, 26% in tuart, 14% in marri, 6% in jarrah and 4% in banksia (Jones and Hillcox, 1995). CBP are deterred by most tannins, but can tolerate very toxic leaves including those of *Gastrolobium* spp., which contain the poison sodium mono-fluoroacetate (1080) (Van Dyck and Strahan, 2008), and this may confer some resistance to predation for this species (Short *et al*., 2005).

CBP use tree hollows almost exclusively where they are available, and are generally not found in peppermint forest unless eucalypts are also present (Jones *et al.,* 1994b). At one site in the Leschenault Peninsular Conservation Park, which had no tuart trees and was dominated by peppermint trees, disused rabbit warrens were the most common den sites (96%) for CBPs and hollows were rarely used (4%), although these CBP were found to be in poor health (Clarke, 2011). CBP also use hollow logs, rock cavities and, like WRP, inhabit roof spaces in houses.

In a trial north of Bunbury, survivorship of translocated WRP was negatively related to the population size of resident CBP at the release site, which indicated that either the prime habitat for CBP was less suitable for WRP or that there was direct competition between the two species for rest sites or home ranges (Clarke, 2011). Overlap of home ranges of the two species has been recorded with some hollows used by both species on different occasions indicating a potential for inter-specific competition (Wayne, 2005; Clarke, 2011). At one site where the main vegetation type was dominated by peppermint, 98% of the home range of both possum species was within this vegetation type (Clarke, 2011). At another site with mixed tuart and peppermint habitat, 72% of WRP home ranges were in the peppermint dominated forest and 27% in the mixed forest, whereas only 4% of CBP home ranges were in the peppermint dominated forest and 96% were in the mixed forest. These findings show clear habitat partitioning between the species where the landscape contains a range of vegetation types.

There have been observations of CBP evicting WRP from tree hollows (Wayne, 2005, K. Williams, personal communication); however WRP generally select smaller hollows (Wayne, 2005; Clarke, 2011) potentially to avoid this competition.

- ❖ Common brushtail possums can compete aggressively with WRP for tree hollows and browse where their ranges overlap, but their habitats are often separated. The apparent preference of WRP for peppermint dominated vegetation may be partly to avoid direct competition with CBP.

8.0 Assessment of potential habitat variables in the Bunbury to Dunsborough region

From the preceding review of WRP biology and ecology as it relates to habitat, a number of important habitat values were identified. In this section, spatially derived variables based on these habitat values are assessed, for which there was existing data coverage for the southern Swan Coastal Plain from Binningup to Dunsborough and east to the Whicher Range. A summary of the habitat variables used in this analysis is shown in Appendix 3. This review only covers native remnant vegetation as considered for the land clearing and development assessment processes. Patches of remnant vegetation within the urban areas are included in the assessment and modelling, but other urban habitats, such as private gardens are not considered, even though they may include native vegetation species and are known to be used by WRP.

Identification of habitat variables is required for modelling that aims to identify and classify areas of suitable habitat for WRP. This classification will assist the assessment process associated with land clearing to ensure adequate areas of high quality habitat are retained to support a nominal minimum population of 2,500 WRP in each WRP management zone in the southern Swan Coastal Plain.

8.1 Spatial scales of habitat – trees, patches and landscapes

It is evident that some habitat values are likely to be important at the tree scale, such as crown density and connections to neighbouring trees, or even within trees, such as the level of nitrogen and phenolic compounds, leaf moisture content and the dimensions of tree hollows. Others are significant within or between patches and vegetation types. For this review, only variables that could be measured using spatially derived metrics at the patch or landscape scale were considered, as these were more readily available for assessment for sites across the southern Swan Coastal Plain.

Small scale spatial or temporal variability in habitat suitability within soil-landform map units may determine the location of WRP home ranges and explain variations in WRP density. Some of this variation can be inferred from minor changes in soil type and landform position. For example, vegetation growing in swales in closer proximity to groundwater is likely to maintain higher foliar moisture and nutrient concentrations during summer than those growing in the nearby deeper sand dunes.

8.2 Habitat patch area

While it may be assumed that larger areas of remnant vegetation have greater habitat value than smaller areas, the fact that WRP occupy small patches within urban areas indicate that factors such as habitat quality rather than patch size may limit the suitability of many larger areas. However, patch size is still a useful parameter for determining potential WRP carrying capacity of the habitat.

For this modelling project, habitat patches were the polygons defined by the union of the remnant vegetation mapping, completed for the Bioplan Project (Webb *et al.,* 2009), and the soil-landform mapping (Tille and Lantzke, 1990; DAFWA, 2007; Appendix 2) within the area of interest using spatial geometric methods in ArcMap

9.2. All habitat variables were attributed to these polygons. The 12,276 habitat patches defined by the polygons in this review ranged in size from 0.25ha to 879ha, the larger areas being along the Whicher Range and truncated by the arbitrarily defined area of interest (Map 2). The total area of the polygons in the area of interest greater than and equal to 0.25ha was 72,571ha.

The minimum area of habitat patch was defined as 0.25ha, or four pixels (each 25mx25m) from Landsat imagery (or about 10–25 mature peppermint trees), to reduce errors associated with attributing some variables to small areas. This patch size also approximates the minimum home range for WRP in this coastal environment. A confidence metric based on the area and area to perimeter ratio (A/P) was applied to all polygons to identify which were too small or narrow to reliably contain a Landsat pixel and these were excluded from the analyses. Confidence level 1 was assigned to areas less than 0.25ha, level 2 was polygons with A/P ratio <16, and level 3 was polygons with A/P >16. Another 3,345 polygons with areas between 0.04 and 0.25ha were mapped but not classified. Boundaries between polygons of the same soil landform unit, and some narrow slivers less than 0.5ha that resulted from the different scales of capture of the soil-landform and remnant vegetation mapping were also dissolved to clean up the data and reduce errors.

Habitat patch area was also categorised to provide the Area_score variable to reduce the bias of the very large polygons:
Score 1: <0.25ha
Score 2: 0.25 – <1.0ha
Score 3: 1.0 – <10ha
Score 4: 10 – <50ha
Score 5: ≥50ha

The total area of all habitat patches within 1km radius of the centroid of each patch was also derived using the ArcMap 10.1 spatial analyst tool to provide a measure of neighbourhood habitat area, and this variable was called the Area_1km.

8.3 Habitat quality and dominance of peppermint

<u>8.3.1 Habitat quality score</u>
Soil and landform mapping provides information about the soil nutrient and moisture gaining and retention capacities of each map unit, which is relevant to plant growth and microclimate for possums, particularly during the critical summer months. This, combined with vegetation information, was used to determine the habitat quality attribute for each map unit.

From the preceding review of habitat in the Bunbury to Dunsborough region, the preferred native vegetation type is likely to be peppermint dominated forest, mixed tuart forest with peppermint, and shrublands with preferred foraging species, particularly fringing vegetation around wetlands with dense melaleucas, kunzeas and acacias. Vegetation types which have other nesting and refuge habitat values (e.g. other eucalypt species with tree hollows, grasstrees) or known foraging species were included in the analysis.

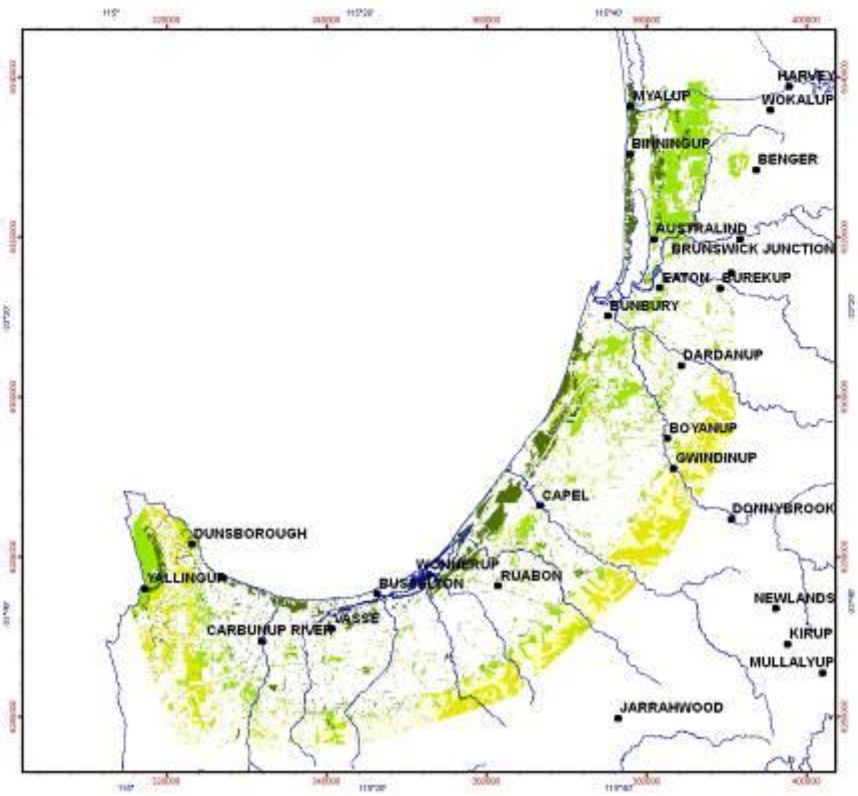
A habitat quality (HQ) score (0–4) was assigned to each map unit based on a combination of vegetation structure and floristic characteristics (0–2), and soil-landform characteristics (0–2), (Map 4):

Vegetation Score 0: Unsuitable vegetation, habitat species absent or minor
Vegetation Score 1: Some habitat species (nesting, refuge or foraging) present

Vegetation Score 2: Habitat species dominant

Soil-landform Score 0: Unsuitable soils or landform, (e.g. beach, surface water, exposed rock, hill tops, ridgelines, mud flats, saline or shallow soils)
Soil-landform Score 1: Mid slopes, dunes, low to moderate fertility soils
Soil-landform Score 2: Moisture gaining flats, swamps, valleys, lower slopes, higher fertility soils.

A brief description of the soil-landform map units and their attributed WRP habitat quality scores are shown in Appendix 2.



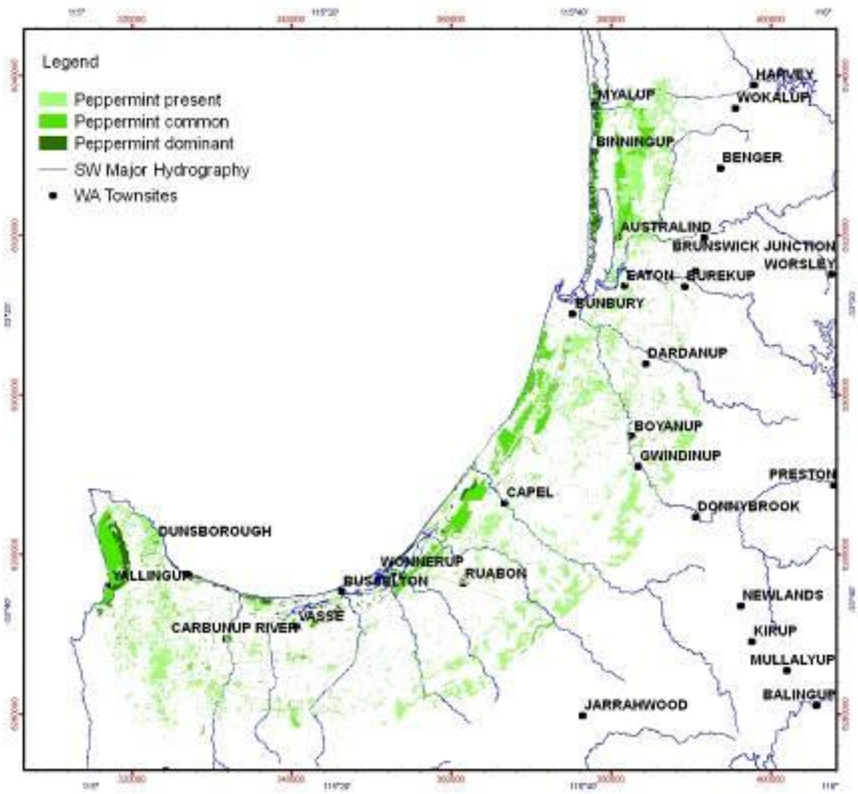
Map 4. Habitat quality of all polygons in the area of interest determined from vegetation and soil-landform data. [HQ4 – dark green; HQ3 – light green; HQ2 – dark yellow; HQ1 – light yellow; HQ0 – not shown].

<u>8.3.2. Presence and dominance of peppermint and tuart</u>
Floristic composition information was available from the soil-landform mapping (DAFWA, 2007) and from quadrat-based flora surveys conducted in the region over the last 20 years and other data collected and compiled during the Bioplan project (Webb *et al.,* 2009). The three dominant species in up to three units were recorded in many but not all remnants assessed during the Bioplan project. This information included presence and dominance of peppermint (*A. flexuosa*) and tuart (*E. gomphocephala*), but the species data was incomplete for the area of interest. Other data on the presence and dominance of peppermint was obtained during an earlier review of 147 remnants in the Busselton area (K. Williams, unpublished data). Tuart distribution and cover information was more reliably available from the Atlas of Tuart Woodlands (Government of Western Australia, 2003).

Peppermint is mainly associated with two soil-landform map units (Spearwood Dunes and Quindalup Dunes) but may be present in other map units across the southern

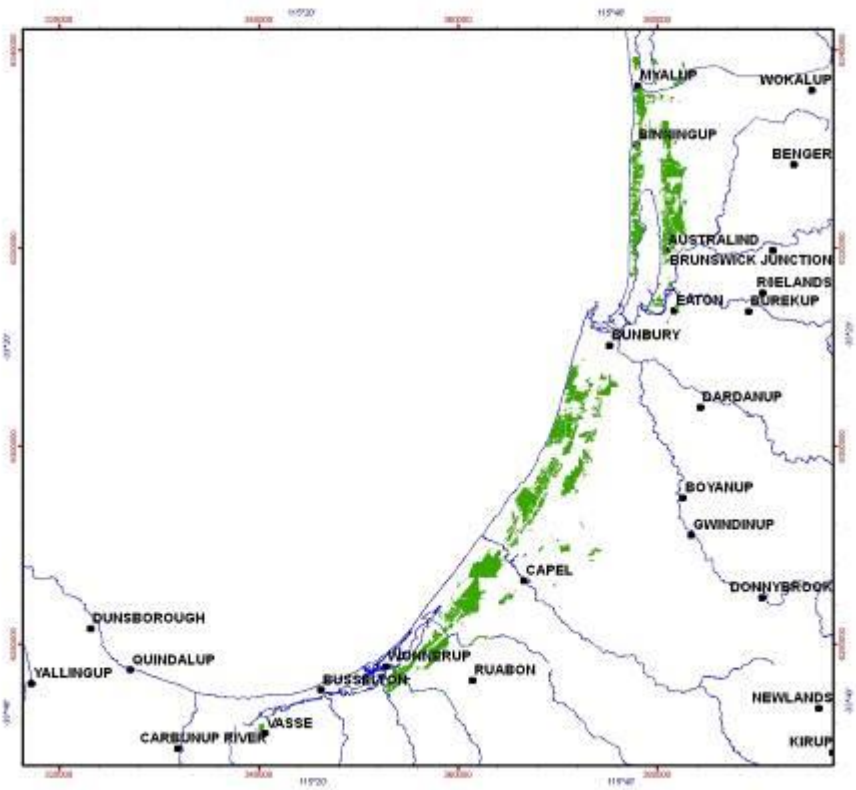
Swan Coastal Plain (e.g. Abba Plain, Whicher Scarp and Bassendean Dunes) (Map 5) (DAFWA, 2007; Webb *et al*., 2009). Where peppermint was recorded within several remnants of a map unit, its presence was inferred and attributed to remnants of that same map unit that lacked other vegetation information.

The presence and dominance of peppermint was used as a separate variable called Ago_flex to assess its importance as a habitat variable in this region:
Score 0: Peppermint absent
Score 1: Peppermint present in understorey
Score 2: Peppermint common in understorey
Score 3: Peppermint dominant



Map 5. Inferred distribution of peppermint (*Agonis flexuosa*) within the area of interest, attributed to each map unit for this project.

Tuart is associated with some of the same map units as peppermint, but its primary distribution is further north (Map 6). Tuart is more common on the deeper Spearwood dunes and less common on the Quindalup Dunes (Government of Western Australia, 2003; Webb *et al*., 2009). There is an area of overlap of peppermint and tuart distribution along the coastal strip between Busselton and Myalup in the area of interest (Maps 5 and 6). Tuart was assessed as being either present (Score 1) or absent (Score 0) and this habitat variable was called Euc_gom.



Map 6. Distribution of tuart (*Eucalyptus gomphocephala*) within the area of interest from the Atlas of Tuart Woodlands (Government of Western Australia, 2003).

8.4 Distance between patches

WRP are usually sedentary with relatively small home ranges. In good quality habitat, dominant females do not move far and are often accompanied by pouch young, but in mixed or poorer quality habitat, they can move several kilometers to find better patches. Males may have larger home ranges and disperse over greater distances to find mates or locate new habitat patches. Distance between patches may be an important limitation to the occupation of some otherwise suitable patches, due to the greater risk of predation of WRP in transit.

Distance to the nearest patch of native vegetation (edge to edge) called Dist_near, and distance to the nearest patch of high quality habitat (HQ4) called Dist_HQ4, were two parameters developed for the habitat modelling using the near table tool in ArcMap 10.1. If the patch itself was HQ4, then the distance was to the next nearest patch of HQ4.

8.5 Canopy cover and canopy trend

Canopy cover of the upper strata in areas of remnant vegetation is clearly important to provide possums with continuous access to foliage, and protection from predators when possums move between patches of preferred vegetation or disperse to other areas. Dense canopy cover in the upper and lower strata also provides more food resources per unit area and greater protection from heat stress. Canopy cover, which measures the area of ground projected to be covered by the tree (or shrub) canopy, provides some measure of canopy connectivity within a patch or polygon. In a fragmented landscape within an agricultural or urban setting, patches of vegetation that are linked together are of higher value and provide more protection than if the patches are isolated. Measures of patch isolation or connectivity are likely to be an important aspect of habitat suitability, but this is the subject of a separate report.

For this study, canopy cover and changes in cover over time (trend class) were estimated for patches of remnant vegetation using indices derived from Landsat satellite imagery at a scale of 25mx25m pixels. Using ER Mapper, canopy density classes were applied to the 2012 Landsat image based on a regression of known canopy density values from sample sites within the region (Molloy *et al.,* unpublished data) with mean vegetation index values (band3 + band5/2). The proportional area of pixels in each canopy class was determined for each polygon using ArcMap 9.2 and the mean value was used as the canopy cover habitat variable (Can_cov).

Canopy density/cover classes (based on McDonald *et al.,* 1990) attributed to each pixel were as follows:
Class 0: <0.2% density or non-remnant vegetation (e.g. pine forests, eucalypt plantations, vineyards, mud flats, beach sand, open water);
Class 1: 0.2–20% density (Very sparse, well separated);
Class 2: 21–50% density (Sparse, clearly separated);
Class 3: 51–80% density (Mid dense, touching or slightly separated);
Class 4: >80% density (Dense, touching or overlapping).

The canopy trend, or change in canopy cover over time (2002–2012) was derived from the Land Monitor imagery acquired between December and February each year. Linear trends of the vegetation indices were determined for each pixel and categorised into 5 classes (large increase, small increase, stable, small decrease, large decrease) and the proportional area of each class per polygon was calculated as a canopy trend index.

8.6 Impact of fire regime
For this project, fuel age data was available from the DPaW fire scar history and fuel age datasets. As each polygon may have had different areas burnt at different times, a fuel age index was developed to incorporate the proportional area burnt within each polygon using three age classes (Class 1: <10 years; Class 2: 10–20 years; and Class 3: >20 years since last burnt, or no record of fire). Some inaccuracies exist in the fuel age dataset as numerous small fires on privately owned land, and some low intensity fires on Crown land were not captured in the earlier DPaW fire history files (e.g. patchy fires in Locke Nature Reserve in the early 1980s were not captured).

Fire intensity data was not available for the area of interest so it was not possible to determine the “patchiness” or variability of the fires or prescribed burns where fuel age data were available.

8.7 Vegetation condition
Vegetation condition may be an important habitat factor in some areas that have been heavily impacted by human disturbances, grazing, intense fire or weed invasion. Disturbances that reduce the understorey density may not affect the carrying capacity of the habitat patch if the upper canopy remains intact. Some disturbances, such as fire and logging are intense and immediate but the vegetation may recover while other disturbances, such as weed invasion and grazing result in a gradual long-term decline in habitat values. The intensity, extent and patchiness of the disturbance may influence whether possums can survive within the patch or neighbourhood until the vegetation recovers and the habitat values are restored. Other disturbances may actually benefit WRP such as the development of artificial wetlands and the use of irrigation and fertilisers in parks and gardens, but these are not considered in this study.

Some information was available on vegetation condition within patches of remnant vegetation from the Bioplan project which was based on the scale of 1 (Pristine) to 6 (Completely degraded) (Webb *et al.*, 2009; adapted from Keighery, 1994) but the dataset was incomplete and thus not suitable for modelling. Only 4625 polygons (30%) of the whole data set had been assessed for vegetation condition. Canopy cover and change in cover over time, along with fire history were considered reasonable surrogate measures of vegetation condition.

8.8 Land tenure

Land tenure is clearly important in the overall land clearing assessment process and in the long term security of habitat for the WRP. For this review, suitable habitat was assessed across all land tenures to determine the total area available for WRP. As each habitat polygon may have one to several different land tenures, an index was developed based on the proportional area of each land tenure class present. Land tenure was classed according to the perceived security of native vegetation retention or level of conservation reservation status:
Score 0: Public roads, water, marine parks;
Score 1: Freehold, UCL, DPaW miscellaneous reserves, leasehold, other Crown reserves;
Score 2: DPaW executive freehold, timber reserves, 5(1)(h) reserves, state forest;
Score 3: National parks, conservation parks;
Score 4: Nature reserves.

Although land tenure is considered at a later stage in the environmental impact assessment process, this spatial data set was developed for the habitat modelling to provide information on the availability of habitat within the various land tenure classes.

8.9 Hollows, dreys and refuges

Although an important aspect of suitable habitat, the presence of hollows and places to rest and shelter during the daytime can be inferred to some extent by the vegetation type (structure and species composition) and age. Mixed eucalypt forests and woodlands are likely to have some suitable hollows, while shrublands or forests with dense understorey and peppermint dominated forests are likely to have branches suitable for building dreys. Older trees have suitable forked branches for resting and some vegetation types on sandier soils contain grasstrees that can be used for refuges. Consequently, this aspect was considered indirectly in the assigning of habitat quality values and modelling of suitable habitat.

8.10 Access to drinking water

During hot weather, it is likely that some WRP may need access to fresh drinking water to alleviate heat stress. Water is available in some wetlands that have a longer period of inundation, in larger rivers (e.g. Abba, Preston, Collie and Sabina Rivers) and drains as well as in farm dams, troughs and irrigation sprinklers. Urban environments can also provide numerous water points in backyards and public gardens.

While this may be an important factor for survival of WRP during peak stress periods, it was not considered to be one that could be used in spatial modelling to determine habitat suitability at the patch scale. Wetlands, estuaries and rivers provide a moist environment and these were allocated a higher habitat quality score than drier environments.

8.11 Predation pressure

Foxes, cats and domestic dogs are present in the Bunbury to Dunsborough region but there is no monitoring or data available to assess how they may affect habitat suitability. It is presumed there is a higher density of dogs and cats in urban areas than in non-urban areas, whereas foxes may be more abundant in agricultural areas and conservation reserves, but this has not been determined.

The impact of predators was not part of the habitat modelling, but assessment of habitat structure and canopy connectivity may provide some indication of the protection afforded by the vegetation to enable safe movement and dispersal of WRP in the presence of predators.

9.0 Habitat modelling for the western ringtail possum

9.1 Habitat suitability classes for mapping

Five habitat suitability classes (Table 2) were created for mapping suitable habitat in the southern Swan Coastal Plain based on the range of WRP densities determined from various spotlight survey data and other density estimates found in the literature (Appendix 1). The total area of habitat required to support a nominal population of 2,500 WRP in each management zone will vary with the habitat suitability class or part thereof (Table 2).

Density estimates depend on an accurate delineation and calculation of the areas being surveyed. In a small number of the studies used to derive these density classes, surveys were restricted to the area within remnants which had obvious signs of WRP occupation, such as sightings, dreys and scats rather than surveying the full extent of vegetation present in each remnant. This method resulted in higher density estimates than would be expected for the whole remnant or polygon.

Table 2. Habitat suitability classes based on estimates of WRP density (see Appendix 1). The number of hectares required to support a nominal population of 2,500 WRP for each class is also shown.

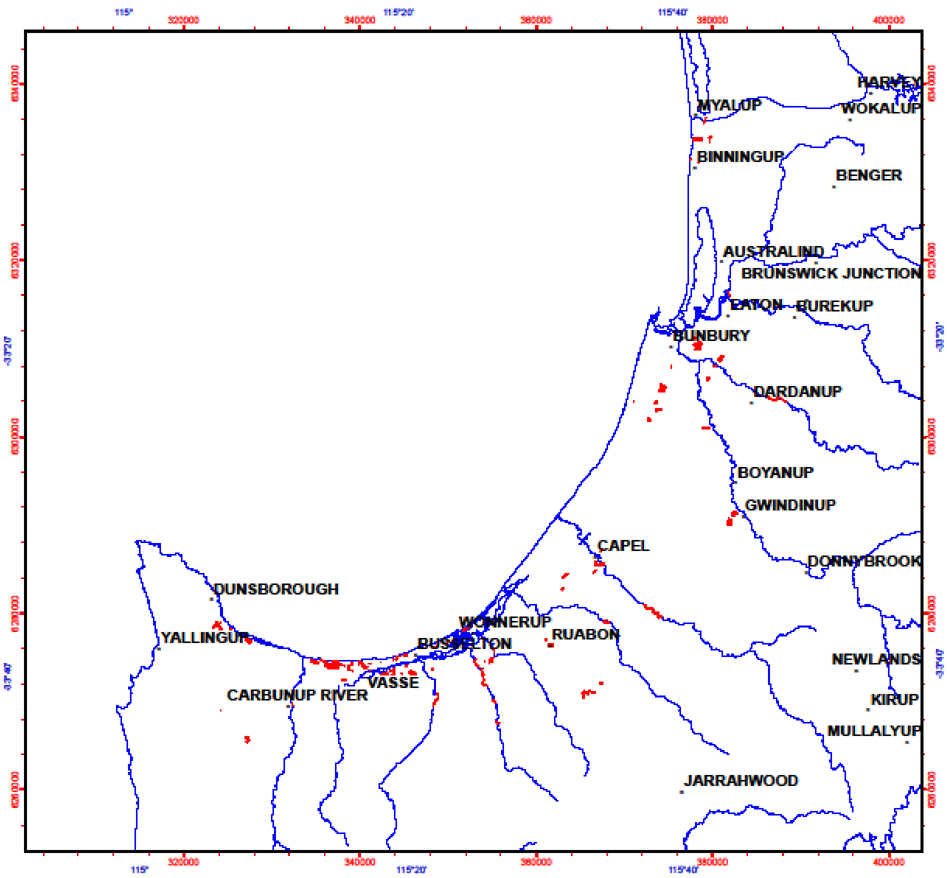
Habitat suitability class	WRP density (No./ha)	Area (ha) required to support 2,500 WRP
A – very high	>10	250
B – high	5–10	250–500
C – medium	2–5	500–1,250
D – low	0.5–2	1,250–5,000
E – very low	<0.5	>5,000
U – unsuitable		

9.2 WRP density in GLM modelling

A general multiple linear regression model (GLM) of habitat suitability was developed using spatially derived independent habitat variables which were available for the Bunbury to Dunsborough region. The aim was to use the model that best explained the range of WRP densities in this dataset and to use the outcomes to predict the WRP density of all other polygons within the area of interest, and then apply the appropriate habitat suitability classifications for mapping (Table 2). WRP density was used as the dependent variable and was considered to be a useful indicator, or surrogate measure, of habitat suitability. A subset of 115 polygons with known WRP density provided the dataset for this GLM. Other models using WRP count data were also examined to remove the confounding effects of relating polygon area with a density measure (see below).

The WRP density data used in the GLM was derived from previous surveys in the Bunbury to Dunsborough region conducted to meet various environmental impact assessment and monitoring requirements for potential land development or mining proposals (G. Harewood, unpublished data). Each survey area was gridded out and the location of each WRP from these spotlight surveys was recorded using a handheld GPS, along with the date and number of animals per location and downloaded as a shapefile in ArcMap (Map 7, G. Harewood, unpublished data). The survey data from 2006 to early 2013 was sorted according to survey date, and the mean number of animals present within each polygon over time was calculated to provide a mean density measure per polygon. Polygons with only one or two WRP sightings were discarded because there was a reasonable chance they were incomplete surveys, as were polygons with obvious survey gaps (e.g. sightings that were only shown along one boundary of the polygon). Some additional density data were used from other surveys where the areas defined in those surveys correlated with the habitat polygons in this project (Jones *et al*., 2007; de Tores and Elscot, 2010). Count data were also used in a separate GLM analysis and to further examine the effects of season and year of survey.

The WRP density figures should be considered conservative measures, as they are based on mean survey data, and are not likely to reflect the potential carrying capacity of the patch because of the difficulties undertaking a full census of all individuals and fluctuations of habitat quality over time. Maximum WRP densities in many polygons were at times 50–100% greater than mean values, particularly when dependent young were present. Analysis of variance of the WRP survey data (234 records) from 2008 to 2012 found no significant difference in mean WRP density between years (range 1.96–4.07/ha), but there was a significant seasonal variation with higher mean density during winter (6.59/ha) than during the other seasons (3.38/ha) ($P<0.001$).



Map 7. Map showing the distribution of 131 polygons (red) with WRP density data derived from spotlight surveys (G. Harewood, unpublished data). Sixteen of these polygons were screened out in the final dataset used in the GLM analysis (see text).

9.3 Habitat variables used for GLM analysis

Spatially derived habitat variables prepared for the GLM analysis were attributed to the soil-landform map units while other variables were attributed to individual polygons which allowed a greater level of discrimination. Only those variables which had spatial data attributed across the whole Bunbury to Dunsborough region were considered suitable candidates. Some variables were highly correlated to each other (e.g. Hab_qual and Ago_flex; Area and Area_score) so these were not used together in the analysis. A brief description of habitat variables used in the modelling is shown in Appendix 3. It is likely that other variables affect the suitability of these polygons for WRP but either there was insufficient regional data or it was not available in a spatial format to be used in the GIS modelling.

9.4 Statistical analysis

To test the relationships between the dependent variable 'WRP density' and the various independent habitat variables, a subset of 115 polygons was selected with known WRP density (G. Harewood, unpublished data). It was assumed that the same survey effort was used for all patches and that all animals (i.e. full census) were counted in each patch however this could not be verified. Scatter plots, linear regressions and single factor analysis of variance (ANOVA) were used to screen independent variables, examine the nature of the relationships and identify any outlying data points. Using Systat®13, the best-fit GLM model was developed for WRP density, based on maximising goodness of fit statistics (R^2 and p values) using backwards stepwise removal of variables. Several variables with skewed distributions were transformed to approximate a normal distribution but the raw data is presented here.

Other GLM models were subsequently examined using the count data which was likely to provide a better assessment of the data by accounting for variability due to the year and season of the surveys and removing the confounding effects of relating WRP density to area of patch (M. Williams, personal communication). These model outputs are presented in Section 9.6.

9.5 Relationships between WRP density and habitat variables

WRP density was significantly related to seven of the habitat variables (Table 3), which are examined individually in more detail in the sections below. These variables mainly relate to the habitat quality score, presence of peppermint, area of habitat patch and distance between patches. Given the nature of this study, and the errors involved in estimating the habitat variables, these relationships should be viewed simply as trends to inform our understanding rather than to imply any empirical outcomes.

Table 3. Linear regression statistics for significant relationships between WRP density (y) and each of the habitat variables (x) for the equation y=a + bx, for 115 polygons based on untransformed data.

Variable (x)	Constant (a)	Constant (b)	R^2	P value
Ago_flex	-0.329	1.850	0.368	<0.001
Hab_qual	-2.977	1.806	0.210	<0.001
Dist_HQ4	3.886	-0.003	0.138	<0.001
Area_score	7.812	-1.533	0.092	<0.001
Dist_near	2.895	0.250	0.069	<0.01
Area_ha	3.810	-0.104	0.058	<0.01
Area_1km	4.404	-0.016	0.038	<0.05

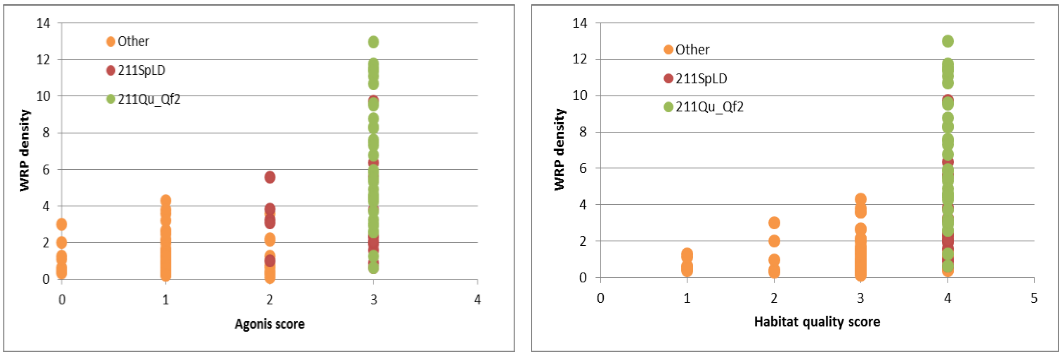
To examine the influence of different map units on WRP density, the two main high quality habitat map units (211Qu_Qf2 and 211SpLD) were separated from the remaining map units which have been termed ‘other’ in the following graphs. Map units 211SpLD1 and 211SpLDw were combined into 211SpLD due to minor soil-landform differences and to simplify data presentation. The Quindalup South Qf2 phase (211Qu_Qf2) covers relict foredunes and undulating plains with deep calcareous sands and mixed coastal scrub. The Spearwood Ludlow flats phase (211SpLD1) covers flats and very low sand dunes with deep yellow brown sand over limestone and forest or woodland of tuart (*E. gomphocephala*) and marri (*C. calophylla*) while the Spearwood Ludlow wet flats phase (211SpLDw) has similar soils but has more flats with poor subsoil drainage in winter and woodlands of peppermint and flooded gum (*E. rudis*) (Tille and Lantzke, 1990) (see Appendix 2 for a description of all soil map units).

<u>9.5.1 Habitat quality and *Agonis flexuosa* scores</u>

WRP density was positively related to the presence and dominance of peppermint (*A. flexuosa*) and to the habitat quality scores (Table 3). High to very high WRP densities (>5/ha) were only found in polygons where peppermint was dominant (Fig. 4a, Ago_flex score 3) or which had high habitat quality scores (Fig. 4b, HQ score 4). Mean WRP densities for the polygons in each Ago_flex category are shown in Table 4. These relationships demonstrate the strong influence that peppermint has on the habitat suitability for WRP in the Bunbury to Dunsborough region. Even so, the Ago_flex score accounted for only 37% of the variation in WRP density and demonstrates that other factors are involved that contribute more or less to their habitat suitability (Table 3).

Where peppermint was dominant, there was a large range in WRP densities (0.6–13/ha) which suggests that the relationship is complex and that other factors interact to affect the suitability of these habitats (Fig. 4a). Attributing one Ago_flex score to each polygon is somewhat misleading given the observed variability in vegetation composition within any plant community. WRP are commonly observed to be in clusters or hotspots of “preferred” habitat trees within the broader remnant of vegetation (B. Jones, personal communication), reflecting fine scale variability in habitat suitability, and so the above estimate of carrying capacity is likely to be overestimated. An alternative method would be to use finer scale vegetation mapping and more accurate WRP density measurement methods, but these were not available for this study.

Most of the polygons in the Ago_flex score 3 and Habitat quality score 4 occurred in map units 211Qu_Qf2 and 211SpLD (Fig. 4) in which peppermint is common or dominant.



(a) (b)

Figure 4. Relationships between WRP densities and the Ago_flex score (a) and habitat quality score (b). Data have been coloured to separate out polygons in map units 211Qu_Qf2 and 211SpLD from all the ‘other’ map units.

Table 4. Mean WRP densities for the Ago_flex score categories, along with the total area of habitat in each category for the 115 polygons.

Variable	Mean WRP density (No. WRP/ha)	Total area (ha)
Ago_flex score 3	5.63	233
Ago_flex score 2	1.77	142
Ago_flex score 1	1.38	228
Ago_flex score 0	1.09	41
Total		644

WRP were present in low densities in 8% of polygons where peppermint was not recorded or unlikely to be present (score 0), and in medium densities in 35% of polygons where peppermint was present only as a minor component in the understorey (score 1) (Table 4). These habitats were either jarrah/marri/banksia forest, or melaleuca dominant shrubland, which contained refuge and foraging species other than peppermint. This indicates that although these vegetation types have a lower WRP carrying capacity than the peppermint dominated vegetation, they can make an important contribution to the overall area of suitable habitat available for this species.

9.5.2 Area of polygon and area within 1km radius

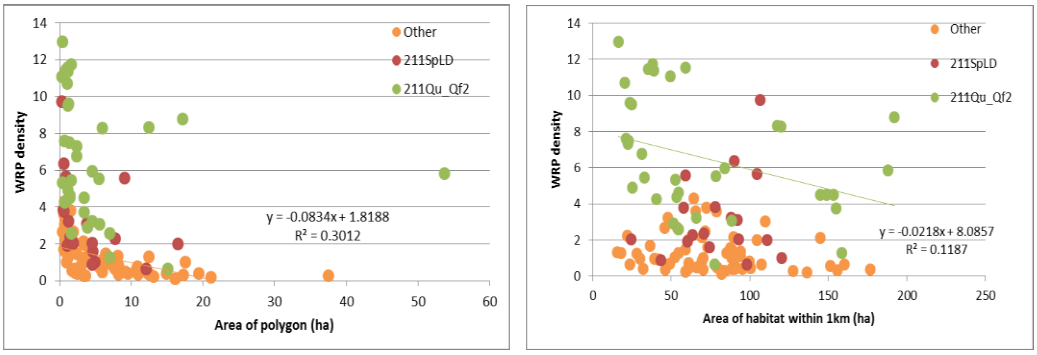
The relationships between WRP density and area of the polygon (Area_ha) and area of habitat within a 1km radius of the polygon (Area_1km) were both negative (Table 3), accounting for only 6% and 4% of the variation in WRP density, respectively (Table 3). Very high densities (>10/ha) were found in the smallest polygons (<2ha) but several polygons up to 54ha also had high densities (5–10/ha) (Fig. 5). While this may reflect relative survey intensity, it still demonstrates the importance of retaining small remnants of suitable WRP habitat. However, long term sustainability of these high densities in small habitat patches is questionable unless they are linked to other larger patches.

Several polygons up to 54ha also had high densities (5–10/ha) (Fig. 5a). One large polygon with WRP density of 5.84/ha appears to be an outlier, but this was part of the Locke Nature Reserve which has been the subject of several comprehensive WRP surveys (Jones *et al.,* 1994b; Jones *et al*., 2007; de Tores and Elscot, 2010) including one using distance sampling spotlight surveys that is expected to be more accurate than other survey methods (de Tores and Elscot, 2010). The density used in this analysis is from the latter study, and although the area used in that study (60.4ha) differed slightly from the polygon used in this project (53.7ha), the density estimate should be relevant. Earlier WRP density estimates for this reserve were 2.8/ha in 2006 (Jones *et al*., 2007) and 2.4/ha in 1991-92 (Jones *et al.,* 1994b).

All of the very high and high density polygons (i.e. >5/ha) were in the Quindalup dune (211Qu_Qf2) or Spearwood dune (211SpLDw and 211SpLD1) map units (Fig. 5a), and of these, only six polygons were greater than 10ha. The remainder of the larger polygons (>10ha) were in map units with lower mean density (<3/ha). When a subset of 36 polygons in the 211Qu_Qf2 map unit were analysed separately, there was no relationship between WRP density and area of polygon. One larger polygon (15ha) in the Quindalup area within the 211Qu_Qf2 map unit had WRP density of 0.63/ha, while another polygon (7ha) west of Locke Nature Reserve had WRP density of 1.3/ha (Fig. 5a). These were both long unburnt areas on private property with 67–69% canopy cover and 100% peppermint in the canopy and would be expected to support high densities of WRP. It may be that these areas were not fully surveyed, or that other factors affected the suitability of these patches that were not covered by this analysis.

The lower WRP density found in larger polygon areas may be explained to some extent by the greater proportion of larger polygons having less suitable vegetation types (i.e. “other” map units in Fig. 5a). For this group of ‘other’ map units, there was a stronger negative relationship between WRP density and Area_ha ($R^2 = 0.301$, $P<0.001$) (Fig. 5a), which was driving the overall trend for all polygons in the analysis.

The weak negative relationship between WRP density and area of habitat within 1km radius (Area_1km) of each polygon (Table 3) suggests a trend of greater density of WRP where there is decreasing area of surrounding habitat. The main contributor to this negative trend was the 211Qu_Qf2 map units for which there was a significant relationship with WRP density ($R^2 = 0.119$, $P<0.05$) (Fig. 5b). The maximum area of habitat of uncleared land in a 1km radius is approximately 314ha. Polygons with very high WRP density (>10/ha) are in areas where there is less than 60ha (20%) of native vegetation remaining in the surrounding 1km radius, down to a minimum of 15ha, or about 95% cleared (Fig. 5b).



(a) (b)

Figure 5. Relationship between WRP density and area of polygon (a) and area of habitat within 1km radius of each polygon (b). Data have been coloured to separate out polygons in two map units (Quindalup Dune 211Qu_Qf2 and Spearwood Dune 211SpLD) from the 'other' map units. Trendlines and statistics for the map units that have a significant relationship with WRP density are shown.

Many of these very high density patches are peppermint-dominated habitat in urban and semi-urban areas and are relatively isolated from other habitat. Fragmentation of native vegetation in this environment does not appear to prevent the occupation of some good quality habitat patches. The urban environment may be less fragmented than it appears as WRP take advantage of gardens, buildings and other infrastructure for foraging, nest sites, movement and dispersal. However, fragmentation may also contribute to higher densities in some patches because the animals cannot easily disperse away from these patches.

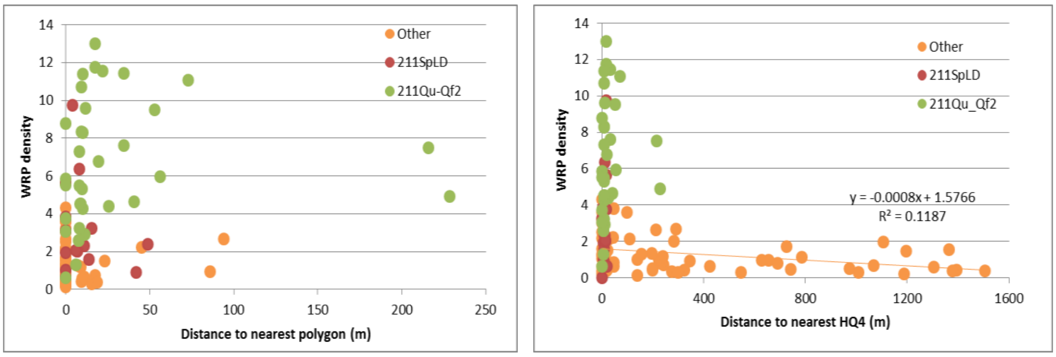
Lower densities in less fragmented neighbourhoods may be partially accounted for by differences in vegetation types, in that areas with a greater proportion of remnant vegetation may have less suitable vegetation types, such as along the Whicher Range. Although areas such as this have a low carrying capacity in the context of the southern Swan Coastal Plain from an overall species conservation aspect these areas should not be disregarded as they may possibly be of higher carrying capacity than other regions such as the Upper Warren and Albany.

9.5.3 Distance to nearest polygon and to nearest high quality habitat polygon

WRP density was positively, though weakly, related to distance to its nearest neighbouring polygon and was negatively related to distance to the nearest polygon with high quality habitat (HQ4) (Fig. 6; Table 3). However, all polygons with high WRP densities (>5/ha) were within 300m of a polygon with high quality habitat. The only polygons in map units other than the Quindalup and Spearwood map units (211Qu_Qf2 and 211SpLD) with densities greater than 2 WRP/ha were within 400m of a polygon with high quality habitat (Fig. 6b). Distance to the nearest polygon and distance to the nearest high quality polygon accounted for 7% and 14% of the variation in WRP density, respectively (Table 3).

Most of the polygons were within 100m of a neighbouring polygon of any habitat value, with a tighter cluster of polygons within 25m, and over 50% having another adjoining polygon (i.e. distance is zero) with different habitat quality (Fig. 6a). Two apparent outliers in Figure 6a have large leverage and these are small (<1.5ha) remnants with high quality habitat (211Qu_Qf2) east of Busselton in a semi-urban environment. However, WRP density was not significantly related to distance to nearest polygon for the any of the separate map unit subsets, including the 211Qu_Qf2 polygons (Fig. 6a). Overall, distance to the nearest polygons was less than 250m for all polygons in this dataset which is not considered to be limiting in terms of WRP movements.

The negative relationship between WRP and distance to nearest high quality habitat (HQ4) for all polygons (Table 3, Fig. 6b) was mainly driven by the wide range of distances to HQ4 (up to 1.5km) among the 'other' polygon points ($R^2 = 0.119$, $P<0.01$). The overall relationship was influenced by the clustering of polygons in map units classed as HQ4, including 211Qu_Qf2 and 211SpLD, in the coastal dune soil systems, while the 'other' map units were more dispersed across the region.



(a) (b)

Figure 6. Relationship between WRP density and distance to nearest polygon (a) and distance to nearest polygon of high quality habitat (HQ4) (b). Data have been coloured to separate out polygons in two map units (Qindalup Dune 211Qu_Qf2 and Spearwood Dune 211SpLD) from the 'other' map units. Trendlines and statistics for the map units that have a significant relationship with WRP density are shown.

The presence of suitable nearby habitat can result in meta-population dynamics with WRP moving between areas of suitable habitat, thereby increasing the effective habitat area of otherwise smaller remnants. This can be important for maintaining populations when impacts occur, such as when an area is burnt or subject to high predation intensity.

9.5.4 Canopy cover and canopy trend

There was no significant relationship between WRP density and canopy cover (2012) (Fig. 7) or canopy cover trend index (2002–2012). Canopy cover varied from 28% (sparse) to 83% (dense) with some of the highest WRP densities in polygons with less than 60% canopy cover. When the 36 polygons within the 211Qu_Qf2 map unit were considered separately, the WRP density decreased significantly with increasing canopy cover ($R^2 = 0.208$, $P<0.01$) (Fig. 7).

Canopy cover at the scale measured in this study for spatial modelling appears to be unreliable for defining habitat suitability for WRP. This was unexpected and is difficult to explain unless density of individual trees is more important than mean density of a habitat patch. Calibrations of canopy density values from sample sites and mean vegetation index values may need to be investigated further. Other measures of canopy cover and connectivity could be developed that more accurately reflect the finer scale canopy cover and connections within habitat patches that from other studies appear to be important.

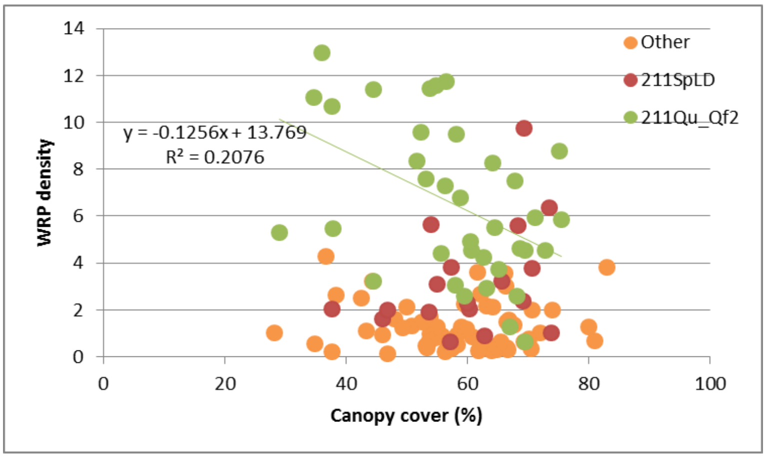


Figure 7. Relationship between WRP density and canopy cover. Data have been coloured to separate out polygons in two map units (Quindalup Dune 211Qu_Qf2 and Spearwood Dune 211SpLD) from the 'other' map units. Trendlines and statistics for the map units that have a significant relationship with WRP density are shown.

9.5.5 Fuel age, land tenure and vegetation condition

WRP density was not related to the classes of fuel age, land tenure or vegetation condition used in this modelling project for the 115 polygons. Very few polygons had been burnt or had fire recorded within the last 20 years so it was not a useful discriminating habitat variable for analysing this data set. In the area of interest, there are 1,256 polygons (34,561ha) with fire history records, including 193 polygons (5,363ha) burnt in the last 10 years. This aspect of habitat suitability needs further investigation.

Land tenure scores varied from 0.17 to 3.99, but only four polygons had a score greater than 1, indicating most were on freehold land, leasehold, UCL or miscellaneous reserves. This was to be expected since the WRP data was derived primarily from surveys conducted on land that was proposed for development or some form of vegetation clearing, which excluded land in the conservation estate.

For polygons that had been assessed for vegetation condition during the Bioplan Project, nearly half of those with high and very high WRP densities had vegetation condition scores equal to or greater than 5.0, i.e. degraded to completely degraded, "where the basic vegetation structure had been severely impacted by disturbance, and where intensive management was required for regeneration" (Webb *et al*., 2009). Within the 211Qu_Qf2 subset of polygons, 50% had vegetation condition equal to or greater than 5, and these had WRP densities ranging from 1.3 to 13/ha. Thus, poor vegetation condition does not appear to have an adverse impact on habitat suitability as many degraded patches which had been grazed, mown or with weedy understories supported high WRP densities.

9.5.6 Soil landform map units

Mean WRP density values were calculated for the eleven main soil landform map unit groups to see if this variable could be used predict WRP density (Table 5). Some minor map units with few records were combined with similar units differing only at the soil phase level (minor landform variations, e.g. valleys and wet valleys). Single factor ANOVA showed there was a significant difference in mean WRP densities among these map units (P<0.001). One major map unit (211Qu_Qf2) had a mean WRP density of 6.57/ha compared with 3.70/ha for 211SpLDw and 3.36/ha for 211SpLD1 (Table 5). There was no significant difference in mean WRP densities among the remaining map units which had a mean density of 1.35/ha. However, this restricted dataset represented only 31 out of 187 map units across the Bunbury to Dunsborough region, so this variable could not be extrapolated and used as a primary discriminator of habitat suitability. Instead, it was expected that differences in soil landforms and vegetation types in the map units across the region were adequately reflected in the habitat quality scores.

Table 5. Mean WRP density, range and number of polygons (n) for the major soil landform map units in the dataset for which WRP density was known from surveys. Some map unit phases have been combined for this analysis.

Soil system	Map unit	Mean WRP density (No./ha)	Range	n
Quindalup South	211Qu_Qf2	6.57	0.63–12.98	35
Spearwood	211SpLDw	3.70	0.65–10.48	14
Spearwood	211SpLD1	3.36	1.02–5.59	5
Abba	213AbCKv	2.23	1.23–3.23	2
Bassendean	212BsGCd2	1.56	0.91–2.65	4
Bassendean	212Bs_B2	1.49	0.29–3.80	6
Bassendean	212Bs_B1	1.48	0.32–4.30	10
Spearwood	211Sp_S1b	1.28	0.28–3.02	7
Abba	213AbABvw	1.07	0.37–2.24	6
Abba	213AbAB1	0.96	0.23–2.14	6
Whicher Scarp	214WsYL	0.71	0.12–1.28	5

9.5.7 Best fit general linear regression model for WRP density

A general linear model using the variables Ago_flex, Area_score, Area_1km, Dist_near, Dist_HQ4 and Can_cov was tested using backwards elimination of variables based on their statistical significance in the model. The variables of Hab_qual and Ago_flex were strongly correlated ($R^2 = 0.658$, $P<0.001$) so they could not be included together in the GLM. Similarly, Area_ha and Area_score were correlated, and since Ago_flex and Area_score provided more robust statistics (Table 3), they were used in the GLM. Soil-landform map units had a strong influence on the relationships between WRP density and many of the habitat variables but there was inadequate survey data to use map unit as an independent variable.

The final GLM comprised just two variables, Ago_flex and Area_score and was of the form:

Equation 1: WRP density = 3.854 + 1.805 (Ago_flex) – 1.370 (Area_score) ($R^2 = 0.441$, $P<0.001$)

This model predicts that larger areas have lower WRP density and although this was found to be the case, it may be a reflection of less rigorous surveys in larger areas, or that high quality habitat with dense peppermint stands are only present as very small fragmented patches or as smaller patches within larger remnants. All other factors being equal, it is also not logical to discount larger patches simply because of their area when predicting habitat suitability. It does however reinforce the point that all small patches of high quality habitat are important as they contribute significantly to the overall WRP carrying capacity of the region.

Larger remnants may be more sustainable in the longer term as they may have greater resilience to disturbances, provide enhanced refuge from predation, and allow for direct reinvasion of WRP after disturbances from refuges within the remnant.

Thus, up to 44% of the variation in WRP density was explained by the combination of just two variables, presence and dominance of peppermint and area. This is a reasonable outcome for this preliminary investigation of habitat variables given that the WRP data set used in the model was not truly representative of all remnant vegetation in the region.

These analyses indicate that within the Bunbury to Dunsborough region, presence and dominance of peppermint (*A. flexuosa*) is the primary component of the habitat which determines the potential WRP carrying capacity. This can be assessed readily by site inspections, but also remotely by referring to vegetation mapping. However, none of the variables satisfactorily explained the large variation in WRP densities found in polygons which had high Ago_flex and Hab_qual scores (Fig. 4). For example, observed WRP density in polygons in the highest habitat suitability class ranged from 0.6 to 13.0/ha (Table 7) and this variation is likely to be due to factors that were not covered in this study.

Some of the variation in WRP density is likely to be due to errors involved in the assumptions that all polygons selected for the GLM were surveyed to the same level of accuracy and effort, and that the polygons defined by the intersection of map units and remnant vegetation coincided with areas that had been surveyed for the environmental assessment process, which was not always the case.

Other sources of variation may be due to the many factors which operate at a finer scale or which could not be measured using the spatial analysis techniques used in this project, such as soil productivity, foliage nutrient quality, microclimates within tree canopies, presence of tree hollows, level of predator control as well as WRP social interactions and dispersal patterns.

Factors relating to the urban interface may also contribute to the variation in WRP density within areas of higher quality habitat, such as type and connectivity of backyard fences, presence of aggressive dogs, access to drinking water, presence of busy roads and nutritive value of garden plants. It is likely that the response of WRP to habitat factors within this urban environment will differ from their response in the natural environment. These urban factors would be difficult to quantify and a different model would be required. Even if the main factors affecting carrying capacity within the urban environment could be determined, it is considered unlikely that these would be useful for assessing habitat value for the purposes of environmental impact assessment and development planning.

9.6 General linear model using count data

Another approach using the WRP count data instead of the WRP density data was evaluated. The count data allows for variations in survey year and season and removes the confounding effects of WRP density with area of patch as an independent variable. This included the year and season of survey and provided 279 records including repeat surveys in some patches, rather than using one mean density record per patch. Before this analysis was undertaken, some of the habitat quality assessments were reviewed and an additional rating of HQ5 was applied to the highest density map unit (211Qu_Qf2) to reflect its superior carrying capacity.

A number of GLM models were examined using the count data and backwards stepwise elimination of variables in the Systat 13 statistical package. The relationship between the count data and each independent variable was examined to assess those with greatest influence on the model and their statistical power (Table 6). The main variables were then combined into a general linear model.

Table 6. Linear regression statistics for significant relationships between WRP count data (y) and the habitat variables (x) for the equation y=a + bx, for 279 survey records in the 115 polygons based on untransformed data.

Variable (x)	Constant (a)	Constant (b)	R^2	P value
Land_tenure	-14.308	26.339	0.293	<0.001
Area_ha	5.041	1.032	0.170	<0.001
Area_score	-18.221	9.736	0.130	<0.001
Hab_qual	-6.644	4.524	0.077	<0.001
Ago_flex	1.273	4.397	0.071	<0.001
Area_1km	2.538	0.110	0.058	<0.001
Soil_sys	902.369	-4.213	0.055	<0.001
Dist_HQ4	12.294	-0.008	0.026	<0.01

The four most useful independent variables in the model were the area of the patch (Area_ha), the habitat quality (Hab_qual), the total area of remnant vegetation within 1km radius (Area_1km) and distance to patch of high quality (Dist_HQ4), which combined to explain around 36% of the variation in the count data:

Equation 2: WRP count = -31.284 + 0.932 (Area_ha) + 7.143 (Hab_qual) + 0.131 (Area_1km) - 0.004 (Dist_HQ4) (R^2 = 0.36, P<0.001).

In this model, WRP counts were positively related to the area of habitat patch, habitat quality and area of habitat within a 1km radius, and negatively related to the distance to the nearest patch of high quality habitat. These relationships all appear to be logical and this model provides additional information about relationships between WRP relative abundance and various habitat variables.

10.0 WRP habitat suitability classes

10.1 WRP habitat suitability classes

The habitat quality assessments were revised to better reflect the vegetation composition and presence of foraging species using expert knowledge of the local vegetation and to ensure greater consistency across the study area. For example, 211VaWOwy was downgraded from HQ3 to HQ2 as it is mostly open saline wetlands with narrow fringes of *Melaleuca* and samphire, even though WRP are known to live in this fringing vegetation. A few Pinjarra map units were upgraded (e.g. 213Pj_B1 from HQ1 to HQ3), Bassendean sands (212Bs_B4 from HQ2 to HQ3) and Cokelup wet flats (213AbCKw from HQ3 to HQ4) due to the vegetation having more suitable foraging species (*Melaleuca* and *Kunzea* species) for WRP than first thought and are known to support WRP (A. Webb, personal communication).

After the revision of habitat qualities, the expected WRP density for each habitat suitability class (Table 2) which was derived from other survey data (Appendix 1) was more in line with the maximum observed WRP density rather than the mean observed density determined for the 115 polygons (Table 7). When the model equation for WRP counts (Equation 2) was applied to these polygons, the predicted mean densities were comparable to the expected mean densities in the HQ4 and HQ5 but were underestimated for the other HQ classes (Table 7).

Table 7. Habitat suitability classes with expected WRP densities and associated habitat quality scores. The observed mean densities and ranges for each habitat quality score for the 115 surveyed polygons are also shown, along with the mean density predicted from the WRP count model.

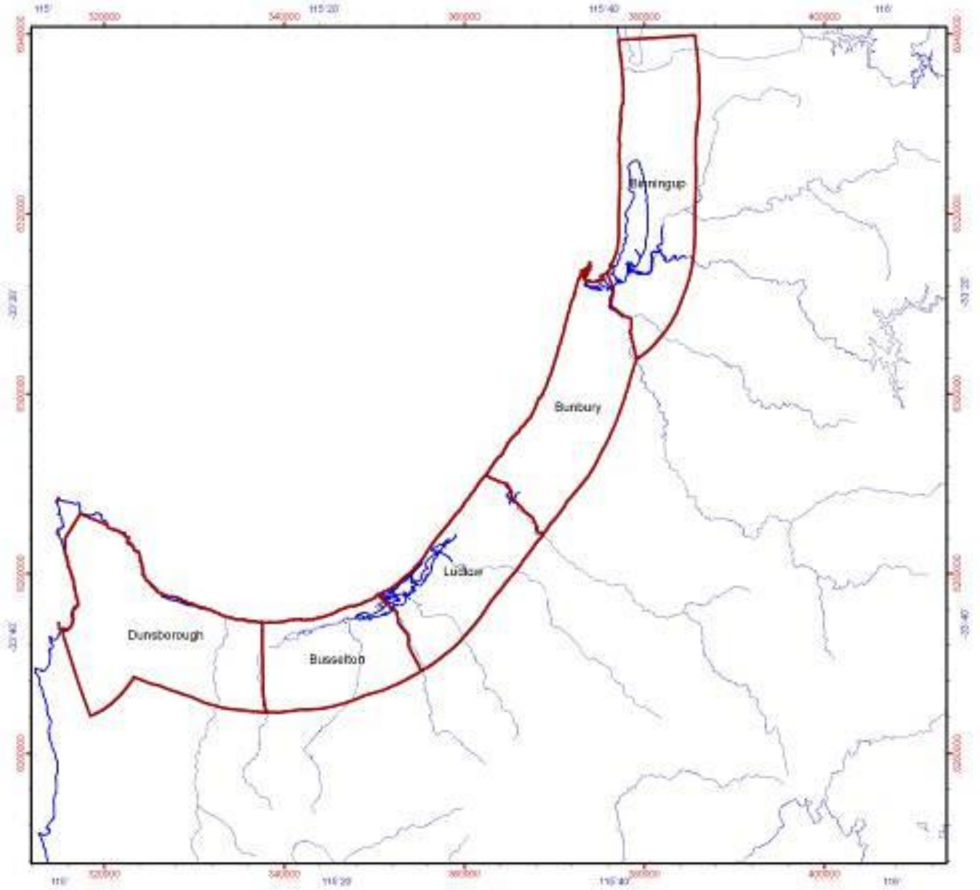
Habitat suitability class	Expected WRP density (No./ha)	Habitat Quality score	Observed mean density (No./ha)	Observed density range	Predicted mean density (No./ha)
A – very high	>10	5	6.51	0.6–13.0	8.64
B – high	5–10	4	2.47	0.4–9.7	5.52
C – medium	2–5	3	1.31	0.1–4.3	0.11
D – low	0.5–2	2	1.01	0.3–2.0	-1.71
E – very low	<0.5	1	0.74	0.4–1.3	-4.54
U – unsuitable					

Although the habitat modelling provided a better understanding of some of the main spatial variables contributing to habitat suitability, the resulting statistical models were not appropriate to apply to the wider dataset in the Bunbury to Dunsborough region, nor to the species area of occupation in the greater south-west, to predict carrying capacity or habitat suitability. Instead, the revised habitat quality data was used as the main variable for mapping habitat suitability classes (Appendix 4). Polygons were then attributed with these habitat suitability classes in the ArcMap project as a quick reference guide in the final mapping.

10.2 WRP habitat areas and management zones

Initial mapping of WRP habitat suitability classes (Appendix 4) was confined to the coastal fringe from Binningup to Dunsborough to focus on the area most likely to be affected by future land developments (e.g. the Future Busselton 2050 strategic growth scenarios). This coastal strip was eight to ten kilometers wide and further divided into five management zones for ease of map presentation and to assess habitat availability within areas of similar soil and vegetation type (Map 8). Divisions between zones were aligned with natural barriers to movement of WRP where possible, e.g. rivers, drainage channels and highways. However, the GIS project associated with this habitat review still retains all the information for the broader area of interest. Due to the scale of the maps in Appendix 4, the mapping of habitat suitability classes simply reflects the habitat qualities assigned to each map unit.

Areas of suitable WRP habitat in the main habitat suitability classes (A, B and C) are shown in Table 8 for each WRP management zone. The very limited extent of high quality habitat left available in this region is evident (Table 8). Habitat suitability class A is the only vegetation type in which this species is known to reach high rates of reproduction that can contribute to maintaining population densities and act as a nucleus for potential species recovery. The remaining 630ha of class A habitat are therefore a priority for conservation.



Map 8. Map showing the five WRP management zones along the 10km coastal fringe of the Binningup to Dunsborough in the southern Swan Coastal Plain.

The potential area of class C is likely to be overestimated, especially in the Bunbury and Binningup zones, as there have been very few surveys in these soil landforms. For example, in the Bunbury zone there were only eight polygons with WRP survey data (0.4% of all polygons in this zone) which were all HQ3 covering just four soil landform map units, while another 27 soil landform units with HQ3 from this zone had no WRP survey data. In the Binningup zone, only 16 polygons with HQ3 and three polygons with HQ4 had WRP survey data (0.9% of polygons in this zone), covering 11 soil map units.

Table 8. Area of suitable WRP habitat in the five management zones of the Bunbury to Dunsborough region across all land tenures.

Zone	Habitat suitability class	Area (>10ha)	Area (2–10ha)	Area (<2ha)	Total area (ha)
Dunsborough	A	149.9	153.5	51.4	354.8
	B	963.7	477.8	292.9	1,734.4
	C	3,594.5	1,419.6	591.0	5,605.1
	Total	4,708.1	2,050.9	935.3	7,694.3
Busselton	A	0	90.3	48.1	138.4
	B	136.2	337.2	237.8	711.2
	C	187.8	296.9	185.9	670.6
	Total	324.0	724.4	471.8	1,520.2
Ludlow	A	49.4	75.9	12.4	137.7
	B	2,232.5	358.0	189.4	2,779.9
	C	589.0	432.9	248.6	1,270.5
	Total	2,870.9	866.8	450.4	4,188.1
Bunbury	A	0	0	0.2	0.2
	B	1,241.9	237.4	156.8	1,636.1
	C	2,947.1	1,241.4	439.4	4,627.9
	Total	4,189.0	1,478.8	596.4	6,264.2
Binningup	A	0	0	0	0
	B	910.6	555.2	161.7	1,627.5
	C	6,026.3	1,894.8	514.2	8,435.3
	Total	6,936.9	2,450.0	675.9	10,062.8
Grand Total		19,029	7,571	3,130	29,730

10.3 Cautionary notes

The habitat modelling and associated habitat suitability classes should be considered as a first approximation and not be relied on to predict potential carrying capacity. In addition:

1. These habitat suitability classes and habitat quality scores are values assigned to the whole map unit, based on a very small sample (1%) of polygons. For the whole region, only 31 soil landform units were sampled out of 187 units, and more than half of these only had one or two surveys.

2. Survey results from one soil landform unit in one zone may not be applicable to that same unit in another zone, given variations in rainfall, temperature and depth to water tables.

3. There will be other variations in habitat suitability within many polygons due to finer scale variations in, for example, vegetation structure, floristic composition, flowering times, maturity of peppermint trees, hydrology, nutritional status, fire patchiness and between-tree connectivity. These variations are beyond the scope of this habitat assessment but should be considered during site assessments.

4. Other factors including possum social behaviour, native and non-native predator and competitor abundances, alternative food resources from gardens and proximity to busy roads are also likely to affect the actual suitability of habitat for WRP.

11.0 Conclusions

The habitat literature review has identified the main biological variables that are likely to define suitable habitat for the western ringtail possums in the southern Swan Coastal Plain.

These habitat variables include:

- presence and dominance of myrtaceous foliage, in particular that of peppermint (*Agonis flexuosa*);
- foliage that is higher in nitrogen and moisture, and lower in certain phenolic compounds;
- presence of dense shade and drinking water to reduce the impacts of heat stress;
- presence of suitable tree hollows and other day time rest sites;
- dense vegetation structure that provides protection from introduced and native predators;
- areas with lower predation pressures or are baited to achieve this;
- high connectivity of tree canopies and habitat patches to allow safe movement of WRP; and
- areas without high intensity fires that have significant direct and indirect impacts on survival of individuals.

Some of these variables were found to be appropriate to use in spatial modelling while others, such as time since last fire, could not be used due to gaps in the data or data that lacked a suitable range of values. Other parameters were appropriate at a much finer scale, such as leaf nitrogen content, tree hollows and water points, and required additional data collection across a broad area, and so were not included in this assessment.

High quality habitats are required to increase the reproductive output of the species to counter declining populations and losses due to predation and other factors.

The general linear modelling of spatially derived parameters provided information on the most important habitat variables within the area of interest from Bunbury to Dunsborough and east to the Whicher Range. WRP density was used as a surrogate measure for estimating habitat suitability using spotlight surveys of areas likely to contain the species. Other models were examined using WRP count data to assess the relationship with patch area. The main variables associated with suitable habitat for WRP based on the WRP density and count based models were:

- habitat quality assessed from soil landform and vegetation type;
- presence and dominance of peppermint;
- area of patch;
- area of habitat within 1km radius; and
- distance to the nearest high quality patch.

Canopy cover, canopy trend, distance to nearest patch, vegetation condition and fuel age were not associated with WRP density estimates for the data set investigated. However, they may still be important and warrant further investigation for other data sets.

Area of patch was strongly related to WRP count data and negatively related to WRP density. Larger patches contained higher numbers of WRP but smaller patches had higher densities of WRP. This suggests that either the small patches were mainly in areas with higher quality habitat or that the possums were not able to disperse safely from these small patches. It is also possible that higher densities of WRP in small patches could result in greater foraging pressure and regrowth of young foliage with higher nitrogen content leading to greater reproductive output, i.e. a positive feedback mechanism. Whether these higher densities are sustainable in these patches and whether the small patches upon which they depend are inherently more susceptible to other pressures such as drought remains unclear.

The range of WRP densities within map units was found to vary widely and much of this variation remained unexplained, particularly within the highest quality map unit along the Quindalup dunes (211Qu_Qf2). This indicates that there are other factors that limit the suitability of this vegetation, or that the population has not yet fully occupied these habitat patches or that other factors related to survey design and selection of habitat variables need to be refined. One option may be to standardise the polygon size at a biologically meaningful scale that enables a more accurate assessment of density and habitat attributes (e.g. 0.25–1.0ha), so that habitat patches are analysed as a composite of multiple polygons. Clearly, assessing relative abundance or population density across a wider range of habitat types in this region and using consistent survey methodology and sampling design is an essential first step. Resolving these questions is beyond the scope of the current assessment and more explicit information on factors influencing density is required in order to reliably define and evaluate habitat required to support a viable population of WRP across the southern Swan Coastal Plain. Attributes to define and assess the viability of a population are also required.

Habitat suitability classes that were mapped in this review were based primarily on an assessment of habitat quality from soil and vegetation data and were informed in some cases by known presence of WRP. These classes provide a guide to the relative carrying capacity of the different soil landform map units but further comprehensive surveys of WRP would be required to ascertain the actual densities or carrying capacities of all apparently suitable habitats in the region.

The reason for the high WRP abundance within the urban environment has also not been adequately explored and it is likely that additional habitat variables and a different model are required to explain this phenomenon. Aspects such as connectivity of backyard fences, presence of nutritious garden browse, protective built structures, dripping taps and presence/absence of cats or aggressive dogs are potential habitat variables that could help to explain variations in abundance of WRP in this urban environment.

Habitat area can be maintained or increased by limiting the area of existing suitable habitat that is cleared, by revegetating land that has been cleared or restoring degraded vegetation that was once suitable habitat. Effective habitat area can also be increased by improving connectivity between habitat patches to enhance access to isolated and potentially under-utilised patches of suitable habitat.

Landscape connectivity is an important aspect of overall habitat suitability to enable dispersal of young and avoid overcrowding and this is being investigated further to assess current and future connectedness under different land use scenarios, including revegetation options to improve landscape connectivity. Ideally, these tools need to be encompassed within a broader decision support framework that considers the cost effectiveness of various habitat management options. This strategic approach could be used to identify habitat requirements to support a viable population of WRP.

In essence, WRP require a secure supply of myrtaceous foliage and a predator safe environment. They do not need a complicated vegetation structure or diet and so it would seem possible to meet their requirements either within the natural or urban environment. This habitat review and mapping has identified and classified suitable habitat for WRP in the southern Swan Coastal Plain that will contribute towards improved management and conservation outcomes for the species.

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APPENDIX 1.

Table 1. Western ringtail possum density estimates for selected sites in the south-west of Western Australia. The estimates were determined using a variety of methods including direct counting and distance sampling (see references). ND – area not determined.

Density Class	WRP/ha	WRP/ha canopy	Total area of site (ha)	Site	Reference
Very Low (<0.5/ha)	0.02		200	Bayonet Head (site 1), Albany	Gilfillan, 2008
	0.05		19.8	Big Grove UCL (site 2), Frenchman's Bay, Albany	Gilfillan, 2008
	0.12		5.0	Leschenault Peninsular Conservation Park north	Clarke, 2011
	0.26		50	Geographe Bay inlet (total area)	Jones *et al.*, 1994b
	0.35		20	Emu Point, Albany	Jones *et al.*, 1994b
	0.46		7.1	Martin's Tank, Yalgorup National Park	Clarke, 2011
	0.46		10.5	Big Grove Development Area, Lot 1 (site 3), Frenchman's Bay, Albany	Gilfillan, 2008
	0.28–0.46		ND	Leschenault Peninsular Conservation Park	de Tores *et al.,* 2008
	0.4 (0.17–0.83)		30	Upper Warren, six sites 2001–02 (individuals captured over 4 months)	Wayne *et al.*, 2005a
Low (0.5–2.0/ha)	0.5 (0.20–0.66)		30	Upper Warren, six sites 2001–02 spotlight transects (5 months)	Wayne *et al.*, 2005a
	0.57		5.7	Preston Beach Rd, Yalgorup National Park	Clarke, 2011
	0.6		22	Geographe Bay inlet (suitable habitat)	Jones *et al.*, 1994b
	0.7		(20)	Emu Point, Albany	Green Iguana, 2007
	0.69–1.04		ND	Yalgorup National Park	de Tores *et al.,* 2008
	1.8		16.8	Kealy paddocks	Jones *et al.*, 2007
Medium (2.0–5.0/ha)	2.4 (2.4–2.6)		40	Locke Estate (Nature Reserve)	Jones *et al.*, 1994b
	2.5 (0.7–4.3)	5.0	1.4	Guerin St Reserve, Geographe	Harewood, 2008
	2.6	7.5	3.6	Legacy site, Locke lease	Jones *et al.*, 2007
	3.2		25	Chariup forest block, upper Warren (individuals	Wayne *et al.*, 2005b

Density Class	**WRP/ha**	**WRP/ha canopy**	**Total area of site (ha)**	**Site**	**Reference**
				captured over 14 months)	
	3.3 (2.3–4.3)	10–18.5	19.2	Busselton Hospital grounds 2009-12	Coffey Environments Australia, 2012
	3.8 (3.6–3.9)	7.3	2.8	Wilmott Park, Geographe	Harewood, 2008
	4.0 (3.7–4.3)		12	Abba River	Jones *et al.*, 1994b
	4.3 (3.3–5.3)	10.6	3.0	Longlands Park, Geographe	Harewood, 2008
High (5.0–10/ha)	5.3	13.1	2.0	Derelict site, Locke lease	Jones *et al.*, 2007
	5.5	13.7	2.1	Scouts site, Locke lease	Jones *et al.*, 2007
	5.7		30	Locke Nature Reserve south	Jones *et al.*, 2007
	5.8		60.4	Locke Nature Reserve	de Tores and Elscot, 2010
	6.4	8.8	2.2	Foursomes Rd Reserve	Harewood, 2008
	7.0		12	Locke Estate (Nature Reserve - main area)	Jones *et al.*, 1994b
	7.5 (6.4–8.6)	13.3	1.4	Glenleigh Rd Reserve	Harewood, 2008
	7.6	15.6	5.1	Siesta Resort, Siesta	Jones *et al.*, 2007
	7.8		1.9	Lot 5, Bussell Highway	de Tores and Elscot, 2010
	8.5	14.2	2.0	Churches of Christ site, Locke lease	Jones *et al.*, 2007
Very High (>10/ha)	10.1	10.3	3.3	Caves Rd Reserve, Abbey	Harewood, 2008
	13.5	31.0	3.5	Aqua resort post-development 2011	B. Jones (unpublished data)
	15.5	18.8	0.6	Lot 8, Siesta	Jones *et al.*, 2007
	16 (15–17)	21.2	2.0	West Busselton primary School	Harewood, 2008
	17.5 (17–18)	23.3	1.9	Busselton Primary School	Harewood, 2008
	18.5 (17–20)	16.7	1.0	Alan St Reserve, Bussell Highway	Harewood, 2008
	21.7	34.7	3.5	Aqua resort pre-development 2007	B. Jones (unpublished data)

APPENDIX 2.

Table 1. Floristic Community Types (Gibson et al. 1994, DEP 1996).

Broad descriptions compiled from Gibson *et al*. (1994) and DEP (1996) datasets, Webb *et al.,* (2009) and additional notes from A. Webb (personal communication).

Floristic Community Type	Description	Major species
s01	*Astartea/Melaleuca* dense shrublands	*Melaleuca acutifolia, M. lateritia, M. rhaphiophylla, M. viminea,* over *Astartea fascicularis, Calothamnus lateralis, Kunzea recurva, Viminaria juncea, Hakea varia* over sedges.
1b	Southern *Corymbia calophylla* woodlands on heavy soils	*Corymbia calophylla, Banksia grandis, Xylomelum occidentalis,* occasional *Eucalyptus marginata* over *Kingia australis, Xanthorrhoea preissii, X. brunonis, Acacia extensa, Hibbertia hypericoides, Pericalymma elliptica, Hypocalymma angustifolium, Adenanthos obovatus.*
3c	*Corymbia calophylla, Xanthorrhoea preissii* woodlands and shrublands.	*Corymbia calophylla, Eucalyptus wandoo* over *Xanthorrhoea preissii, Acacia saligna, A. incurva, Astroloma ciliatum* over *Neurachne alopecuroidea*.
4	*Melaleuca preissiana* damplands	*Melaleuca preissiana,* isolated *Corymbia calophylla, Nuytsia floribunda* over *Hypocalymma angustifolium, H. ericifolium, Pericalymma elliptica, Adenanthos obovatus, Xanthorrhoea preissii, Dasypogon bromeliifolius,* over sedges and herbs.
s05	*Acacia saligna* wetlands	*Melaleuca preissiana, M. rhaphiophylla, Banksia littoralis* over *Pericalymma elliptica, Hakea varia, Kunzea micrantha, Hibbertia vaginata, Acacia saligna, A. alata. A. stenoptera, Xanthorrhoea brunonis, X. preissii, Gahnia trifida* over sedges and herbs.
5	Mixed shrub damplands	*Melaleuca preissiana, Banksia ilicifolia,* isolated *Corymbia calophylla, Nuytsia floribunda* over *Hypocalymma angustifolium, H. ericifolium, Pericalymma elliptica, Adenanthos obovatus, Xanthorrhoea preissii, Dasypogon bromeliifolius, Kunzea ericifolia,* over sedges and herbs.
7	Herb rich saline shrublands in clay pans	*Melaleuca cuticularis, M. osullivanii, M. viminea* over *Pericalymma elliptica, Regelia ciliata, Kunzea micrantha, Verticordia densiflora, Eutaxia virgata, Viminaria juncea* over sedges and annually renewed herbs.
8	Herb rich shrublands in claypans	*Melaleuca preissiana* occasional *Corymbia calophylla* over *Acacia saligna, A. stenoptera, A. pulchella, Kunzea recurva, Hakea varia, Hypocalymma angustifolium, Xanthorrhoea brunonis, Viminaria juncea* over sedges and annually renewed herbs.
9	Dense shrublands on clay flats	*Melaleuca viminea, M. preissiana,* over *Astartea spp, M. pauciflora, Hakea varia, Pericalymma elliptica, Kunzea micrantha,* over *Lepidosperma longitudinale, Cyathochaeta avenacea and Restionaceae* sedge species
10a	Shrublands on dry clay flats	*Melaleuca cuticularis, M. osullivanii, M. viminea* over *Pericalymma ellipticum, Regelia ciliata, Kunzea micrantha, Verticordia densiflora, Eutaxia virgata, Viminaria juncea* over sedges.
10b	Shrublands on southern ironstones	A heath associated with shallow soils over ironstone rock supporting many endemic species; *Dryandra nivea* subsp. *uliginosa, D. squarrosa* subsp. *argillaceae, Hakea oldfieldii, Calothamnus quadrifidus* subsp. *teretifolius*, *Kunzea* aff. *micrantha, Grevillea manglesioides, Pericalyyma elliptica, Viminaria juncea, Melaleuca incana,* over sedges.
11	Wet forests and woodlands	*Eucalyptus marginata, E. rudis, Melaleuca rhaphiophylla, Banksia littoralis* over *Acacia pulchella, Astartea fascicularis, Jacksonia furcellata, Adenanthos meisneri, Phyllanthus calycinus, Hibbertia stellaris, Astroloma pallidum, Leucopogon propinquus* over sedges and herbs.
12	*Melaleuca teretifolia* and/or *Astartea* aff. *fascicularis* shrublands	*Melaleuca rhaphiophylla, Eucalyptus rudis,* occasional *M. preissiana* over *Melaleuca teretifolia, M. lateritia, Astartea scoparia, Calothamnus lateralis, Pericalymma elliptica* over sedges and rushes.
13	Deeper wetlands on heavy soils	*Melaleuca rhaphiophylla, Eucalyptus rudis,* occasional *M. preissiana* over *Melaleuca teretifolia, M. pauciflora, M. lateritia, M. viminea, Hakea varia, Astartea scoparia, Calothamnus lateralis, Pericalymma elliptica* over sedges and rushes.
16	Highly saline seasonal wetlands	*Melaleuca cuticularis, M. rhaphiophylla, M. viminea, over Samolus repens, Frankenia pauciflora, Suaeda australis, Holsarcia* and *Sarcocornia* spp. and sedges, *Ghania trifida* and *Sporobolus virginicus* on elevated terraces. Also *Atriplex* and *Chenopodium* spp. on fringes.
17	*Melaleuca rhaphiophylla – Gahnia trifida* seasonal wetlands	*Melaleuca rhaphiophylla, M. viminea, Eucalyptus rudis, M. cuticularis,* occasional *Banksia littoralis, Agonis flexuosa* over *Acacia saligna, Hakea varia, Melaleuca incana, Gahnia trifida, Lepidosperma gladiatum.*
18	Shrublands on calcareous silts	*Melaleuca rhaphiophylla, M. teretifolia, M. lateritia, Acacia saligna,* over *Gahnia trifida, Lepidosperma longitudinale.*
19	Quindalup-Spearwood dune interface sumplands and lakes	*Acacia saligna, Banksia littoralis, Melaleuca rhaphiophylla, M. preissiana* over dense sedges such as *Baumea spp.,Lepidosperma spp, Typha spp., Carex spp.,* and herbs.
21a	Central *Banksia attenuata – Eucalyptus marginata* woodlands	*Banksia attenuata, Eucalyptus marginata,B. ilicifolia* occasionally *Allocasuarina fraseriana,* over *Bossiaea eriocarpa, Petrophile linearis, Hibbertia hypericoides, Melaleuca thymoides, Dasypogon bromeliifolius, Kunzea glabrescens, Jacksonia furcellata, Leucopogon propinquus.*
21b	Southern *Banksia attenuata* woodlands	*Banksia attenuata, B.ilicifolia, Eucalyptus marginata* occasionally *Agonis flexuosa,* over *Acacia extensa, Bossiaea eriocarpa, Petrophile linearis, Hibbertia hypericoides, Melaleuca thymoides, Dasypogon bromeliifolius, Kunzea glabrescens, Jacksonia furcellata, Leucopogon propinquus.*

21c	Low lying *Banksia attenuata* woodlands or shrublands	*Banksia attenuata, B. ilicifolia, Melaleuca preissiana, Corymbia calophylla, Eucalyptus marginata, Nuytsia floribunda, Agonis flexuosa,* occasional *M. rhaphiophylla, E. rudis,* over *Xanthorrhoea brunonis, Petrophile linearis, Hypocalymma angustifolium, H. robustum, Pericalymma elliptica, Bossiaea eriocarpa, Hibbertia hypericoides, Melaleuca thymoides, Dasypogon bromeliifolius, Kunzea glabrescens.*
25	Southern *Eucalyptus gomphocephala* – *Agonis flexuosa* woodlands	*Eucalyptus gomphocephala, Agonis flexuosa, Banksia attenuata, B. grandis,* occasional *E. marginata, Corymbia calophylla* over *Macrozamia riedlei, Hibbertia hypericoides, Phyllanthus calycinus, Hardenbergia comptoniana, Bossiaea eriocarpa, Dianella revoluta*
29a	Coastal shrublands on shallow sands	*Agonis flexuosa* scattered over *Diplolaena dampieri, Syridium globulosum, Olearia axillaris, Phyllanthus calycinus, Hibbertia cuneiformis Lepidosperma gladiatum*
30b	Quindalup *Eucalyptus gomphocephala* and/or *Agonis flexuosa* woodlands	*Eucalyptus gomphocephala* and/or *Agonis flexuosa* dominant, over *Spyridium globulosum, Hibbertia cuneiformis, Leucopogon parviflorus, Phyllanthus calycinus, Hardenbergia comptoniana, Templetonia retusa, Acacia littorea, A. rostellifera, Lepidosperma gladiatum, L. squamatum*

Table 2. The soil systems which occur in the Bunbury to Dunsborough region (DAFWA, 2007).

Soil System	Name	Description
211Qu	Quindalup South	Coastal dunes, of the Swan Coastal Plain, with calcareous deep sands and yellow sands. Mixed coastal scrub.
211Sp	Spearwood	Sand dunes and plains. Yellow deep sands, pale deep sands and yellow/brown shallow sands. Tuart-marri forest and woodland in south, heath and open woodland in north.
211Va	Vasse	Poorly drained estuarine flats, of the Swan Coastal Plain. Tidal flat soil, saline wet soil and pale deep sand. Samphire, sedges and paperbark woodland. Samphire flats and paperbark woodlands.
212Bs	Bassendean	Swan Coastal Plain from Busselton to Jurien. Sand dunes and sandplains with pale deep sand, semi-wet and wet soil. Banksia and paperbark woodlands and mixed heaths.
213Ab	Abba	Poorly drained flats, on the southern Swan Coastal Plain. Grey deep sandy duplex and wet soil. Woodland of jarrah, marri and paperbark.
213Fo	Forrestfield	Undulating foot slopes of the Darling and Whicher Scarps. Duplex sandy gravels, pale deep sands and grey deep sandy duplexes. Woodland of jarrah, marri, wandoo and some *Banksia grandis*.
213Pj	Pinjarra	Swan Coastal Plain from Perth to Capel. Poorly drained coastal plain with variable alluvial and aeolian soils. Variable vegetation includes of jarrah, marri, wandoo, paperbark, sheoak and flooded gum forest and woodland.
214Bp	Blackwood Plateau	Lateritic plateau, in the Donnybrook Sunkland. Sandy gravel, loamy gravel and deep sand. Jarrah and marri forest.
214Gv	Goodwood Valleys	Valleys, of the Donnybrook Sunkland. Sandy gravel, loamy gravel and deep sand. Jarrah-marri forest and woodland.
214Th	Treeton Hills	Rises and low hills, of the western Donnybrook Sunkland. Sandy gravel, grey deep sandy duplex and loamy gravel. Jarrah-marri forest and woodland.
214Ws	Whicher Scarp	Low scarp and raised platform, on the northern edge of the Donnybrook Sunkland. Sandy gravel and pale deep sands, loamy gravel and non-saline wet soils. Jarrah-marri forest and woodland.
216Co	Cowaramup Uplands	Lateritic plateau, in the Leeuwin Zone. Sandy gravel, loamy gravel and grey sandy duplex. Jarrah-marri forest.
216Gr	Gracetown Ridge	Limestone ridge, in the coastal edge of the Leeuwin Zone. Yellow deep sand and red deep sand. Coastal scrub, peppermint woodland and jarrah-marri-karri forest.
216Wv	Wilyabrup Valleys	Granitic valleys in the Leeuwin Zone. Loamy gravel, sandy gravel and loamy earth. Jarrah-marri-karri forest.

Table 3. Soil landform map units in the Bunbury to Dunsborough region.

Descriptions of major soil landform map units based on the soil landform database (*DAFWA, 2007), with additional vegetation descriptions from the floristic community types (FCTs) and quadrats derived from the Bioplan Project (**Webb *et al*., 2009). FCTs in bold type are the dominant vegetation type for that map unit. The total area of each map unit greater than 5ha within the area of interest is shown. Scores derived for this habitat review for habitat quality (0-5) and *Agonis flexuosa* (0-3) are also shown (see text for a full description of these scores).

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
211Qu__Qd	Quindalup South Qd Phase	Small gently undulating plains (deflation basins) enclosed by discrete parabolic dunes with moderately deep to very deep calcareous sands over limestone.		Tuart-**Peppermint** woodland over shrubs and sedges on dunes Dense acacia shrubland	30b	3	3	216
211Qu__Qf2	Quindalup South Qf2 Phase	Relict foredunes and gently undulating beach ridge plain with deep uniform calcareous sands.	Scrub and woodland of stunted peppermint (Agonis flexuosa). Partially cleared for urban/recreational development, sand mining and grazing. Much of the remaining vegetation is in a disturbed state.	Tall melaleuca shrubland over sedges in fringing seasonal wetlands. Tuart-**Peppermint** woodland over shrubs and sedges on dunes	17, 30b	5	3	632
211Qu__Qp1	Quindalup South Qp1 Phase	Complex of nested low relief parabolic dunes with moderate to steep slopes and uniform calcareous sands showing variable depths of surface darkening.		Tuart-**Peppermint** woodland over shrubs and sedges on dunes	30b	3	3	761
211Qu__Qp2	Quindalup South Qp2 Phase	Long walled discrete parabolic dunes with moderate to steep slopes and uniform calcareous sands showing variable depths of surface darkening.		Tall melaleuca shrubland over sedges in fringing seasonal wetlands. **Peppermint** shrubland over sedges on dunes. Tuart-**Peppermint** woodland over shrubs and sedges on dunes	17, 29a, 30b	3	2	781
211Qu__Qp3	Quindalup South Qp3 Phase	Subdued (small) parabolic dunes on the eastern margins of the dune system with uniform calcareous sands.		**Peppermint** woodland around dune edges		3	2	303
211Qu__Qqp	Quindalup South Qqp Phase	Flat to very gently undulating plain with variably leached calcareous sand generally overlying calcrete horizon at 60-90 cm depth (for management purposes similar to Qd).		Tuart-**Peppermint** woodland over shrubs and sedges on dunes	30b	4	3	208
211Sp__S1a	Spearwood S1a Phase	Dune ridges with shallow to moderately deep siliceous yellow-brown sands, very common limestone outcrop and slopes up to 15%.		Tuart-Marri-**peppermint** forest on Yalgorup dunes		3	2	107
211Sp__S1b	Spearwood S1b Phase	Dune ridges with deep siliceous yellow brown sands or pale sands with yellow-brown subsoil and slopes up to 15%.		Banksia woodland over shrubland on upland dunes Open Tuart-**Peppermint** Forest over open shrubland on dunes	21a, **25**	3	2	1674

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
211Sp__S1c	Spearwood S1c Phase	Dune ridges with deep bleached grey sands with yellow-brown subsoils, and slopes up to 15%.		Banksia woodland over shrubland on upland dunes Open Tuart-**Peppermint** Forest over open shrubland on dunes.	21a, 25	3	1	1079
211Sp__S1d	Spearwood S1d Phase	Dune ridges with moderately deep to very deep siliceous yellow-brown sands, rare limestone outcrop and slopes 3-20% occurring on the eastern slipface.		Open Tuart-**Peppermint** Forest over open shrubland on dunes	25	3	1	83
211Sp__S2a	Spearwood S2a Phase	Lower slopes (1-5%) of dune ridge with moderately deep to deep siliceous yellow-brown sands or pale sands with yellow-brown subsoils and minor limestone outcrop.		Open Tuart-**Peppermint** Forest over open shrubland on dunes	25	4	2	1617
211Sp__S2b	Spearwood S2b Phase	Lower slopes (1-5%) of dune ridge with shallow to deep siliceous yellow-brown sands and common limestone outcrop.		Open Tuart-**Peppermint** Forest over open shrubland on dunes	25	4	2	222
211Sp__S2c	Spearwood S2c Phase	Lower slopes (1-5%) of dune ridge with bleached or pale sands with yellow-brown or pale brown subsoil (like S1c). Usually occurs on the eastern edge of the Spearwood Dunes.		Mixed wetland forests and woodlands Banksia woodland on upland dunes. Tuart-Marri-Jarrah open forest over Banksia-**Peppermint** woodland	11, **21a**	3	1	859
211Sp__S3	Spearwood S3 Phase	Interdunal swales and depressions with gently inclined side slopes and deep rapidly drained siliceous yellow-brown sands.		Open Tuart-**Peppermint** Forest over open shrubland on dunes	25	4	2	122
211Sp__S3a	Spearwood S3a Phase	Poorly drained interdunal swales and depressions with gently inclined side slopes, with deep bleached white/grey sands underlain by an organic pan or peat deposit.		Includes Muddy Lakes with dense Acacia and Melaleuca shrubland and sedges	19	3	0	245
211Sp__S4a	Spearwood S4a Phase	Flat to gently undulating sandplain with deep, pale and sometimes bleached, sands with yellow-brown subsoils.				3	1	399
211Sp__S4b	Spearwood S4b Phase	Flat to gently undulating sandplain with shallow to moderately deep siliceous yellow-brown and grey-brown sands with minor limestone outcrop.				3	1	131

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
211Sp__S4c	Spearwood S4c Phase	Flat to gently undulating sandplain with deep, yellow-brown or dark brown siliceous sands that are seasonally inundated.				3	1	41
211SpLD1	Ludlow flats Phase	Flats and very low dunes. Deep yellow brown siliceous sands over limestone (i.e. Spearwood Sands).	Forest and woodland. In the east this unit is dominated by tuart (Eucalyptus gomphocephala) forest with a peppermint (Agonis flexuosa) understory and a grassy floor. On the edges of the tuart forest scattered marri (C. calophylla) and bull banksia (Banksia grandis).	Open Tuart-**Peppermint** Forest over open shrubland on dunes. Marri-Peppermint woodland. Yate and **Peppermint** low open forest.	25	4	2	2288
211SpLDv	Ludlow vales Phase	Narrow floodplains in small depressions along creeks and rivers. Sandy alluvial soils.	Woodland of peppermint (Agonis flexuosa)	Riverine **Peppermint** woodland with Melaleuca shrubland		4	3	42
211SpLDvw	Ludlow wet vales Phase	Narrow swampy small depressions. Sandy soils.	Woodland of flooded gum (Eucalyptus rudis)	Flooded gum-**peppermint** forest		4	2	37
211SpLDw	Ludlow wet flats Phase	Flats with poor subsoil drainage in winter. Deep yellow brown siliceous sands over limestone (i.e. Spearwood Sands).	Woodland of peppermint (Agonis flexuosa) and flooded gum (Eucalyptus rudis). Scattered marri (C. calophylla) can occur in these woodlands, especially in better drained areas. Sedges (Juncus spp.) are sometimes present in the less well drained areas.	Flooded gum-**peppermint** woodland, scattered Marri and sedges Blackbutt and Yate open forests on better soils		4	3	370
211SpLDwr	Ludlow wet rocky flats Phase	Flats with high winter water tables and shallow brown and yellow sands over limestone (i.e. Shallow Spearwood Sand). Limestone often present on surface.	Open woodland of peppermint (Agonis flexuosa) and flooded gum (Eucalyptus rudis). Scattered marri (C. calophylla) occurs in these woodlands, especially in better drained areas. Sedges (Juncus spp.) are sometimes present in the less well drained areas.	Flooded Gum, tall melaleuca shrubland over sedges in fringing seasonal wetlands. Tuart-**Peppermint** woodland over shrubs and sedges on dunes	**17,** 30b	4	3	213
211SpW_SWAMP	Spearwood wet, swamp Phase	Swamp.	McArthur and Mattiske (1985): Melaleuca spp. and Eucalyptus rudis in zone of water level fluctuation; sedges and reeds in shallow water. McArthur and Bartle (1980): Vegetation is often zoned depending on water table level, and includes Melaleuca spp.	Tall melaleuca shrubland over sedges in fringing seasonal wetlands. Tall melaleuca shrubland on silt Cokelup and Big Swamp.	17, 18	4	1	397
211SpX_LANDFILL	Spearwood Landfill Phase	Landfill. Disturbed land.		Low woodland over shrubland and sedges on wetland Low woodland over shrubland and sedges on claypan wetland	s05, 8	3	0	34
211VaWOw	Vasse Wonnerup wet flats Phase	Poorly drained flats around the edge of the Vasse Estuary. Dark calcareous sands and mixed estuarine deposits.	Saltmarsh, samphire (Halosarcia sp.) paperbark (Melaleuca sp.) woodland and some areas of reed beds. Flooded gum (Eucalyptus rudis) is also present in some locations.	Saltmarsh-samphire flats and Melaleuca cuticularis woodland	16**, 17**	3	1	442

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
211VaWOwy	Vasse Wonnerup very wet saline flats Phase	Vasse, Wonnerup and Broadwater Estuaries, low lying depressions which are often underwater in winter and saline in summer.	Mainly saltmarsh and samphire (Halosarcia spp.). Some areas are devoid of vegetation due to waterlogging and salinity. Paperbark (Melaleuca spp.) woodland and some areas of reed beds.	Tall Melaleuca dense shrubland over sedges in fringing seasonal wetlands Saltmarsh and samphire flats. New River.	**16,** 17	2	1	1247
212Bs__B1	Bassendean B1 Phase	Extremely low to very low relief dunes, undulating sandplain and discrete sand rises with deep bleached grey sands sometimes with a pale yellow B horizon or a weak iron-organic hardpan at depths generally greater than 2 m; banksia dominant.		Scattered trees over mixed open low shrubland on drier dampland. Banksia woodland over shrubland near wetland.	5, **21a, 21b, 21c**	3	1	2818
212Bs__B1a	Bassendean B1a Phase	Extremely low to very low relief dunes, undulating sandplain and discrete sand rises with deep bleached grey sands with an intensely coloured yellow B horizon occurring within 1 m of the surface; marri and jarrah dominant.		Banksia woodland over shrubland on upland dunes. Banksia and eucalyptus woodland over shrubland near wetland.	21a, 21b, 21c	3	1	1294
212Bs__B1b	Bassendean B1b Phase	Very low relief dunes of undulating sand plain with deep bleached grey sandy A2 horizons and pale yellow B horizons.		Banksia woodland on dunes Banksia woodland over shrubland on upland dunes.	21a, 21b	3	1	1136
212Bs__B2	Bassendean B2 Phase	Flat to very gently undulating sandplain with well to moderately well drained deep bleached grey sands with a pale yellow B horizon or a weak iron-organic hardpan 1-2 m.		Scattered trees over mixed dense low shrubland on dampland. Banksia woodland on dunes Banksia woodland over shrubland on upland dunes.	4, 21a, 21b	3	1	1037
212Bs__B3	Bassendean B3 Phase	Closed depressions and poorly defined stream channels with moderately deep, poorly to very poorly drained bleached sands with an iron-organic pan, or clay subsoil. Surfaces are dark grey sand or sandy loam.		Scattered trees over mixed dense low shrubland on dampland. **Peppermint** and Marri around dampland. Banksia woodland on upland dunes.	**4**, 21a	3	1	325
212Bs__B3a	Bassendean B3a Phase	Broad depression and narrow swales between sand ridges with poor to very poorly drained grey and brown sands, with an iron-organic (or siliceous) hardpan at generally less than one metre.		Melaleuca tall dense shrubland over sedges on inundated clay flat	9	3	0	995
212Bs__B4	Bassendean B4 Phase	Broad poorly drained sandplain with deep grey siliceous sands or bleached sands, underlain at depths generally greater than 1.5 m by clay or less frequently a strong iron-organic hardpan.		Melaleuca dense shrubland over sedges.	s01	3	0	116

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
212Bs__B5	Bassendean B5 Phase	Shallowly incised stream channels of minor creeks and rivers with deep grey siliceous sands or bleached sands, underlain at depths generally greater than 1.5 m by clay or less frequently a strong iron-organic hardpan.		Flooded gum woodland, mostly degraded		4	0	74
212Bs__B6	Bassendean B6 Phase	Sandplain and broad extremely low rises with imperfectly drained deep or very deep grey siliceous sands.		Scattered trees over mixed open low shrubland on drier dampland.	5	3	0	1018
212BsGCd2	Bassendean Golf Course deep sandy rises Phase	Gently sloping low dunes and rises (0-5% gradients) with deep bleached sands.	Woodland, mainly banksia (Banksia attenuata, B. ilicifolia, B. grandis) with a scrubby, mainly proteaceous, understory. Peppermint (Agonis flexuosa) is sometimes present. Stunted jarrah (Eucalyptus marginata) and marri (C. calophylla) are sometimes present.	Banksia woodland	21a, 21b	3	1	401
212BsGCdw	Bassendean Golf Course wet deep sands Phase	Poorly drained depressions (mainly in swales). Deep sandy soils with surface organic matter build up.	Scrub, sedgelands and low swampy heathlands. Melaleuca spp.	Sedgeland and paperbark scrub		3	1	20
212BsW_SWAMP	Bassendean wet, swamp Phase	Swamp		Marri woodland over shrubland on low lying wet sand. Scattered trees over mixed open low shrubland on drier dampland. Dense tall melaleuca shrubland fringing inundated wetland and sedgeland. Melaleuca tall dense shrubland fringing inundated wetland on clay. Closed low melaleuca forest	1b, **4,** 5, **12, 13**	3	0	291
213AbAB1	Abba Flats Phase	Flats and low rises with sandy grey brown duplex (Abba) and gradational (Busselton) soils.	Jarrah-Marri (Eucalyptus marginata, C. calophylla) woodland. Blackboys (Xanthorrhoea spp.) commonly present. Extensively cleared.	Marri woodland over shrubland on low lying wet sand.	1b	3	2	1286
213AbAB2	Abba gentle slopes Phase	Very gently sloping terrain. Pale sandy earths, Semi-wet soils, Pale deep sands and Duplex sandy gravels	Jarrah-Marri (Eucalyptus marginata, C. calophylla) woodland. Blackboys (Xanthorrhoea spp.) commonly present.	Jarrah-marri woodland	1b	3	2	62
213AbABd	Abba deep sandy rises Phase	Gently sloping low dunes and rises (0-5% gradients) with deep bleached sands.	Woodland, mainly banksia (Banksia attenuata, B. ilicifolia, B. grandis) with a scrubby, mainly proteaceous, understory. Peppermint (Agonis flexuosa) is often present. Stunted jarrah (Eucalyptus marginata) and marri (C. calophylla) are sometimes present,	Marri woodland over shrubland on low lying wet sand. Banksia woodland over shrubland on upland dunes.	1b, **21b**	3	2	464

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
213AbABv	Abba vales Phase	Small narrow depressions along drainage lines. Alluvial soils.	Mainly cleared	Riverine **peppermint,** Flooded Gum and paperbark woodland Mainly cleared		4	3	79
213AbABvw	Abba wet vales Phase	Small narrow swampy depressions along drainage lines. Alluvial soils.	Scrub, Melaleuca spp. and Nuytsia floribunda. Some marri (C. calophylla) woodland.	Paperbark scrub. Marri and Blackbutt on drier soils		4	2	182
213AbABw	Abba wet flats Phase	Winter wet flats and slight depressions with sandy grey brown duplex (Abba) and gradational (Busselton) soils.	Scrub, Melaleuca spp. and Nuytsia floribunda. Some marri (C. calophylla) woodland.	Herb-rich saline shrublands in claypans Melaleuca tall dense shrubland over sedges on inundated clay flat Shrublands on dry clay flats and southern ironstones	7, 9, 10a, 10b	4	1	773
213AbABwy	Abba very wet saline flats Phase	Poorly drained depressions with some areas which become saline In summer. Shallow sands over clay subsoils (i.e. Abba Clays).	Scrub, Melaleuca spp. and Nuytsia floribunda. Barley grass and button grass are often present in pastures. There are also some bare saline patches. Seasonally inundated.	Paperbark scrub and barely grass flats Dense herb-rich saline shrublands in claypans Melaleuca tall dense shrubland over sedges on inundated clay flat Shrublands on dry clay flats and southern ironstones	7, 9, 10a, 10b	2	0	48
213AbCKv	Cokelup vales Phase	Narrow floodplains in small depressions along creeks and rivers. Clayey alluvial soils.	Woodland, paperbark (Melaleuca rhaphiophylla, M. teretifolia). Flooded gum (Eucalyptus rudis) is sometimes present.	Paperbark-flooded gum woodland. Very divers. Largely cleared		4	1	35
213AbCKw	Cokelup wet clayey flats Phase	Poorly drained flats with heavy clayey (Cokelup) soils. Some areas saline in summer.	Paperbark (Melaleuca rhaphiophylla, M. teretifolia) woodland. Flooded gum (Eucalyptus rudis) is sometimes present. Extensively cleared for pasture. Barley grass (Hordeum sp.) and button grass (Cotula sp.) are often present in pastures. Bare patches.	Paperbark-flooded gum woodland and barley grass flats Melaleuca and Acacia mixed shrubland over sedges Melaleuca tall dense shrubland over sedges on inundated clay flat	8, 9	4	1	326
213AbJD1	Jindong flats Phase	Well drained flats with sandy gradational grey brown (Busselton) soils, some red brown sands and loams (Marybrook Soils).	Jarrah-Marri (Eucalyptus marginata, C. calophylla) Forest. Blackboys (Xanthorrhoea spp.) commonly present. Extensively cleared.	Marri woodland over shrubland on low lying wet sand.	1b	4	1	333
213AbJDf	Jindong fertile flats Phase	Well drained flats with deep red brown sands, loams and light clays (i.e. Marybrook soils).	Marri (C. calophylla) Forest. Marri often forms very tall, dense stands. The understory is often peppermint (Agonis flexuosa). Jarrah (E. marginata), blackboy (Xanthorrhoea spp.), Kingia australis and Dasypogon hookeri are sometimes present. Largely cleared.	Marri woodland over shrubland on low lying wet sand. Marri forest with **peppermint** understorey.	1b	4	2	236

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
213AbJDw	Jindong wet flats Phase	Slight depressions, which are poorly drained in winter, with deep red brown sands, loams and light clays (i.e. Marybrook Soils).	Largely cleared for agriculture.	Marri woodland over shrubland on low lying wet sand. Largely cleared for agriculture	1b	4	1	7
213AbW_SWAMP	Abba wet, swamp Phase	Swamp.	Foothills wetlands	Scattered trees over mixed dense low shrubland on dampland. Melaleuca shrubland	4	4	0	42
213AbX_URBAN	Abba disturbed land, urban Phase	Urban		Marri woodland Armstrong Reserve		4	2	5
213FoCSs	Forrestfield CSs Phase	Very low relief (1-5%) foot slopes with rapidly drained deep bleached grey sands and occasionally deep yellow brown sands. Minor occurrence of gravels.		Mountain Marri, Jarrah-Marri woodland and low forest		3	1	558
213FoCSw	Forrestfield CSw Phase	Seasonally inundated swamps, depressions and seepage areas near the base of the foothills with very poorly drained deep bleached siliceous sands (similar to P7b phase).		Melaleuca shrubland		3	0	22
213Pj__B1	Pinjarra, B1 Phase	Extremely low to very low relief dunes, undulating sandplain and discrete sand rises with deep bleached grey sands sometimes with a pale yellow B horizon or a weak iron-organic hardpan at depths generally greater than 2 m; banksia dominant.		Banksia dominant. Dense Kunzea shrubland		3	0	231
213Pj__B1a	Pinjarra, B1a Phase	Extremely low to very low relief dunes, undulating sandplain and discrete sand rises with deep bleached grey sands with an intensely coloured yellow B horizon occurring within 1 m of the surface; marri and jarrah dominant.		Marri and Jarrah dominant. Banksia woodland		3	0	101
213Pj__B1b	Pinjarra, B1b Phase	Very low relief dunes of undulating sand plain with deep bleached grey sandy A2 horizons and pale yellow B horizons.		Banksia woodland		3	0	23
213Pj__B2	Pinjarra, B2 Phase	Flat to very gently undulating sandplain with well to moderately well drained deep bleached grey sands with a pale yellow B horizon or a weak iron-organic hardpan 1-2 m.		Banksia woodland		2	0	44

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
213Pj__B3	Pinjarra, B3 Phase	Closed depressions and poorly defined stream channels with moderately deep, poorly to very poorly drained bleached sands with an iron-organic pan, or clay subsoil. Surfaces are dark grey sand or sandy loam.		Melaleuca shrubland Largely cleared		1	0	6
213Pj__B6	Pinjarra, B6 Phase	Sandplain and broad extremely low rises with imperfectly drained deep or very deep grey siliceous sands.		Melaleuca wetland Largely cleared		1	1	18
213Pj__P1a	Pinjarra P1a Phase	Flat to very gently undulating plain with deep acidic mottled yellow duplex soils. Shallow pale sand to sandy loam over clay; imperfect to poorly drained and generally not susceptible to salinity.		Marri, Wandoo woodland on heavy soils.	3c	2	1	431
213Pj__P1b	Pinjarra P1b Phase	Flat to very gently undulating plain with deep acidic mottled yellow duplex (or ¿effective duplex¿) soils. Moderately deep pale sand to loamy sand over clay: imperfectly drained and moderately susceptible to salinity in limited areas.		Marri, Wandoo woodland on heavy soils.	3c	2	1	532
213Pj__P1d	Pinjarra P1d Phase	Flat to very gently undulating plain with deep acidic mottled yellow duplex soils. Shallow pale sand to sandy loam over clay; imperfect to poorly drained and moderately susceptible to salinity.		Marri, Wandoo woodland on heavy soils.	3c	2	1	80
213Pj__P2	Pinjarra P2 Phase	Flat to very gently undulating plain with deep alkaline mottled yellow duplex soils which generally consist of shallow pale sand to sandy loam over clay.				2	1	37
213Pj__P3	Pinjarra P3 Phase	Flat to very gently undulating plain with deep, imperfect to poorly drained acidic gradational yellow or grey-brown earths and mottled yellow duplex soils, with loam to clay loam surface horizons.		Marri, Wandoo woodland on heavy soils. Low woodland over shrubland on claypan wetland Melaleuca and Acacia mixed shrubland over sedges	3c, 8	2	1	294
213Pj__P3a	Pinjarra P3a Phase	Flat to gently undulating plain with deep, moderately to imperfectly drained gradational or duplex soils, with loam to clay loam surface horizons and subsoils going alkaline.		Marri, Wandoo woodland on heavy soils. Low woodland over shrubland on claypan wetland	3c, 8	2	1	17

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
213Pj__P4	Pinjarra P4 Phase	Poorly drained flats, sometimes with gilgai microrelief and with moderately deep to deep black, olive grey and some yellowish brown cracking clays and less commonly non-cracking friable clays with generally acidic subsoils.		Dense Melaleuca shrubland on clay flats Deeper wetlands on heavy soils Benger	9, 13	2	0	140
213Pj__P4a	Pinjarra P4a Phase	Poorly drained flats. Cracking clays similar to P4 with a thin veneer of grey sand.		Dense Melaleuca shrubland on clay flats Deeper wetlands on heavy soils Benger	9, 13	2	0	10
213Pj__P5	Pinjarra P5 Phase	Poorly drained flats, commonly with gilgai microrelief and with deep black-grey to olive-brown cracking clays with subsoils becoming alkaline.		Woodland over shrubland on heavy clays. Melaleuca tall dense shrubland fringing inundated wetland on clay.	3c, **13**	2	0	39
213Pj__P5a	Pinjarra P5a Phase	Poorly drained flats. Cracking clays similar to P5 with a thin veneer of grey sand.		Woodland over shrubland on heavy clays. Melaleuca tall dense shrubland fringing inundated wetland on clay.	3c, **13**	2	0	93
213Pj__P7	Pinjarra P7 Phase	Seasonally inundated swamps and depressions with very poorly drained variable acidic mottled yellow and gley sandy duplex and effective duplex soils.		Melaleuca tall dense shrubland over sedges on inundated clay flat	9	3	0	199
213Pj__P7a	Pinjarra P7a Phase	Seasonally inundated swamps and depressions with very poorly drained variable acidic mottled yellow and gley duplex soils becoming alkaline with depth.		Melaleuca tall dense shrubland over sedges on inundated clay flat	9	2	0	67
213Pj__P7b	Pinjarra P7b Phase	Seasonally inundated swamps and depressions or seepage areas near the base of the foothills with very poorly drained deep bleached siliceous sands.		Yarloop		1	0	18
213Pj__P8	Pinjarra P8 Phase	Broad poorly drained flats and poorly defined stream channels with moderately deep to deep sands over mottled clays; acidic or less commonly alkaline gley and yellow duplex soils to uniform bleached or pale brown sands over clay.		Melaleuca shrubland fringing wetland		2	0	128
213Pj__P9	Pinjarra P9 Phase	Shallowly incised stream channels of minor creeks and rivers with deep acidic mottled yellow duplex soils.		Marri, **Peppermint** woodland		3	1	251

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
213PjSWP10	Pinjarra P10 Phase	Gently undulating to flat terraces adjacent to major rivers, but below the general level of the plain, with deep well drained uniform brownish sands or loams subject to periodic flooding.		Jarrah-marri-flooded gum forest over **Peppermint**		4	2	750
213PjSWP6a	Pinjarra P6a Phase	Very gently undulating alluvial terraces and low rises contiguous with the plain, with deep moderately well to well drained soils associated with major current river systems and larger streams. Acidic red and yellow duplex soils.		Marri **Peppermint** woodland over shrubland on low lying wet sand.	1b	4	1	189
213PjSWP6b	Pinjarra P6b Phase	Very gently undulating alluvial terraces and low rises contiguous with the plain, with deep moderately well to well drained soils associated with prior stream deposits. Soils are uniform brownish sands.		Marri **Peppermint** woodland over shrubland on low lying wet sand.	1b	4	1	36
213PjSWP6c	Pinjarra P6c Phase	Very gently undulating alluvial terraces and fans. Moderate to moderately well drained uniform friable brown loams, or well-structured gradational brown earths.		Marri **Peppermint** woodland over shrubland on low lying wet sand.	1b	4	1	80
213PjW_SWAMP	Pinjarra wet, swamp Phase	Swamp.		Deeper wetlands on heavy soils. Melaleuca, Typha, reeds	13	3	0	366
214BpBD	Bidella Subsystem	Shallow (5-25 m) minor valleys with gentle side slopes (2-10%) and broad swampy floors, soils are sandy gravels and deep sands.	Jarrah-marri (Eucalyptus marginata-C. calophylla) forest and woodland with sheoak (Allocasuarina fraseriana), bull banksia (Banksia grandis) and snotty gobble (Persoonia longifolia). The valley floors support banksias (B. littoralis, B. attenuata, B. ilicifolia	Jarrah-marri open forest and tall woodland		2	0	443
214BpJL	Jalbaragup Subsystem	Shallow (10-30 m) minor valleys with gentle to low sideslopes (5-20%) and narrow terraced floors. Soils are sandy gravels with some loamy gravels and deep sands.	Jarrah-marri (Eucalyptus marginata-C. calophylla) forest and woodland with bull banksia (Banksia grandis) and snotty gobble (Persoonia longifolia). Understorey of Gahnia trifida, Hakea ceratophylla, H. lasiantha, Dasypogon hookeri and tea-trees (Agonis spp.)	Jarrah-marri forest and woodland		2	0	1226

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
214BpKI	Kingia Subsystem	Broad undulating lateritic crests and divides over sedimentary rocks, relief 5-20 m, slopes 1-10%. Soils are sandy gravels with some deep sands.	Jarrah-marri (Eucalyptus marginata-C. calophylla) forest and woodland with a mid-storey of sheoak (Allocasuarina fraseriana), bull banksia (Banksia grandis), snotty gobble (Persoonia longifolia) and woody pear (Xylomelum occidentale).	Banksia woodland over shrubland on upland dunes.	21b	1	1	4826
214GvKI	Kingia Subsystem (Goodwood)	Lateritic isolated crests and narrow ridges over sedimentary rocks, relief 5-20 m, slopes 1-10%. Soils are sandy gravels with some deep sands.	Jarrah-marri (Eucalyptus marginata-C. calophylla) forest and woodland with a mid-storey of sheoak (Allocasuarina fraseriana), bull banksia (Banksia grandis), snotty gobble (Persoonia longifolia) and woody pear (Xylomelum occidentale).	Jarrah-marri forest and woodland		1	0	313
214GvPR	Preston Subsystem	River channels, narrow flood plains and well drained alluvial terraces. Soils are brown loamy earths and some brown deep sands.	Marri (C. calophylla), peppermints (Agonis flexuosa), blackbutt (E. patens) and flooded gum (E. rudis) with an understorey including Gahnia trifida, Hakea ceratophylla, H. lasiantha, white myrtle (Hypocalymma angustifolium), pineapple bush (Dasypogon hookeri).	Marri-**peppermint**-blackbut-flooded gum forest		3	2	599
214GvRO2	Rosa gentle slopes Phase	Gentle valley slopes and footslopes (Relief 10-30 m, slopes 3-10%).	Marri forest with jarrah, sheoak, bull banksia and snotty gobble.	Jarrah-marri forest and woodland		2	0	137
214GvRO3	Rosa low slopes Phase	Low valley slopes (relief of 30-60 m and gradients of 5-20%).	Marri forest with jarrah, sheoak, bull banksia and snotty gobble.	Jarrah-marri forest and woodland		2	0	8129
214GvRO4	Rosa moderate slopes Phase	Moderate valley slopes (relief 20-50 m, slopes 15-30%).	Marri forest with jarrah, sheoak, bull banksia and snotty gobble.	Jarrah-marri forest and woodland		1	0	886
214ThTRd3	Treeton sandy slopes Phase	Slopes (with gradients generally 5-10% but ranging from 2-15%) with deep bleached sands.	Woodland, predominantly jarrah (Eucalyptus marginata) and marri (C. calophylla) with Banksia spp. Partly cleared for agriculture.	Jarrah-marri-banksia woodland		1	0	50
214ThTRf	Treeton fertile flats Phase	Well drained valley flats and floodplains with deep alluvial soils, often red brown loams (i.e. Marybrook soils).	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Blackbutt (E. patens) and peppermint (Agonis flexuosa) are often present. Largely cleared for agriculture.	Marri-jarrah-blackbutt-**peppermint** forest and woodland		4	2	33
214ThTRh	Treeton hillslopes Phase	Slopes with gradients generally ranging from 2-15% and gravelly duplex (Forest Grove) and pale grey mottled (Mungite) soils.	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Largely cleared for agriculture.	Marri-jarrah forest and woodland		1	0	1654
214ThTRi3	Treeton ironstone slopes Phase	Low slopes (gradients ranging from 2-10%) with shallow gravelly sands over laterite.	Woodland, predominantly jarrah (Eucalyptus marginata), marri (C. calophylla) and Banksia grandis. Mainly left uncleared.	Jarrah-marri-banksia woodland		1	0	435

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
214ThTRv	Treeton valley Phase	Narrow V-.shaped drainage depressions.	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Largely cleared for agriculture. Myrtaceous scrub on narrow swampy valley floors.	Marri-jarrah forest and woodland		3	0	331
214ThTRvw	Treeton wet valley Phase	Broad U-shaped drainage depressions with swampy floors.	On the sideslopes; Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata) on the sideslopes. Largely cleared for agriculture. On valley floor; forest and tall woodland, predominantly marri and jarrah with myrtaceous spp.	Marri-jarrah-paperbark-titree forest and woodland		3	0	197
214WsWC2	Whicher gentle slopes Phase	Slopes 3-10%.	Jarrah-marri (Eucalyptus marginata-C. calophylla) forest and woodland with mountain marri (E. haematoxylon) and a mid-storey of Banksia spp. Common understorey species include woody pear (Xylomelum occidentale), sheoak (Allocasuarina fraseriana), paperbarks	Jarrah-marri-banksia woodland		1	0	3215
214WsWCv	Whicher Valleys Phase	Minor valleys within the escarpment, relief 10-40 m, slopes 5-15%.	Jarrah-marri (Eucalyptus marginata-C. calophylla) forest and woodland with mountain marri (E. haematoxylon) and a mid-storey of Banksia spp. Common understorey species include woody pear (Xylomelum occidentale), sheoak (Allocasuarina fraseriana), paperbarks	Jarri-marri-banksia woodland		2	0	581
214WsYL	Yelverton Subsystem	A raised shelf with a level to gently undulating surface, 10-40 m above the Swan Coastal Plain. Soils are sandy gravels, loamy gravels, sandy earths and deep sands.	Jarrah-marri (Eucalyptus marginata-C. calophylla) woodland. Acacia browniana, Bossiaea ornata, Daviesia preissii, Hibbertia montana, holly leaved hovea (Hovea chorizemifolia), Leucopogon capitellatus and snotty gobble (Persoonia longifolia)	Jarrah-marri woodland		1	0	1392
214WsYL1	Yelverton flats Phase	Raised flats. Duplex sandy gravels, semi-wet soils, yellow deep sands and sandy earths and loamy gravels	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Largely cleared for agriculture.	Marri-jarrah forest and woodland		2	0	696
214WsYL2	Yelverton very gentle slopes Phase	Undulating terrain. Duplex sandy gravels, semi-wet soils, yellow deep sands and sandy earths and loamy gravels	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Largely cleared for agriculture.	Banksia woodland over shrubland on upland dunes. Marri-jarrah forest and woodland	21b	3	1	923
214WsYL3	Yelverton gentle slopes Phase	Slopes 5-10%.	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Largely cleared for agriculture.	Marri-jarrah forest and woodland		1	1	125
214WsYLd	Yelverton deep sandy flats Phase	Level to gently undulating raised shelf, lying 10-40 m above the Swan Coastal Plain. The soils are mainly sands.	Woodland, predominantly jarrah (Eucalyptus marginata) and marri (C. calophylla) with Banksia spp. Partly cleared for agriculture.	Banksia woodland over shrubland on upland dunes.	21b	3	1	1407

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
214WsYLf	Yelverton fertile flats Phase	Occurs on floors of major valleys cutting through the shelf. Soils are brown deep sands and brown loamy earths.	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Blackbutt (E. patens) and peppermint (Agonis flexuosa) often present. Largely cleared for agriculture.	Marri-jarrah-blackbut woodland with **peppermint** understorey		4	2	140
214WsYLi	Yelverton ironstone Phase	Flats with shallow gravelly sands over sheet laterite. Laterite outcrop sometimes present. Gradients 0-2%.	Woodland, predominantly jarrah (Eucalyptus marginata), marri (C. calophylla) and bull banksia (Banksia grandis). Mainly left uncleared.	Jarrah-marri-banksia woodland		1	0	165
214WsYLv	Yelverton valleys Phase	Narrow v shaped minor valleys cutting through the shelf. Soils are brown deep sands and brown loamy earths.	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata) on the sideslopes. Largely cleared for agriculture. Myrtaceous (Melaleuca spp. and Leptospermum spp.) scrub on narrow swampy valley floors.	Marri-jarrah forest and woodland		3	1	158
214WsYLvw	Yelverton wet valleys Phase	Broad U-shaped minor valleys with swampy floors. Soils on the valley floors are non-saline wet soils.	On sideslopes; forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Largely cleared for agriculture. On valley floor; forest and tall woodland, predominantly marri and jarrah with myrtaceous species (Melaleuca spp.)	Marri-jarrah forest and woodland with paperbark and ti-tree on valley floor		3	1	742
214WsYLw	Yelverton wet flats Phase	Poorly drained depressions on the shelf surface. Soils are non-saline wet soils and grey-brown sands and loams.	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata), with myrtaceous (Melaleuca spp., Leptospermum spp.) understory. Some areas of myrtaceous scrub. Largely cleared for agriculture. Rushes (Juncus sp.) common	Marri-jarrah-paperbark-ti tree woodland		3	0	199
214WsYLwi	Yelverton wet ironstone flats Phase	Winter wet flats with shallow red brown sandy and loamy soils over sheet laterite (bog iron ore).	Low heath with emergent paperbarks (Melaleuca spp.), Nuytsia floribunda and Kingia australis.	Low heath with paperbarks		2	0	25
216CoCO1	Cowaramup flats Phase	Flats (0-2% gradient) with gravelly duplex (Forest Grove) and pale grey mottled (Mungite) soils.	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Largely cleared for agriculture.	Marri-jarrah forest and woodland		3	0	988
216CoCO2	Cowaramup gentle slope Phase	Gentle slope (2-5% gradient) with gravelly duplex (Forest Grove) soils.	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Largely cleared for agriculture.	Marri-jarrah forest and woodland		3	1	1198
216CoCOd2	Cowaramup deep sandy rises Phase	Flats and gently sloping rises (gradients 0-5%), with deep bleached sands. Some areas of low and moderate slopes (gradients 5-15%).	Woodland, predominantly jarrah (Eucalyptus marginata) and marri (C. calophylla) with Banksia spp. and Casuarina spp. Partly cleared for agriculture.	Jarrah-marri-banksia-she oak woodland		2	0	921

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
216CoCOdw	Cowaramup wet sandy flats Phase	Poorly drained flats and depressions with deep organic stained sands.	Scrub, sedgelands and low swampy heathlands, Melaleuca spp. Some patches of jarrah/marri (Eucalyptus marginata/C. calophylla) woodland	Paperbark scrub, sedgelands and low swampy heathlands		3	0	49
216CoCOi	Cowaramup ironstone rises Phase	Flats and gentle slopes (0-5% gradient) with some laterite outcrop and shallow gravelly sands over laterite.	Woodland, predominantly jarrah (Eucalyptus marginata), marri (C. calophylla) and Banksia grandis. Mainly left uncleared.	Jarrah-marri-banksia woodland		1	0	598
216CoCOu	Cowaramup, undifferentiated upland Phase	Flats and gentles slopes (0-5% gradient) with gravelly duplex (Forest Grove) and pale grey mottled (Mungite) soils.	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Largely cleared for agriculture.	Marri-jarrah forest and woodland		2	0	12
216CoCOv	Cowaramup vales Phase	Small, narrow V-shaped drainage depression with gravelly duplex (Forest Grove) soils.	On sideslopes; forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Largely cleared for agriculture. Myrtaceous scrub on narrow swampy valley floors.	Marri-jarrah forest and woodland		4	1	390
216CoCOvw	Cowaramup wet vales Phase	Small, broad U-shaped drainage depressions with swampy floors. Gravelly duplex (Forest Grove) soils on sideslopes and poorly drained alluvial soils on valley floor.	On valley floor; forest and tall woodland, predominantly marri and jarrah with myrtaceous (Melaleuca spp., Leptospermum spp.) understory. Some areas of myrtaceous scrub. Largely cleared for agriculture. Rushes (Juncus sp.) commonly present	Marri-jarrah-paperbark-titree woodland and forest		4	1	266
216CoCOw	Cowaramup wet flats Phase	Poorly drained flats and slight depressions with pale grey mottled (Mungite).	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata) with myrtaceous (Melaleuca spp., Leptospermum spp.) understory. Some areas of myrtaceous scrub. Largely cleared for agriculture. Rushes (Juncus sp.) common	Marri-jarrah-paperbark-titree forest, woodland and scrub		3	0	22
216GrGT3	Gracetown low slopes Phase	Low slopes (gradients 5-10%) with deep yellow brown siliceous sands over limestone (i.e. Spearwood Sands). Not exposed to prevailing winds.	Forest and woodland, containing peppermint (Agonis flexuosa), marri (C. calophylla), jarrah (E. marginata), bullich (E. megacarpa), Banksia spp. and blackboy (Xanthorrhoea spp.) with a shrub and grass understory. Some small areas of karri (E. diversicolor).	**Peppermint**-jarrah-marri forest and woodland		4	3	697
216GrGTe	Gracetown exposed flats Phase	Ridge crest, exposed to prevailing winds, with deep and shallow yellow brown siliceous sands over limestone (i.e. Spearwood sands).	Scrub (usually around 4 m tall) with Melaleuca spp., Acacia spp. and Dryandra spp. Areas of stunted peppermints (Agonis flexuosa), blackboy (Xanthorrhoea spp.), marri (C. calophylla), jarrah (E. marginata) and Banksia spp.	Coastal scrub with **peppermints**		3	2	508

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
216GrGTEe	Gracetown exposed slopes Phase	Moderate slopes (gradients 10-15%) on the west coast exposed to prevailing wind directly off the ocean, with deep and shallow yellow brown siliceous sands over limestone (i.e. Spearwood Sands).	Low heath of Dryandra spp., Melaleuca spp., Olearia spp., Acacia spp. Areas of stunted peppermints (Agonis flexuosa) and marri (C. calophylla) and blackboy (Xanthorrhoea spp.). Vegetation may reach 4 m tall in some areas.	Coastal heath with **peppermints**		3	2	1017
216GrGTv	Gracetown valley Phase	Deepish narrow valleys incised into the Gracetown Ridge.	Forest and woodland of peppermint (Agonis flexuosa), marri (C. calophylla), jarrah (E. marginata), bullich (E. megacarpa), Banksia spp. and blackboy (Xanthorrhoea spp.).	**Peppermint**-marri-jarrah-bullich forest and woodland		4	3	17
216GrKPr	Kilcarnup rocky dunes Phase	Low to steep dunes (gradients 5-10%). not exposed to prevailing winds. Dark calcareous sands containing limestone rubble.	Generally scrub or tall peppermint woodland. Peppermints (Agonis flexuosa), Banksia spp., Acacia spp., Blackboy (Xanthorrhoea spp.) and Melaleuca spp. are often present.	Scrub and **peppermint** woodland		2	3	146
216GrKPrE	Kilcarnup exposed rocky dunes Phase	Steep dunes (gradients usually in excess of 20%) with dark calcareous sands containing limestone rubble, on the west coast exposed to prevailing winds directly off the ocean.	Low coastal heath and tall/dense scrub (up to 3 m tall). Stunted peppermints (Agonis flexuosa), Scaevola crassifolia, Olearia axillaris, Acacia spp., Melaleuca spp. and Parrot Bush (Dryandra sessilis) are present.	Coastal heath and **peppermint** scrub		3	2	219
216GrWLv	(Gracetown) Wilyabrup valley Phase	Narrow V-shaped drainage depressions.	On sideslopes; woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Largely cleared for agriculture. Myrtaceous scrub on narrow swampy valley floors.	Marri-jarrah woodland and paperbark scrub		4	1	25
216WvMT4	Metricup gentle slope Phase	Moderate slopes (gradients mainly 10-15%) with gravelly duplex (Forest Grove) soils.	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Some cleared for agriculture.	Jarrah-marri forest and woodland		2	1	528
216WvMTr	Metricup rocky slope Phase	Moderate slopes (gradients mainly 10-15%) with shallow gravelly soils and occasional laterite and granitic outcrop.	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Some cleared for agriculture and Special Rural Subdivisions.	Jarri-marri forest and woodland		2	0	65
216WvMTv	Metricup valley Phase	Valleys with moderately inclined sideslopes and valley floors with relatively steep gradients. Gravelly duplex (Forest Grove) soils.	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Partly cleared for agriculture.	Jarrah-marri forest and woodland		3	1	259
216WvMTvr	Metricup rocky valley Phase	Deeply incised valleys with steep sideslopes and valley floors with relatively steep gradients. Shallow gravelly soils and occasional lateritic and granitic outcrop.	Forest and tall woodland, predominantly marri (Eucalyptus calophylla) and jarrah (E. marginata). Largely uncleared.	Jarrah-marri forest and woodland		2	0	301
216WvWL3	Wilyabrup gentle slope Phase	Gradients 5-10%	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Some pockets of karri (E. diversicolor) forest. Largely cleared for agriculture.	Marri-jarrah forest and woodland, with pockets of karri		3	1	402

MAP UNIT*	Map unit name*	Map unit description*	Map unit vegetation notes*	Vegetation structure**	FCT quadrat**	Habitat quality score	Agonis score	Area (ha)
216WvWL4	Wilyabrup moderate slope Phase	Gradients 10-15%.	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Some pockets of Karri (E. diversicolor) forest. Largely cleared for agriculture.	Marri-jarrah forest and woodland		2	0	357
216WvWLd3	Wilyabrup deep sand Phase	Low slopes (gradients generally 5-10%) with deep bleached sands.	Woodland, predominantly jarrah (Eucalyptus marginata) and marri (C. calophylla) with Banksia spp. and Allocasuarina spp. Partly cleared for agriculture.	Jarrah-marri-banksia-sheoak woodland		1	0	101
216WvWLf	Wilyabrup fertile flat Phase	Well drained valley flats and floodplains with deep alluvial soils. Often red brown loams (i.e. Marybrook soils).	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Blackbutt (E. patens) and peppermint (Agonis flexuosa) are often present. Largely cleared for agriculture.	Marri-jarrah-blackbutt-**peppermint** forest and woodland		4	2	33
216WvWLfw	Wilyabrup wet fertile flat Phase	Poorly drained valley flats and floodplains with deep alluvial soils.	Largely cleared for agriculture. Rushes (Juncus spp.) commonly present in cleared paddocks.			4	0	7
216WvWLr3	Wilyabrup rocky slope Phase	Low slopes (gradients generally 5-10%) with shallow rocky soils and some granitic outcrop.	Forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata).	Woodland on sandy clay loam	3b	3	1	118
216WvWLv	Wilyabrup narrow valley floor Phase	Narrow V-shaped drainage depressions.	On sideslopes; forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Largely cleared for agriculture. Myrtaceous scrub on narrow swampy valley floors.	Marri-jarrah forest and woodland		4	2	249
216WvWLvw	Wilyabrup swampy valley floor Phase	Broad U-shaped drainage depressions with swampy floors.	On sideslopes; forest and tall woodland, predominantly marri (C. calophylla) and jarrah (E. marginata). Largely cleared for agriculture. On valley floor; forest and tall woodland, predominantly marri and jarrah with myrtaceous species (Melaleuca spp.)	Marri-jarrah-paperbark-titree forest and woodland		4	2	67

APPENDIX 3.

Additional information used for the general linear regression modelling for assessing suitable WRP habitat (Section 9).

Table 1. A brief description of the independent habitat variables developed for the habitat suitability model and the general linear regression model.

Variable	Description	Data sets	Comments	Values
Poly_ID	Unique polygon identifier	DAFWA 2007; Bioplan 2009	Not used as a variable	12,080 polygons
Map_unit	Soil-landform map unit to phase level	DAFWA, 2007; Bioplan 2009	Primary polygon unit derived from union of datasets	Map unit code
Soil_System	The number associated with each major soil system grouping	DAFWA, 2007	A primary subdivision of map units	211, 212, 213, 214 and 216
Hab_qual	Based on vegetation structure, floristic composition, soil type and landform position	DAFWA 2007; Bioplan 2009, floristic community types and flora quadrats	Value attributed to each map unit	0–4 (later revised to 0-5 for mapping)
Area_ha	Area of polygon	DAFWA, 2007; Bioplan 2009	Value for each polygon >0.25ha	ha
Area_score	Area of polygon assigned to classes	DAFWA, 2007; Bioplan 2009	Value for each polygon as a score	1–5
Area_1km	Area of all polygons within 1km of polygon centroid	DAFWA, 2007; Bioplan 2009	Value for each polygon derived using ArcMap 10.1 spatial analyst	ha
Dist_near	Distance to nearest polygon from edge of polygon	DAFWA, 2007; Bioplan 2009	Value for each polygon derived using the near table tool in ArcMap 10.1	m
Dist_HQ4	Distance to nearest polygon of Hab_qual 4 from edge	DAFWA, 2007; Bioplan 2009	Value for each polygon derived using the near table tool in ArcMap 10.1	m
Can_cov	Mean canopy cover (density) of vegetation 2012	Landsat imagery, 2012	Mean value for each polygon derived using ER Mapper	%
Can_trend	Index of canopy vigour trend analysis of	Landsat imagery, 2000–2012	Value for each polygon derived using ER	0–6

	vegetation 2002-2012		Mapper	
Veg_cond	Index of vegetation condition	Bioplan 2009; Keighery, 1994	Value for each polygon, incomplete dataset	1–6
Fuel_age	Fuel age score at 2012, i.e. years since last burnt	DEC fuel age shapefile	Value for each polygon. Where multiple fuel ages occurred within a polygon a proportion was applied to the weighted scores and then summed.	1–3
Ago_flex	Presence and dominance of peppermint (*Agonis flexuosa*)	Bioplan 2009; WRP habitat review 2006	Value for each map unit, adjusted for each polygon where Agonis data was available	0–3
Euc_gom	Presence of tuart (*Eucalyptus gomphocephala*)	Bioplan 2009; Atlas of Tuart Woodlands (Government of Western Australia, 2003)	Value attributed to each polygon for presence or absence of tuart.	0–1
Land_tenure	Land tenure classed to reflect security of tenure	State cadastral database. Landgate, June 2012	Value attributed to each polygon. Where multiple tenures occurred within a polygon a proportion was applied to the weighted scores and then summed.	0–4

Notes on the statistical analysis of habitat variables in the general linear models:

1. A landscape variable that categorised polygons into urban, agricultural, riparian and scarp was found to be significant ($R^2 = 0.375$, $P<0.001$), but this was mainly due to the urban category which had a mean WRP density of 6.15 WRP/ha compared with 1.40 WRP/ha for the other categories combined which were not significantly separated. This variable was not readily applied using spatial techniques to all other polygons and was not taken further.

2. There was a significant effect of the four major soil system groupings (zones 211 to 214) on WRP density ($R^2 = 0.269$, $P<0.001$) with mean density being greatest in the 211 systems (4.90/ha, n = 62) and least in the 214 systems (0.82/ha, n = 8). This provided a useful screening for some map units but didn't cover all map units or soil systems in the region, including the 216 soil systems (see Appendix 2 for a description of the soil systems).

3. There was no relationship between WRP density and the proportional area of any of the canopy density trend classes per polygon (i.e. large increase, small increase, stable, small decrease or large decrease in canopy cover during the period 2002–2012).

4. Only two polygons had tuart recorded as being present in the WRP subset, although there are 1,002 polygons with tuart present within the area of interest.

5. Only 19 of the 115 WRP polygons had a record for fuel age, the most recent being burnt in 1964, so all these were classed in the >20 years fuel age class. In the overall data set, there were 1282 polygons with some portion burnt within the last 20 years, and 218 polygons that were all burnt within the last 10 years, so fuel age is likely to be important but could not be included in the analysis.

6. There was no estimate or indication of survey effort and no absence data. It was assumed that the same survey effort was used for all patches and that all animals were counted in each patch. This was probably true for smaller patches, but unlikely for larger patches and the WRP density in these was possibly underestimated. The WRP survey data did not cover the full range of map units and was somewhat biased towards remnants that were likely to have supported WRP. Furthermore, the habitat patches and polygons defined for this project did not always correspond with those surveyed for EIA purposes (usually based on cadastral boundaries), although this was accommodated as much as possible by the initial screening out of polygons that showed very uneven or skewed survey point distributions.

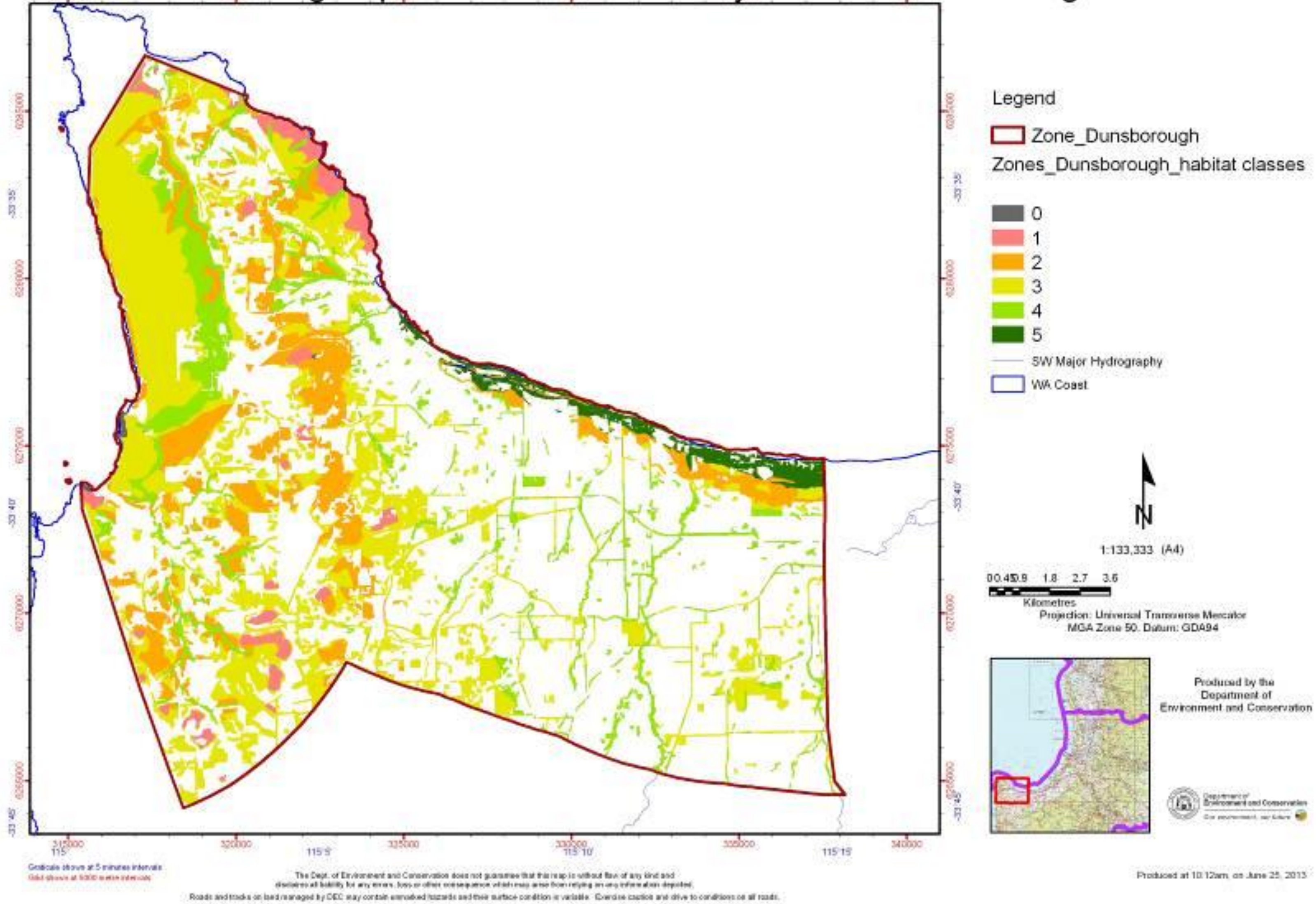
7. For the 36 polygons in the 211Qu_Qf2 map unit, which all have the same Ago_flex score (score 3), the best general linear model included Area_1km and Can_cov and was:

WRP density = 13.202 – 0.008 (Area_1km) – 0.105 (Can_cov) ($R^2 = 0.219$, $P<0.05$).

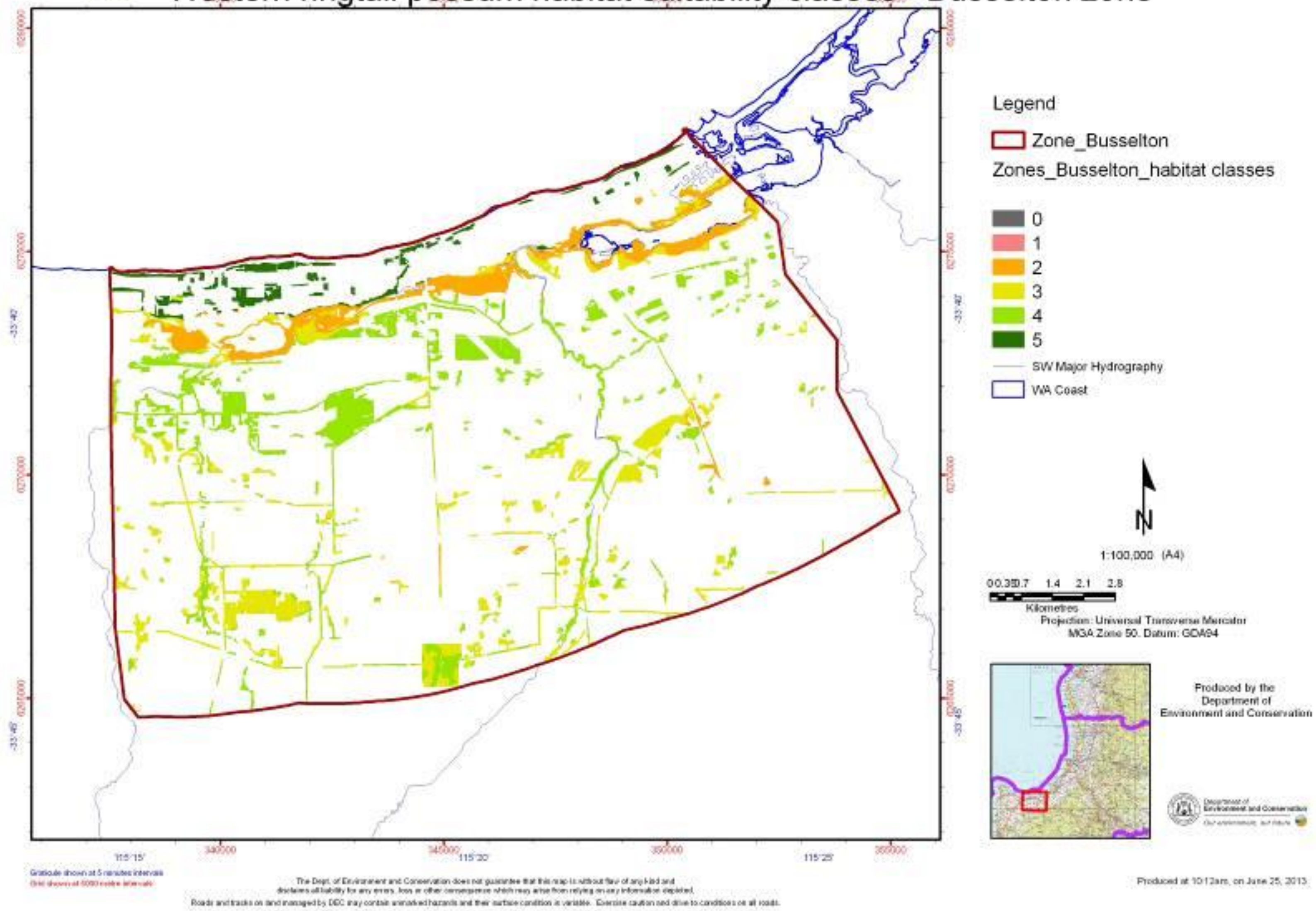
APPENDIX 4.

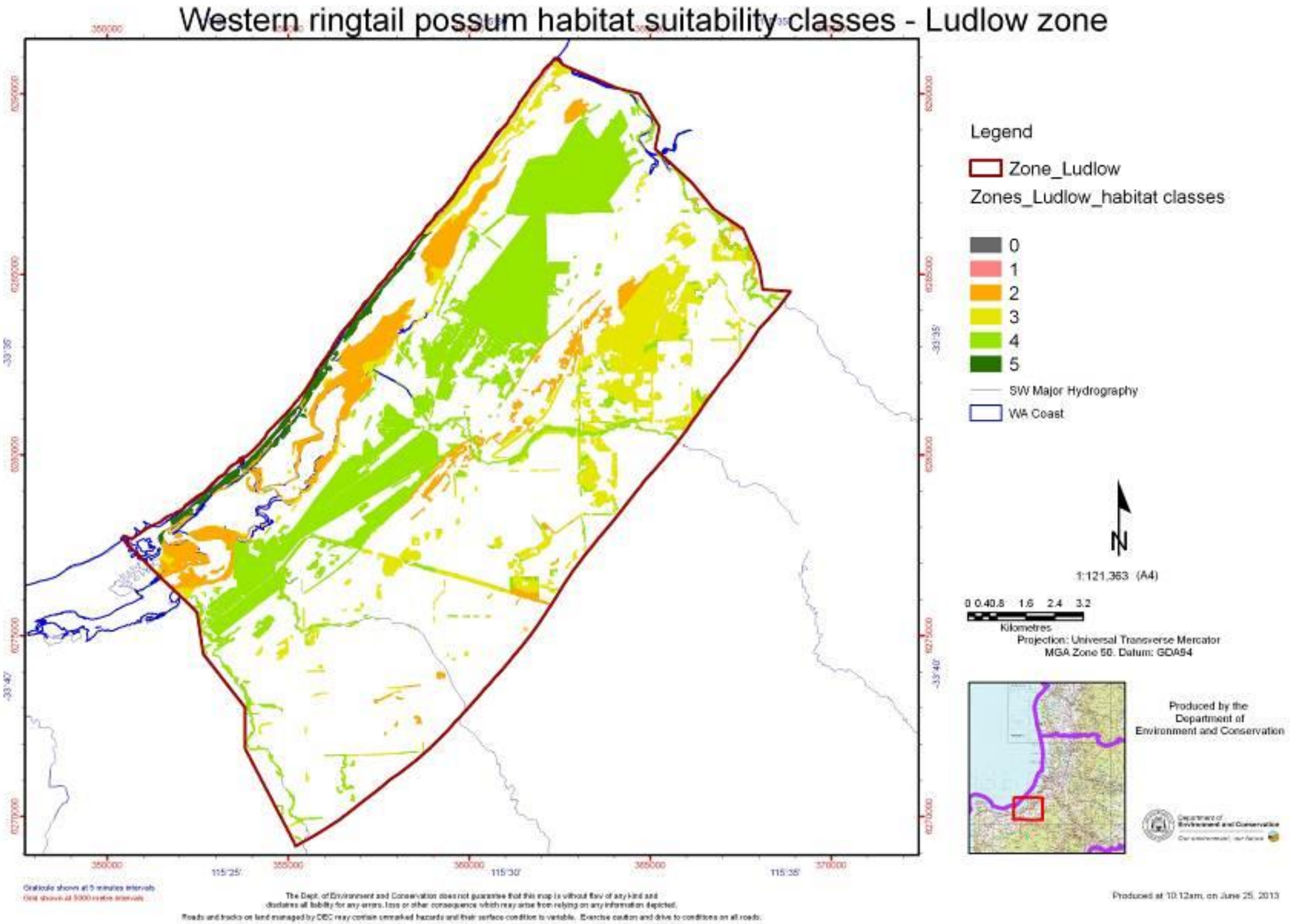
Habitat Suitability maps for the five WRP management zones

Western ringtail possum habitat suitability classes - Dunsborough zone

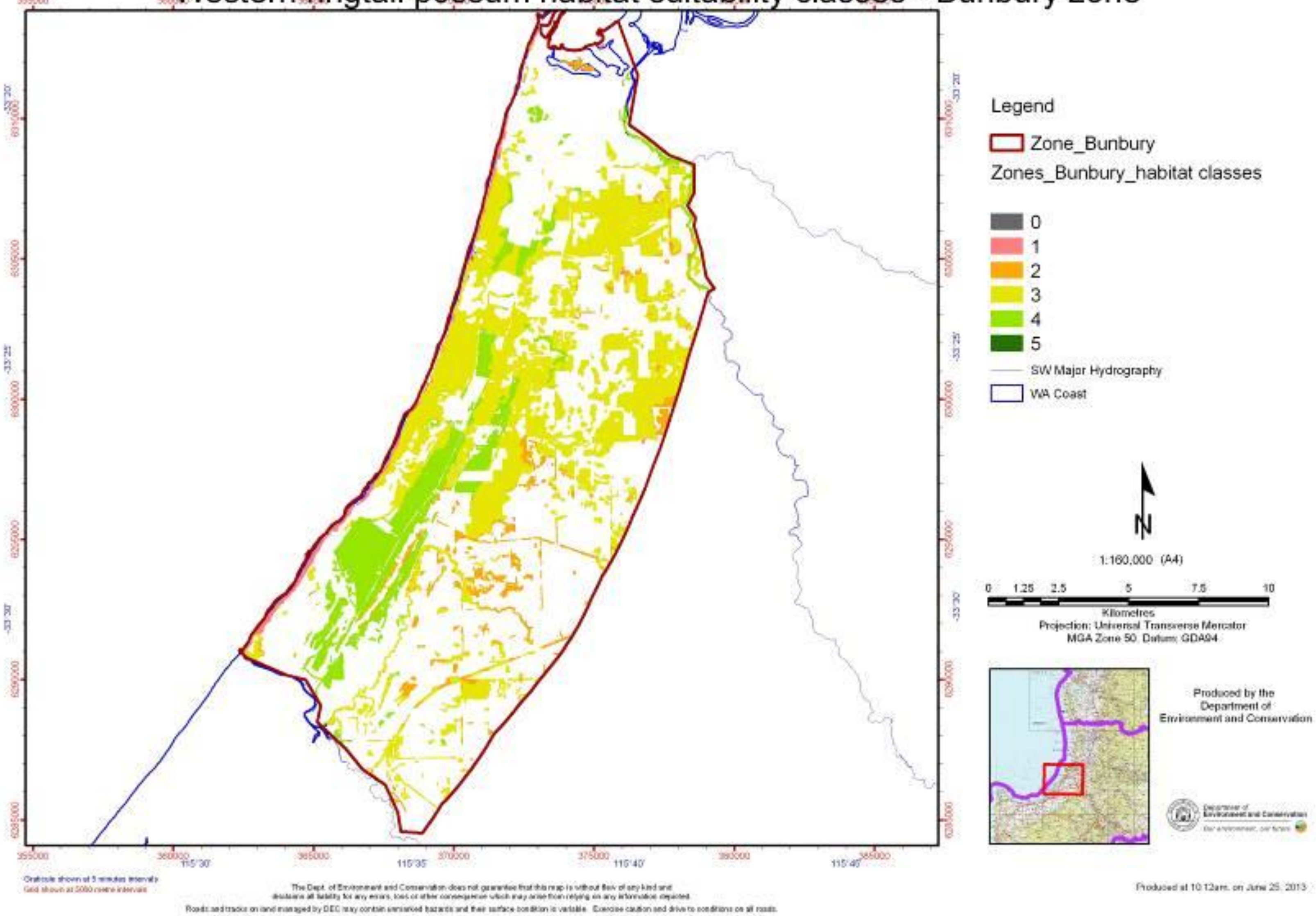


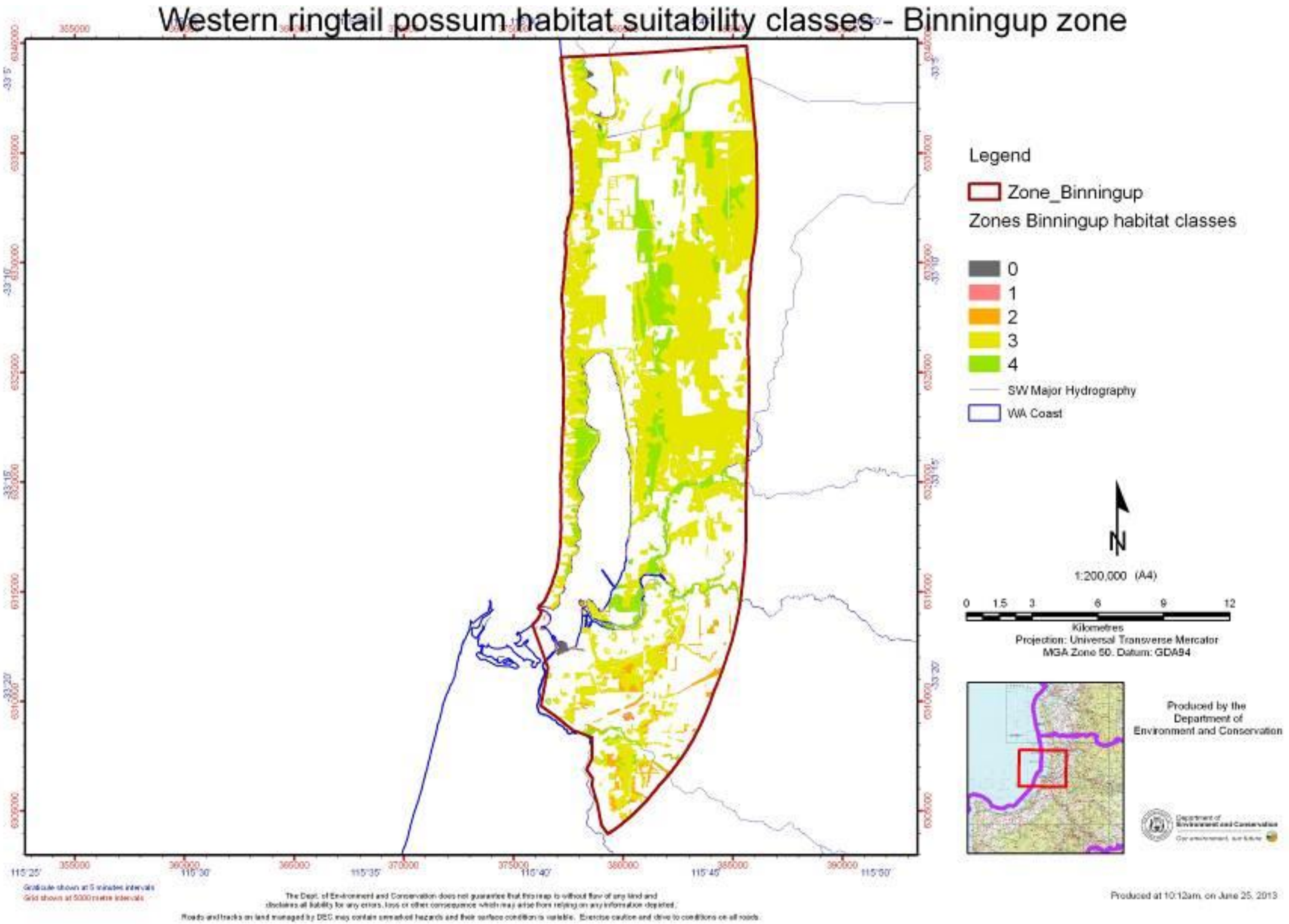
Western ringtail possum habitat suitability classes - Busselton zone




Western ringtail possum habitat suitability classes - Ludlow zone
Legend
Zone_Ludlow
Zones_Ludlow_habitat classes
0
1
2
3
4
5
SW Major Hydrography
WA Coast
N
1:121,363 (A4)
0 0.40.8 1.6 2.4 3.2
Kilometres
Projection: Universal Transverse Mercator
MGA Zone 50. Datum: GDA94
Produced by the
Department of
Environment and Conservation
Department of Environment and Conservation
350000
355000
360000
365000
370000
115°25'
115°30'
115°35'
Graticule shown at 5 minutes intervals
Grid shown at 5000 metre intervals
The Dept. of Environment and Conservation does not guarantee that this map is without flaw of any kind and disclaims all liability for any errors, loss or other consequence which may arise from relying on any information depicted.
Roads and tracks on land managed by DEC may contain unmarked hazards and their surface condition is variable. Exercise caution and drive to conditions on all roads.
Produced at 10:12am, on June 25, 2013

Western ringtail possum habitat suitability classes - Bunbury zone





Western ringtail possum habitat suitability classes - Binningup zone
Legend
Zone_Binningup
Zones Binningup habitat classes
0
1
2
3
4
SW Major Hydrography
WA Coast
N
1:200,000 (A4)
0 1.5 3 6 9 12
Kilometres
Projection: Universal Transverse Mercator
MGA Zone 50. Datum: GDA94
Produced by the
Department of
Environment and Conservation
Produced at 10:12am, on June 25, 2013