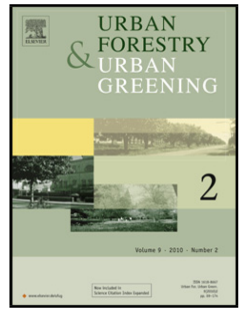
https://doi.org/10.1016/j.ufug.2017.10.016

Bryant, G.L., Kobryn, H.T., Hardy, G.E.St.J. and Fleming, P.A. (2017) Habitat islands in a sea of urbanisation. Urban Forestry & Urban Greening, 28 . pp. 131-137.

Accepted Manuscript



Title: Habitat islands in a sea<!–<query id="Q1">Please check the doc head Öriginal articleänd correct if necessary.</query>–> of urbanisation

Authors: Gillian L. Bryant, Halina T. Kobryn, Giles E. StJ. Hardy, Patricia A. Fleming

PII: S1618-8667(17)30249-2
DOI: https://doi.org/10.1016/j.ufug.2017.10.016
Reference: UFUG 26004

To appear in:

Received date: 27-4-2017
Revised date: 30-8-2017
Accepted date: 22-10-2017

Please cite this article as: { https://doi.org/

Urban Forestry & Urban Greening

Habitat islands in a sea of urbanisation

Gillian L. Bryant, Halina T. Kobryn, Giles E. StJ. Hardy, and Patricia A. Fleming*

School of Veterinary and Life Sciences, Murdoch University, South Street, Murdoch, WA 6152

*Corresponding author. Email: t.fleming@murdoch.edu.au +61 8 9360 6577

ORCIDs:

Kobryn: 0000-0003-1004-7593

Hardy: 0000-0001-7419-5064

Fleming: 0000-0002-0626-3851

Highlights

- Digging mammals, such as quenda, contribute to ecosystem services and bushland health.
- We studied quenda presence across the fastest growing Australian regional city.
- Quenda persist in urban bushland reserves, despite proximity to roads and housing.
- Vegetation extent and condition are primary factors correlated with their presence.
- Quenda avoid reserves frequented by people walking dogs.

Abstract

Cities can provide important habitat for wildlife conservation. Many species do not make much use of anthropogenic resources, but instead are largely reliant on natural habitat remaining within a matrix of urban development, and are engulfed by encroaching housing development. Understanding which factors influence their presence and activities will allow us to manage these habitat remnants for biodiversity conservation. To this aim, we carried out a field survey recording evidence of quenda (*Isoodon obesulus fusciventer*) foraging digs over 106 reserves managed by the City of Mandurah, the fastest growing regional city in Australia. We identified vegetation extent and condition as primary factors correlated with the presence of quenda digging activity. In addition, the extent of canopy cover and amount of woody debris are important habitat variables to quenda, while there was a negative correlation with access to the reserves by domestic dogs (*Canis lupus familiaris*). Although we included a range of urbanisation measures in the analyses (including the amount of roads nearby to each reserve, the distance to roads and the distance to buildings), none were correlated with quenda digging activity. This study indicates that quenda can persist in the urban landscape despite human activities, but highlights the importance of protected bushland reserves for their conservation.

Key words: bandicoot; novel habitat; mammal; Peramelidae; predator; urbanisation

Introduction

The spread of anthropogenic development across the globe has created many novel environments (Ellis and Ramankutty, 2008; Ramalho and Hobbs, 2012) that provide unique opportunities for wildlife. Although some species actively avoid urban areas ('urban avoiders', sensu McKinney, 2006; 'urbanophobes', sensu Witte et al., 1985), cities can also provide important habitat for many others, and can therefore be important locations for biodiversity conservation (Miller and Hobbs, 2002). Many synanthropic species ('urban exploiters', sensu McKinney, 2006) actively invade cities, where they exploit anthropogenic food and shelter to attain population densities far above those found for rural habitats (Bateman and Fleming, 2012). Other species do not make much use of anthropogenic resources, but rather are largely reliant on natural habitat lying within a matrix of urban development. These engulfed populations face the challenge of maintaining movement through an increasingly fractured landscape to access remnant patches of suitable habitat, have to adapt to declining habitat quality and encroachment of weeds, as well as the presence of introduced feral and domestic predators within these habitat patches.

Urban sprawl in Western Australia has resulted from a marked population increase over the last two decades. Perth is the most rapidly growing of all Australia's major cities. The development of housing now stretches more than 120 km north to south, joining up with Mandurah, Australia's fastest growing regional city. This human population explosion has rapidly changed the landscape to a sea of buildings, urban parks, and roads. However, there are still at least 1,000 isolated patches of remnant native vegetation within this Perth-Mandurah urban footprint – vital bushland spaces for our persisting plant and animal biodiversity, and to serve community as parks. In a country where the vast majority of the population live in a city, planning of future development needs to take into account the habitat for endemic fauna and flora to retain the quality of life that Australians currently experience.

Digging mammals can play an important role in maintaining healthy urban bushlands. These ecosystem engineers turn over substantial volumes of soil as they dig to forage on invertebrates, subterranean fungi, and plant material (e.g. Valentine et al., 2013; Valentine et al., 2017). Their digging activities drive ecosystem processes such as soil formation, water infiltration, nutrient cycling, and seedling recruitment (reviewed by Davidson et al., 2012; Eldridge et al., 2012; Fleming et al., 2014). Additionally, mycophagous mammals disperse beneficial fungi (e.g. mycorrhizae) and their diggings (Fig. 1) can create suitable sites for microbial growth. Mammal diggings and their scats can therefore increase plant vigour and resilience, increase biodiversity, and consequently improve ecosystem functioning.

Bandicoots (Peramelidae) manipulate and move soil using their strong forefeet and claws (biopedturbation) as they forage for mycorrhizal fungi, invertebrates, tubers and seeds. The quenda (*Isoodon obesulus fusciventer*) is one of five subspecies of southern brown bandicoot, although quenda are sufficiently different from eastern states subspecies (Westerman et al., 2012) to warrant being classified a species on its own (K. Travouillon WA Museum pers. comm.). Quenda play an important role in ecosystem regulation, with an individual quenda creating up to 45 foraging pits a night and displacing ~10 kg soil/day (up to 3.9 tonnes soil/year) (Valentine et al., 2013).

Many bandicoot species have not fared well in the face of urbanisation. For example, in the greater Melbourne area, there has been a wave of local extinctions of *Isoodon obesulus obesulus* populations emanating outwards from the city as urban development has expanded (Maclagan, 2016). By contrast, quenda have remained present as their habitat has steadily become engulfed by urban development in Western Australia (Howard et al., 2014). However, habitat availability for quenda is decreasing daily; connecting and enhancing bushland remnants can increase their functional role for biodiversity conservation.

Because bandicoots, on account of their body shape (Coetsee et al., 2016), are notoriously difficult to attach radio-tracking devices to for long-term monitoring of post-translocation survival (Nastov, 2009), there has been little evidence for the success of translocated quenda populations. Some studies suggest success in the short-term (Cairnes, 2007), while animals also readily disperse from the release site (Nastov, 2009) and are vulnerable to starvation, predation, and injury on roads (Mawson, 2004). Despite this scant and contradictory evidence, quenda are regularly trapped and relocated to make way for ongoing housing development that invariably means loss of fauna habitat. City councils need to approve clearing for developments, but also need to identify suitable bushland sites for translocation of moved animals. Translocation sites need to be identified with consideration of resident animals and well as habitat quality, as the presence of quenda is strongly correlated with the amount of native vegetation present (Howard et al., 2014). Identifying population strongholds and factors that are correlated with quenda presence may therefore assist with appropriate site selection for translocated animals.

In addition to the existence of suitable habitat and resident quenda populations, vulnerability of urban bandicoot populations to introduced predators also needs to be given consideration. A previous citizen science study on quenda in the Perth metropolitan area found that predation accounted for 30% or mortality events (113 reported quenda deaths), with 98% of the predators being identified as cats (*Felis catus*), dogs (*Canis lupus familiaris*), or red foxes (*Vulpes vulpes*) (the remaining 2% by raptors) (Howard et al., 2014). Many urban bushland reserves have red foxes present, with numbers controlled on an ad hoc basis by pest management services contracted by Shire or City Councils. Although there are laws requiring domestic cats are de-sexed and microchipped (Western Australia *Cat Act 2011*), stray and domestic cats are not restricted (by law) in regard to their movements through reserves. And finally, many reserves allow dog walkers, with dogs permitted on and off the lead. A key aspect of the suitability of reserves is therefore whether there is sufficient suitable cover to reduce predation risk for bandicoots.

In this study, we set out to identify factors that were correlated with the presence of quenda foraging digs across the urban bushland reserves. Comparing different activity levels with environmental measures may indicate factors that deter these animals from foraging at particular sites. This study therefore sets out to increase understanding of the ecology and habitat requirements for conservation of quenda, informing management.

Methods

Reserves managed by Mandurah were identified through GIS maps produced using the City of Mandurah's Management Order layer. Over the period from 8^{th} - 15^{th} July 2014 (i.e. mid-winter), a census of 106 reserves was carried out to quantify quenda digging activity across the city and capture a range of habitat variables that could be linked with quenda presence. Following field surveys, GIS analysis of these sites was undertaken and the data were analysed statistically for associations with the identified factors.

Quenda presence and level of digging activity was quantified for each location through field survey for signs of foraging digs. Foraging digs were identified based on their distinctive size and shape (Figure 1); these diggings are conical in shape (following the shape of their nose and mandible) with an average diameter of 100.9 ± 3.9 mm, depth of 69.6 ± 3.2 mm (depth range 35–135 mm), and volume of 191 ± 15 ml (Valentine et al., 2013). The foraging digs are sufficiently distinctive; no other species present create similar sign.

The reserves surveyed ranged from urban parks, estuary foreshore areas, vegetated reserves, and bush pockets. The GPS location of each site was recorded (Garmin GPS72H, Garmin Corporation, Taiwan) and its location described (e.g. closest street names and/or name of reserve if present). At each of the 106 study locations, we surveyed for quenda digs, and then carried out a broad habitat survey, focussing on the whole reserve, and then recording at a smaller scale using quadrats located at the approximate centre of each reserve (or the largest remnant patch of bush was targeted for urban parks where available) (Table 1).

Fences around reserves ranged from wire barricades (cyclone barrier fences, ring-lock), which varied in terms of state of repair and sometimes were not complete on all sides of the reserve. Due to the highly variable nature of fencing around the reserves, we did not include the presence of fences around reserves per in our statistical analysis, but did use evidence of fencing to assess the likelihood that stray and domestic dogs could access the reserves. We assumed that there was no dogs in a reserve ('no dogs=0') where there was suitable fencing and signage precluding dogs. We assumed that dogs were present ('dogs present=1') where there was signage indicating dogs were allowed off lead, allowed on a lead, or there was no signage precluding dogs but evidence that dogs had been present (e.g. scats, footprints, dogs present at the time of data recording). We attempted to record evidence of cats and foxes in reserves, but there was insufficient sign at the time of the survey to make this attempt valuable.

We also collected data for a GIS-based desktop survey of each site using ArcGIS 10.2 software (Environmental Systems Research Institute, USA). We obtained GIS layers for management and bushland shape (custodians: City of Mandurah) and native vegetation extent (2014 custodian: Department of Agriculture & Food WA). We used the Buffer function in ArcGIS to create 200 m and 2,000 m buffers and clipped these buffers to available land area (i.e. removing watercourses such as the ocean or estuary). The available land area buffers were intersected with GIS data layers to identify the extent of available native vegetation and road density. The Distance function was used to calculate proximity of closest road, urban development, wetland and native vegetation.

A multiple regression analysis (Statistica 8.0, Statsoft Inc, 2007), with a multinomial distribution and a logit link function, was used to determine which factors were most strongly correlated with the level of quenda digging activity across Mandurah. The variables listed in Table 1 were included as independent factors and quenda digging activity as the dependent factor.

Results

We recorded quenda foraging digs for 106 reserves covering the entire study area (Figure 2). Although we surveyed numerous small reserves within the highly urbanised centre of this range, there were no digs recorded in the central zone of Mandurah.

Quenda digging activity was correlated with a range of habitat variables (Table 2). We found more quenda foraging digs for reserves with a higher percentage canopy cover, more woody debris, and greater percentage cover of native vegetation within a 200 m buffer of the site (Figure 3a-c). In addition, reserves that were categorised as having the best quality vegetation condition (i.e. 'excellent') usually had more quenda digging activity and there was quenda digging activity in numerous reserves categorised as 'good' and 'mediocre' (Table 3, Figure 3d; Appendix 1). Presence of domestic dogs on the reserve was also significantly correlated with the presence of quenda foraging digs (Figure 3e, Table 2).

Interestingly, factors that are correlated with the degree of urbanisation, including the distance to roads, the amount of linear meters of roads within buffer zones surrounding the reserves and also the distance to any urban development such as buildings (houses, offices etc.) were not significantly correlated with the amount of quenda digging activity.

Discussion

Many mammal species are excellent urban adapters, persisting in novel urban and peri-urban landscapes, despite high levels of human disturbance. Quenda appear to be one of those species. Somewhat surprisingly, the GIS measures we used in our analyses to indicate urbanisation (e.g. density of roads and urban development and distances to roads) were not significantly correlated with quenda activity within reserves across the city. Instead, habitat quality (including canopy cover, native vegetation extent, and woody debris) was strongly correlated with quenda persistence. Quenda digging activity was greater for reserves classified as 'excellent', 'good' and 'mediocre' condition (Table 3), than in reserves categorised with lower quality category (e.g. 'poor', 'degraded' or 'urban park'). Most notably, we found marked differences in quenda activity between reserves where domestic dogs were present or excluded (e.g. through fencing or signage). Bandicoots may therefore persist in highly developed novel landscapes, as long as there is suitable habitat for foraging and protection from predators. Urban areas may suit bandicoots due to the complexity of habitats available, with the mosaic of open sites for foraging and protective cover for rest sites within the urban matrix likely to suit their feeding and nesting requirements.

Bandicoots make use of a range of novel habitats in urban environments for foraging. Quenda regularly forage across open lawns (this study; Fitzgibbon et al., 2011). Long-nosed bandicoots (*Parameles nasuta*) utilise open areas, spending two-thirds of foraging time in the open, and a lack of understorey and absence of leaf litter have been identified as major microhabitat features reflecting their habitat choice (Chambers and Dickman, 2002). The density of bandicoot foraging digs made by eastern barred bandicoot (*Parameles gunnii*) is positively correlated with ground cover and plant height, although they also forage over garden lawns (Dufty, 1991). Open areas could also provide better manoeuvrability or increased visibility of predators during foraging (Chambers and Dickman, 2002).

Dense, structurally complex cover is required by bandicoots for protective diurnal nest sites (e.g. Chambers and Dickman, 2002; Fitzgibbon et al., 2011; Mallick et al., 1997). Man-made debris (e.g. corrugated iron, timber and machinery), has been recorded as opportunistically used for nest sites (Dufty, 1991), in addition to vegetation in suburban gardens (Seebeck, 1979). Long-nosed bandicoots primarily nest during daylight hours in dense (>60% cover) scrub vegetation, especially in thickets of introduced weedy species (e.g. *Lantana camara* or Pampas grass *Cortaderia selloana*) (Chambers and Dickman, 2002) or blackberry (*Rubus fruticosus* aggregate) (Mallick et al., 1997). Southern brown bandicoots also make extensive use of blackberry thickets (Packer et al., 2016; Paull, 1993), and in a study across 13 study sites in South Australia, were more abundant in sites with heavily disturbed vegetation dominated by blackberry (Packer et al., 2016). Bandicoots therefore appear to prefer dense vegetation, irrespective of the nature of this vegetation. Their use of invasive shrubs (e.g. *Lantana*, blackberry) presents a conundrum for bandicoot conservation management in urban landscapes (Mallick et al., 1997); these novel habitats may traditionally be perceived as having limited value for ecological restoration, and yet these ecosystems have value (Perring et al., 2013; Standish et al., 2013) if removal of weeds would result in increased vulnerability of bandicoots to introduced predators.

Our data showing reduced quenda activity at parks where there was evidence of domestic dogs supports the results of Carthey and Banks (2012), who found that bandicoots in Sydney avoid backyards with domestic dogs (but not domestic cats). By contrast, in Hobart, Tasmania, where dingos (*C. lupus dingo*) have never been present, bandicoots appear to be naïve to the presence of both dogs and cats (Frank et al., 2016). The recent citizen science study on quenda in the Perth metropolitan area reported quenda living and sometimes even feeding side-by-side with resident cats and dogs (Howard et al., 2014), despite the potential predation risk. We could not take into account domestic cat ownership in our study, although numerous stray/domestic cats were observed on occasion moving into and out of the reserves during the study. We also did not record evidence of red fox presence, although these predators are known to have a substantial impact on quenda populations (e.g. Abbott and Whitford, 2001; Harris et al., 2010). Proper survey of the numbers of these predators would require longer-term monitoring (e.g. with camera traps).

We are currently managing ecosystems that have undergone a massive loss of ecosystem processes over the last ~200 years (Fleming et al., 2014). The loss of digging mammals from our urban landscapes can lead to untold outcomes in the future, and it is quite likely that the effects of lost tree recruitment have yet to be felt for many systems. For example, without digging mammals to break up the hydrophobic surface crust of the soil and create a heterogeneous surface (e.g. Eldridge and Mensinga, 2007; Garkaklis et al., 1998), plant seeds are more likely to fall prey to seed predators and are less likely to find suitable sites for germination, leading to reduced recruitment (e.g. Alkon, 1999; Guo, 1996; James and Eldridge, 2007; Murphy et al., 2005; Newell, 2008). Maintaining populations of urban quenda can therefore serve to ensure healthy bushland reserves within the urban matrix, and their foraging digging activity needs to be recognised for its ecological value rather than as a social nuisance.

Conclusions and recommendations for management

We identified which of 106 reserves were currently being used by quenda, and therefore could be suitable for future translocations.

Vegetation condition was clearly a primary factor associated with the presence of quenda across the reserves surveyed. Actions such as weed control and feral pig control may serve to improve habitat quality.

Control of introduced predators is also a priority, including baiting or trapping for red foxes and feral cats, increased signage for dog owners, as well as installing fences around or within reserves to delineate habitat for quenda.

Understanding how quenda move between habitat patches is important, because even small populations can be viable if they are embedded in a permeable landscape that offers opportunities for individuals to move between seasonally available resources and for genetic mixing. Managing these animals at the metapopulation level, enabling movement that could preserve long-term genetic viability of populations through underpasses and vegetation corridors, can ensure the future for urban quenda.

Acknowledgements

This work was funded by the City of Mandurah and the Research Centre for Climate Change Woodland and Forest Health. Our thanks to Brett Brenchley for his support and to Kenny Travouillon (WA Museum) for contributions.

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Figures and Tables

Figure 1. Photographs of (a) a quenda, and (b) example of their foraging digs identified. In (b), the author is indicating the impression of the animal's tail while the arrows indicate the impression of the quenda's hind feet positioned while digging.

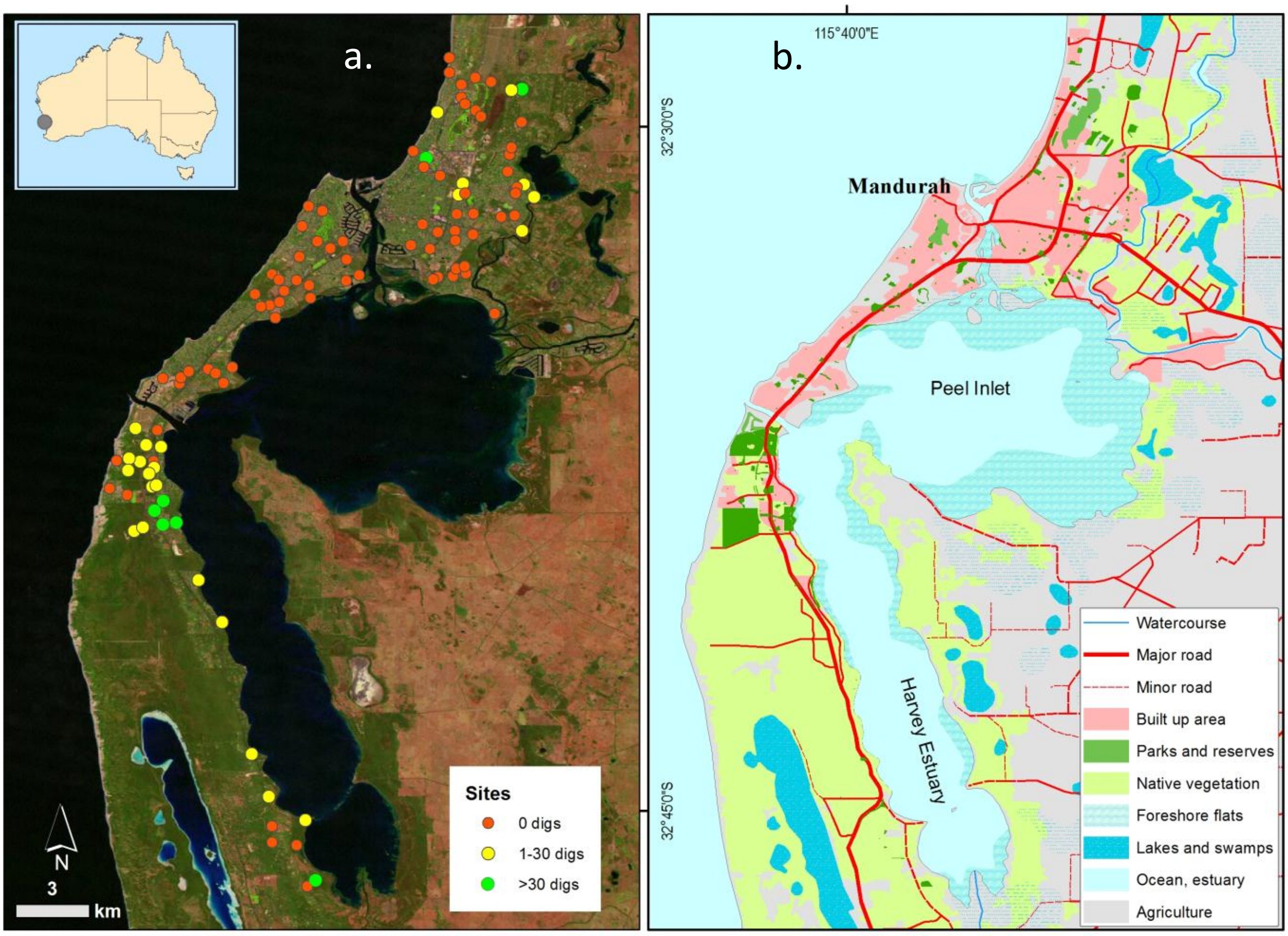

Figure 2. Survey sites of reserves managed by the City of Mandurah showing the relative numbers of quenda diggings recorded shown against (a) satellite image (Landsat Australia) and (b) urban map (Geoscience Australia topographic layer maps 1:250000 series; City of Mandurah for parks and reserves boundaries). Green dots indicate there were more than 30 foraging digs within the 10 x 10 m quadrat, yellow dots indicate 1–29 foraging digs were recorded, and red dots indicate that no digs were recorded.

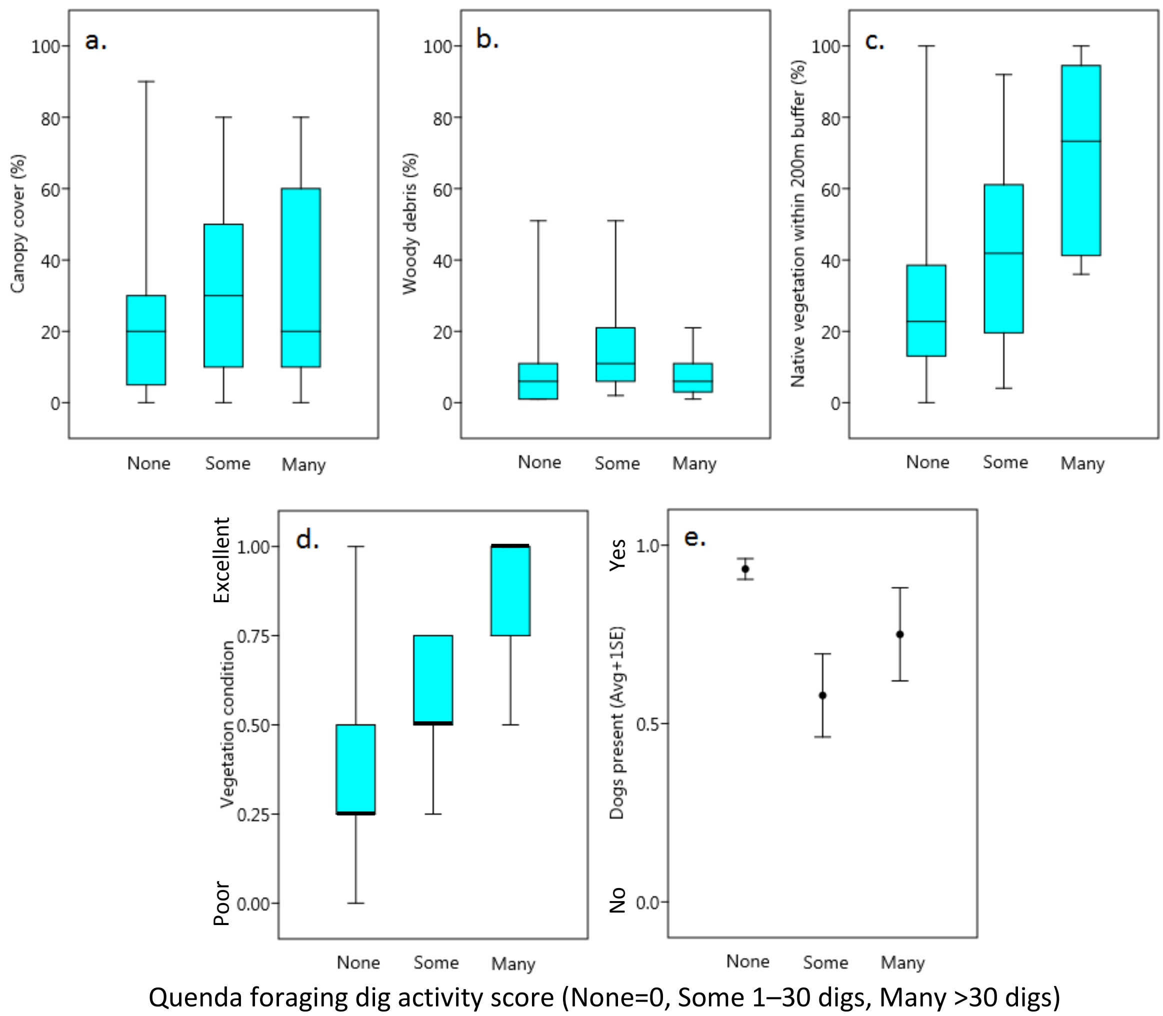

Figure 3. Habitat variables that were significantly correlated with the amount of quenda digging activity across reserves managed by City of Mandurah: no foraging digs ('None', 75 sites), 1–30 ('Some', n=19 sites), or >30 ('Many', 12 sites) foraging digs recorded in 100 m^2. a-d show medians (horizontal line), with boxes representing quartiles and whiskers the range of data. a) estimated percent canopy cover within a 10 x 10 m quadrat, b) estimated percent of woody debris within a 5 x 5 m quadrat, c) percentage of native vegetation extent within a 200 m buffer zone around each study site, d) vegetation condition (scored as: excellent=1/good=0.75/mediocre=0.5/ degraded=0.25/poor=0), and e) presence of dogs at each site, average ± 1SE of score: no dogs=0/dogs=1 (allowed off lead, allowed on a lead, or there being no signage precluding dogs and evidence of dogs recorded).

Table 1. List of habitat variables recorded for each sample location.

	Scale	Variable measured	Method
On ground field surveys	Whole reserve	Presence of dogs	Scored as: no dogs=0, or dogs=1 (allowed off lead, allowed on a lead, or there being no signage precluding dogs and evidence of dogs recorded).
		Fencing	Recorded as completely or partially fenced, or fences absent
	10 x 10 m quadrat	Percentage canopy cover	Subjective estimate†
		Vegetation condition score	Subjective categories†: excellent=1, good=0.75, mediocre=0.5, degraded=0.25, poor=0
		Vegetation type	1. Coastal woodland jarrah or tuart woodland, 2. Coastal heath, or 3. Estuary vegetation
		Total number of quenda digs in quadrat	Categorised as: 1. None (0 digs), 2. Some (1–30 digs), and 3. Many (>30 digs)
	5 x 5 m quadrat (nested within the larger quadrat)	Percentage cover of bare ground, leaf litter, understory vegetation cover (<1 m vegetation height)	Subjective estimate†
		Dominant understory species	Species identified and recorded and percentage cover for each dominant understory species recorded
		Soil type	1. Loamy sand, 2. Sand, 3. Silt, or 4. Clay
GIS analyses	200 m and 2,000 m buffers around each site	Native vegetation extent	Percentage of native vegetation cover within the buffer
		Road density	Total amount of linear metres of roads in each buffer size
	Distance measures	Distance (m) to nearest road Urban development (e.g. house, building etc.) Ramsar wetland Native vegetation	Distance (m) for each

† All subjective estimates were carried out by one person (GLB)

Table 2. Multiple regression analysis indicating factors contributing to the amount of quenda digging activity across reserves managed by City of Mandurah. Asterisks indicate significant factors (*P<0.05).

Variable (degree of freedom=2)	Wald statistic	*P* value
% Canopy cover	**9.30**	**0.047***
% Woody debris	**0.608**	**0.026***
% Native vegetation (200 m buffer)	**1.87**	**0.050***
Vegetation condition	**11.3**	**0.008***
Dogs? (Y/N)	**1.46**	**0.010***
% Leaf litter	7.32	0.403
% Bare ground cover	1.82	0.392
% Vegetated (<1 m height)	6.12	0.738
% Native vegetation (2000 m buffer)	6.01	0.633
Distance (m) to native vegetation	0.914	0.728
Linear road length (m) (200 m buffer)	2.20	0.217
Linear road length (m) (2000 m buffer)	3.06	0.875
Irrigated lawns close? (Y/N)	9.77	0.481
Distance (m) to urban development	0.635	0.469
Distance (m) to road	1.52	0.179
Distance (m) to Ramsar wetland	3.44	0.333

Appendices

Table 1. Examples of 51 of the larger reserves that have been considered. Identification of 12 reserves managed by City of Mandurah with >30 quenda foraging digs, 19 reserves with 1≥30 digs and 20 reserves with no digs and the associated vegetation category condition score for those reserves. NB. Reserves categorised as 'poor', 'degraded' and 'urban park' condition with an absence of quenda digs recorded are not shown here.

# Of foraging digs	Vegetation condition	Dogs (Y/N)	Name/description of reserve
> 30 digs	Excellent	N	Fernwood Rd bush site (western side of road)
		N	Gumnut Reserve
		Y	Marlee Reserve*
		Y	Touchstone Reserve
	Good	Y	Estuary Strip North Bouvard area
		Y	Island Point Reserve (north east corner)*
		N	Kulin Road reserve
		N	Southern green zone
		N	Tim's Thicket bush area (east)
		N	Tim's Thicket Coastal area (west)
	Mediocre	N	Bouvard Wood Reserve
		N	Corner Old Coast Road and Ocean road
Between 1≥30 digs	Good	N	Bush Fire Brigade area
		N	Corner Turner Close and Ocean Road
		N	Dawesville reserve (eastern side)*
		Y	Estuary Koolyanga Reserve
		Y	Estuary Strip south Bouvard area
	Mediocre	Y	Buy back Marlee extension
		N	Caddadup Reserve (Eastern side)*
		Y	Corner Alanta Place and Montana Loop Reserve
		Y	Corner Albany Drive and Cuballing Retreat
		N	Corner southern Estuary Rd and Old Coast Road
		N	Dandaragan Rd strip
		N	Dawesville gold course Caddadup Res
		N	Dawesville reserve (western side)*
		Y	Ronsard Rd
		Y	St Ives Carnegie Place
		Y	Strip area Balingup Loop
	Poor	N	Caddadup Reserve (Water corp site)
		N	Corner Balwina Road and Bular Rd Reserve
		N	Corner Calvert and Stafford Court Reserve
No digs found	Excellent	N	Tindale Reserve*
	Good	N	Bush Buy Back (red zone) Southern region*
		Y	Harry Perry Reserve
		Y	Island point Reserve (southern corner)*
		Y	Novara Foreshore Reserve
	Mediocre	Y	Caddadup Reserve (North east side)*
		Y	Camden Way Reserve
		Y	Caspian Drive Res*
		Y	Corner Hudson Drive and Dottorel Drive
		N	Corner Jubata and Dotterel Drive*
		Y	Eros Reserve (Karinga Road)
		Y	Janis Street coastal strip
		Y	Linville Reserve*
		N	Marungi Way Park*
		Y	Norma and Allan Withers Reserve (Hooghly St.)*
		N	Ocean Road and Florida Road reserve
		Y	Paraguay Ave Reserve*
		Y	Pleasant Grove Reserve
		Y	Riverview Street reserve
		Y	Walpole Way Reserve

*Indicates reserves with ring-lock fencing around the reserve (to some degree)