Signs of wildlife activity and *Eucalyptus wandoo* condition

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Soil disturbance by terrrestrial vertebrates when foraging for food and shelter is not only a sign of activity but an ecosystem function required for soil health. Many forests and woodlands worldwide are currently showing signs of a decline in condition due to various causes. *Eucalyptus wandoo,* endemic to south-west Western Australia, has undergone a decline in condition over the last decade. This paper explores the influence of *E. wandoo* condition (e.g. loss of canopy) and the associated changes in the habitat (e.g. changes in leaf litter and bare ground cover) on the foraging activities and soil disturbance by vertebrates. The number of diggings and scats, a representation of the foraging effort by some vertebrates, were recorded in Dryandra Woodland and Wandoo Conservation Park, Western Australia. Mixed-model ANOVAs were used to explore the relationships between the number of scats and diggings with tree and habitat characteristics. More vertebrate diggings and scats were recorded beneath healthier *E. wandoo* trees. Diggings and scats were also correlated with time since last fire and seasonal differences, with more time since last fire and wetter months related to more diggings and scats. Changes in foraging effort, or turnover of soil by verterbates, could be a result modification of the level of soil turnover and alter many ecosystem services such as tree recruitment and nutrient cycling, in turn altering the habitat quality and even tree condition itself.

Soil is disturbed by terrestrial vertebrates when searching for food. Changes in soil disturbance can influence ecosystem processes such as soil turnover, potentially altering habitat quality and tree condition. Forest and woodland declines in condition are occurring worldwide. This study linked *Eucalyptus wandoo* decline in the south-west of Western Australia to changes in soil disturbance.

Additional keywords: diggings, ecosystem function, *Eucalyptus wandoo,* foraging resources, scats, time since last fire.

Introduction

Diggings, bioturbation, pedturbation or simply ‘soil disturbance’ by vertebrates is often caused by the foraging activity of animals in their search for subterranean food (Whitford and Kay 1999; Garkaklis *et al*. 2004). Digging vertebrates often create very distinctive foraging pits; for example, the open, deep diggings of *Bettongia pencillata* (Garkaklis *et al*. 1998) differ from the conical pits of *Isoodon obesulus* (Braithwaite 1995; FitzGibbon and Jones 2006; Long 2009; Valentine *et al*. 2013) and the bulldozing tracks of *Tachyglossus aculeatus*, the short-beaked echidna (Travers *et al*. 2012). Diggings can therefore be used to provide an index of foraging activity of particular species (e.g. James and Eldridge 2007).

In their search for food or shelter, vertebrates can leave other signs of their foraging activity, scats. Using scats to monitor signs of animals is a passive sampling technique that can estimate the presence of particular species. Scat sampling is especially effective for species that are rare or difficult to survey (Southgate *et al*. 2005). Monitoring scats in the present study is to determine the presence of a species and in addition to the measure for foraging activity of vertebrates, diggings.

Many woodlands and forests in the south-west of Western Australia are showing signs of a decline in condition and even mortality (Reid and Landsberg 2000; Yates and Hobbs 2000; Armistead 2008; Robinson 2008; Allen *et al*. 2010; Wentzel 2010). *Eucalyptus wandoo*, a smooth-barked tree endemic to Western Australia, has been undergoing declines in condition since the 1970s and more recently in the 2000s (Wandoo Recovery Group 2006). Symptoms of decline in *E. wandoo* include the retraction, or loss, of canopy foliage, which increases the amount of sunlight reaching the understorey. The proportion of dead branches within a canopy of a declining *E. wandoo* tree also increases, followed by a recovery phase where the growth of epicormics in the canopy are evident. On the forest floor, increases in the leaf litter cover and a decrease in bare ground cover as a result of the canopy foliage loss is evident (Moore *et al*. 2013*a*, 2013*b*).

Changes in tree condition and the surrounding habitat have the potential to alter foraging resources for arboreal and terrestrial vertebrates. For example, the soil disturbance created by digging mammals such as *B. penicillata* and *I. obesulus* when seeking subterranean food resources such as invertebrates, truffles, roots, tubers and fungi (Taylor 1993; Braithwaite 1995; Pizzuto *et al*. 2007) could be altered by the changes in the canopy and the leaf litter layer. This, in turn, might alter vital ecosystem services provided by soil disturbance and alter the habitat and tree condition of *E. wandoo* woodland. We examine whether there are changes in foraging activities (diggings and scats) of vertebrates that can be linked to condition in *E. wandoo*, and to associated habitat changes. Specifically, we explore: (1) whether the foraging activity of vertebrates is higher beneath healthier *E. wandoo* trees, (2) whether the foraging activity of vertebrates is related to habitat variables, and (3) whether the number of diggings and scats recorded differ spatially and temporally.

Methods

Site description

Study sites were located in *E. wandoo* woodlands at Dryandra Woodland (32°48′33″S, 116°53′08″E), located 160 km south-east of Perth, Western Australia, and Wandoo Conservation Park (31°54′36″S, 116°27′42″E), located 75 km east of Perth. *E. wandoo* stands are open-canopy woodlands (~30% canopy cover) with an understorey of small shrubs (<1 m high) including *Gastrolobium* spp., *Macrozamia riedlei*, *Acacia pulchella* and *Xanthorrhoea preissii* (Yates and Hobbs 1997). Understorey vegetation in these reserves is very open, with only 20% ± 18% cover, with minimal understorey vegetation >1 m high. *E. wandoo* grows on clayey-loam soils that harden during the warmer months, making penetration difficult (Mercer 1991). Both reserves have histories of land clearing, stock grazing, harvesting (logging) and controlled fire management (DCLM 1980). Although the reserves have differing conservation statuses (Dryandra Woodland: State Forest and Nature Reserve; Wandoo Conservation Park: Conservation Park) they are both managed by the same government agency (Department of Parks and Wildlife) for conservation of flora and fauna and are two of the three largest blocks of *E. wandoo* remaining.

Sites within Dryandra Woodland and Wandoo Conservation Park were selected using Landsat data and Vegmachine (Wallace *et al*. 2006; CSIRO 2010), which determines changes in vegetation condition over time from reflectance values. Using Vegmachine, we selected sites that were either predominantly declining or healthy (12 of each, six in each reserve at least >500 m away from the edges of remnant vegetation) from 1990 till 2009, since this period spanned the most recent decline in *E. wandoo*. Although sites were termed declining or healthy, *E. wandoo* decline is heterogeneous in nature, where healthy and declining trees are adjacent (Brouwers *et al*. 2012; Moore *et al*. 2013*b*), differing from declines in other eucalypts such as *Eucalyptus gomocephala* (tuart) (Wentzel 2010) and *Eucalyptus marginata* (jarrah) (Matusick *et al*. 2013*a*, 2013*b*), in which entire stands of trees are dead or declining. This led to the study occurring at the tree level, rather than at the site level.

Diggings and scat count assessments

We surveyed diggings and scats at the base of four trees per site (totalling 96 *E. wandoo* trees of various condition states). A radius of 1.8 m (giving a survey area of 10 m^2) from the base of each tree was monitored for diggings and scats. Prior to the commencement of this monitoring, survey areas were cleared of all scats and diggings already present were marked so they could be excluded from future counts. All subsequent diggings were counted monthly, individually marked using wooden pop sticks and the species that dug them identified. Over time many of the diggings were not identifiable due to age and weather conditions. Where new diggings were made over the top of the old diggings, they were counted as new diggings (pop sticks were not removed so it was possible to determine a new digging from an old digging). Surveys (sampling events) were repeated 10 times between May 2010 and April 2011. Note that on two occasions, August 2010 and January 2011, two months passed between the scat and diggings counts.

Diggings made by *B. penicillata* and *I. obesulus* can become very similar and difficult to differentiate after a month (James and Eldridge 2007); however, monthly surveying allowed differentiation between these two species. *Oryctolagus cuniculus* (European rabbit) diggings were identified as burrows and cavities; their diggings were visibly different from those of *B. pencillata* and *I. obesulus* in depth and size (Eldridge and Kwok 2008). All other diggings were easily identifiable and different from one another. *Tachyglossus aculeatus* leave nose tracks through the soil and debris (Travers *et al*. 2012). *Turnix varia* (painted button quail) leave shallow holes from a pivoting action where they have been foraging (Marchant *et al*. 1990). *Macropus* spp. create shallow hip holes when resting (Eldridge and Rath 2002). Lastly, *Varanus* spp. create long narrow digs when searching for other lizards and invertebrates (Eldridge and Kwok 2008; Eldridge and James 2009). All diggings were identified to species and *B. penicillata* and *T. aculeatus* diggings were analysed separately.

All scats >1 cm diameter were identified, counted and removed from the survey area after each monthly sampling event. Scats that could not be identified in the field were examined in the laboratory using Triggs (2006) as a guide. The scats from *Macropus fuliginosus* (western grey kangaroo) and *Macropus irma* (brush-tailed wallaby) were combined (hereafter *Macropus* spp.), since studies have shown that scats of these two species cannot be reliably differentiated (Bulinski and McArthur 2000). Scats of *T. vulpecula* were identifiable to species. All other scats were pooled.

A range of tree and habitat characteristics were recorded as covariate data on all 96 trees (Table 1). Percentage measures were adjusted by arcsine-square-root transformation of the proportional data to meet the assumptions of parametric statistics (Zar 1998).

Analysis

To determine the relationships between the scat and diggings densities and the tree and habitat characteristics, mixed-model ANOVAs were performed with site (1–24) and sample event (time) as random factors and the tree and habitat variables as covariates (Statsoft 2007). Diggings and scat data were analysed across both locations, with the exception of *B. penicillata* diggings, which were analysed only for Dryandra Woodland.

Results

Diggings

In total, 854 diggings (over the 960 m^2) were recorded over one year (10 sampling events) beneath the 96 trees in Dryandra Woodland and Wandoo Conservation Park. These were carried out by a range of vertebrates: *T. varia*, *T. aculeatus*, *B. penicillata*, *I. obesulus*, *Varanus* spp. and *Macropus* spp. (Table 2). *O. cuniculus* and *Macrotis lagotis* (bilbies, Dryandra Woodland only) were present but there was no evidence of their activities (diggings or scats) beneath the trees monitored. However, 19% of diggings could not be identified due to collapse or lack of identifying features.

Total digging density differed over sample event (time) and site (Table 4). *T. aculeatus* made a majority of the diggings, 44% (Table 2), which varied over time (Fig. 1*a*, Table 4). *B. penicillata* diggings (26% of diggings at Dryandra Woodland) did not differ over the sampling events (time) or at the 12 sites in Dryandra Woodland (Fig. 1*b*, Table 4).

Total diggings were positively related to time since last fire (Fig. 2*a*) and negatively related to crown dieback (Fig. 2*b*). *T. aculeatus* diggings were positively related to time since last fire (Fig. 3, Table 4). There were no discernible relationships with *B. penicillata* diggings and tree and habitat characteristics.

Scats

In total, 18 766 scats were collected over 10 sampling events beneath the 96 trees, with more collected from Dryandra Woodland (11 125 over 480 m^2) than Wandoo Conservation Park (7656 over 480 m^2) (Table 3). These scats were identified as from 12 known species, including *Macropus* spp. (75%), *T. vulpecula* (10%), *O. cuniculus* (5%), *Myrmecobius fasciatus* (numbat) (<1%), *B. penicillata* (<1%), *Felis catus* (feral cat) (<1%), *Vulpes vulpes* (red fox) (<1%), *Sus scrofa* (feral pig) (<1%), *Dromaius novaehollandiae* (emu) (<1%), *Dasyurus geoffroii* (chuditch) (<1%), *T. aculeatus* (<1%) and *I. obesulus* (1%) (Table 3). Some scats were recorded from only one location; i.e. *S. scrofa*, *V. vulpes*, *B. penicillata* and *M. fasciatus* were recorded only in Dryandra Woodland, and *D. novaehollandiae* was recorded only in Wandoo Conservation Park. Some scats, 5%, could not be identified.

Total scat density differed over sample event (time) and site (Table 4). Sample event (time) and site were related to the number of *T. vulpecula* scats (Fig. 1*c*, Table 4). *Macropus* spp. scats differed over sample event (time) and site (Fig. 1*d*; Table 4).

Tree and habitat characteristics had no effect on the total scat density (Table 4). Time since last fire was positively related to *T. vulpecula* scats recorded (Fig. 4; Table 4). There were no discernible relationships with tree and habitat characteristics and the *Macropus* spp. scats recorded.

Discussion

We hypothesised that healthier *E. wandoo* trees would provide more resources and shelter for vertebrates, resulting in more foraging activity at the base of healthy *E. wandoo* trees. However, there were few relationships between vertebrate foraging activity and tree and habitat characteristics. The only correlation was a single negative relationship between crown dieback and total digs, indicating that more foraging activities occurred beneath *E. wandoo* trees with more canopy and less dieback. Perhaps this preference for healthy *E. wandoo* trees is a result of their full canopies providing shelter, food resources and a stable microhabitat for terrestrial vertebrates. This study indicates that a healthy *E. wandoo* woodland does provide more resources for vertebrates and result in more foraging activities. However, more research that incorporates other habitat variables not explored here is required to substantiate the original hypothesis (Catling and Burt 1994, 1995; Catling *et al*. 2001; Gibson 2001).

Fire has the potential to alter a landscape and habitat complexity and wildlife (Hobbs 1987; Burrows and Abbott 2003; Fisher and Wilkinson 2005; Valentine *et al*. 2012). In the present study more *T. aculeatus* diggings and *T. vulpecula* scats were recorded under trees that had experienced a longer interval between fires (contributing to significant results for the total diggings and scats). Older fire histories are often linked to more coarse woody debris, structurally complex vegetation and leaf litter (Lunney and O'Connell 1988; Catling *et al*. 2001; Schurbon and Fauth 2003; Gresser 2009). Diggings made by *T. aculeatus* would be more common beneath trees with an older fire history as fewer fire events lead to a build-up of coarse woody debris, a main source of their invertebrate prey, termites (Abensperg-Traun *et al*. 1991; Wilkinson *et al*. 1998; Eldridge and Mensinga 2007). Complex vegetation in areas that have not been recently burnt provides resources such as flowers, foliage and invertebrates to be utilised by *T. vulpecula* for shelter and food resources (Inions *et al*. 1989; Lindenmayer *et al*. 1996; Lindenmayer and Cunningham 1997). *B. penicillata* digs for hypogeous fungi, roots and seeds that would be more abundant in a complex leaf litter layer that builds up in the absence of fire (Christensen 1980; Garkaklis *et al*. 2003). Studies in the same sites have demonstrated strong links between leaf litter beneath trees and time since last fire (Moore *et al*. 2013*b*). However, fire events are required for some ecosystem processes. Within Dryandra Woodland, the dominant understorey species, *Gastrolobium oxylobioides* and *A. pulchella*, require fire for germination and are used by *B. penicillata* (Christensen 1980). Understorey cover of 50–80% is preferred by *B. penicillata*, which avoids very dense or open areas (Christensen 1980). Overall, mosaics of fire ages across the two reserves are more likely to provide ample resources for vertebrates and lead to the creation of more diggings and scats.

With the exception of *B. penicillata*, activity as evidenced by both diggings and scats changed over time. Underground food resources are likely to change over the seasons due to changes in the soil moisture, growth of trees and plants and soil porosity (Boeken *et al*. 1998; Eldridge and James 2009; Cai *et al*. 2010) along with foraging intensity. For example, in wetter winter months increased growth of grasses and herbs above ground, and subterranean fungi, may contribute to more foraging and defaecation by wildlife. Although, *B. pencillata* diggings were not significantly different over time, the standard errors of the counts indicate that there was high variation from month to month. However, as the standard errors overlap, a non-significant relationship was found. Environmental factors that change over the seasons may alter the food resources for vertebrates and therefore their signs of foraging activity.

Tree condition, habitat characteristics, foraging activities and the resultant ecosystem functions potentially have a cyclical relationship. Changes in the habitat as a result of *E. wandoo* decline as well as fire events can modify this cyclic relationship. The present study has indicated that changes in tree condition and habitat can alter the foraging activities of terrestrial vertebrates. Loss or alteration of soil disturbance, an ecosystem function, can in turn reduce habitat quality, tree recruitment and tree condition.

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Fig. 1. *Tachyglossus aculeatus* diggings (*a*), *Bettongia penicillata* diggings (*b*), *Trichosurus vulpecula* scats (*c*) and *Macropus* spp. scats (*d*) underneath 96 trees over 10 separate sampling events in 2010 and 2011 at Wandoo Conservation Park and Dryandra Woodland. Values are average number of diggings ± standard error. Note that *Bettongia penicillata* diggings are from Dryandra Woodland only.

Fig. 2. Relationships between total diggings and time since last fire (*a*) and crown density (*b*) underneath 96 trees over 10 sampling events in 2010 and 2011 at Wandoo Conservation Park and Dryandra Woodland. Each point represents diggings per site per sampling event.

Fig. 3. Relationships between *Tachyglossus aculeatus* diggings and time since last fire underneath 96 trees over 10 sampling events in 2010 and 2011 at Wandoo Conservation Park and Dryandra Woodland. Each point represents diggings per site per sampling event.

Fig. 4. *Trichosurus vulpecula* scats and the relationship with time since last fire underneath 96 trees over 10 sampling events in 2010 and 2011 at Wandoo Conservation Park and Dryandra Woodland. Each point represents scats collected per site per sampling event.

Table 1. Tree and habitat characteristics measured on the 96 trees at Wandoo Conservation Park and Dryandra Woodland

Time since last fire was measured at each of the 24 sites, not on the individual tree as per the other characteristics. Crown density, uncompacted live crown ratio and crown dieback originate from the USDA tree condition assessment used by US foresters for *Pinus* spp. (Schomaker *et al*. 2007), adapted for use on eucalypt trees. The proportion of dead branches, epicormic growth (Podger 1980; Stone 1999) and canopy cover (Wentzel 2010) originate from other studies that investigated the relationships between tree condition and wildlife

Characteristic	Definition
Whitford tree condition measure (Whitford *et al*. 2008)	Describes tree condition using a pictorial scale (C1 = healthy, to C6 = dead).
Crown density (%)	Percentage of crown that contains foliage, branches, and reproductive structures.
Uncompacted live crown ratio (%)	Percentage of live crown to above-ground tree length, i.e. ratio of crown to tree trunk.
Crown dieback (%)	Percentage of crown that has undergone recent dieback, or lost foliage.
Proportion of dead branches (%)	Percentage of all major branches with a diameter >20 cm that are senescent.
Epicormic growth (%)	Percentage of foilage in the canopy that is epicormic growth (i.e. growth from beneath the bark, as the tree recovers from a decline).
Canopy cover (%)	Four canopy cover measurements taken 1.5 m from the base of each tree at north, south, east and west facings using a spherical densitometer and averaged for each tree to give a single canopy cover measure.
Tree leaf litter (%)	Measured by estimating the leaf litter cover in two 1-m^2 survey areas at the base of each tree, within the same 10-m^2 survey area that all diggings and scats were recorded.
Time since last fire (years)	Time since last fire was taken from site records (Department of Parks and Wildlife, Hills and Great Southern Districts) and indicates years since a fire event.

Table 2. The number of diggings recorded from Wandoo Conservation Park and Dryandra Woodland (96 trees, total 960 m^2) attributed to six vertebrates species and unknown species over one year

Bettongia penicillata diggings were recorded only at Dryandra Woodland

Species	No. of digs
Tachyglossus aculeatus (echidna)	397
Bettongia penicillata (brush-tail bettong)	176
Isoodon obesulus (southern brown bandicoot)	44
Turnix varia (painted button quail)	41
Varanus spp.	19
Macropus spp.	1
Unknown species	176

Table 3. The number of scats collected from Wandoo Conservation Park and Dryandra Woodland from 12 species of known and unknown vertebrates over one year

Macropus spp. includes the two species of macropods

Species	Wandoo Conservation Park	Dryandra Woodland	Total
Macropus spp.	6715	7449	14164
Trichosarus vulpecula	177	1782	1959
Oryctolagus cuniculus	313	801	1114
Isoodon obesulus	51	219	270
Bettongia penicillata	0	154	154
Myrmecobius fasciatus	0	17	17
Tachyglossus aculeatus	1	11	12
Sus scrofa	0	9	9
Dromaius novaehollandiae	5	0	5
Vulpes vulpes	0	4	4
Felis catus	1	2	3
Dasyurus geoffroii	1	1	2
Unidentified scats	392	676	1053
Total	7656	11125	18766

Table 4. Summary of mixed-model ANOVAs demonstrating relationships between diggings and scats, tree and habitat characteristics, sample number and site in Dryandra Woodland and Wandoo Conservation Park

Significant values are shown in bold

			Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
Dependant variable			Total digging density		*Tachyglossus aculeatus diggings*		*Bettongia penicillata* diggings[A]		Total scat density		*Trichosurus vulpecula* scats		*Macropus* spp. scats	
	Effect	d.f.	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Time since last fire (years)	*Fixed	1	**8.161**	**0.012**	**6.194**	**0.026**	0.001	0.985	1.235	0.284	**8.492**	**0.011**	0.267	0.613
Canopy cover (%)	*Fixed	1	1.793	0.201	0.556	0.468	0.004	0.960	4.197	0.059	3.873	0.068	4.113	0.061
Crown dieback (%)	*Fixed	1	**5.178**	**0.039**	2.644	0.126	0.315	0.718	0.057	0.815	0.759	0.398	0.347	0.565
Crown density (%)	*Fixed	1	4.269	0.057	0.283	0.603	7.087	0.401	0.046	0.833	0.234	0.636	0.028	0.869
Epicormic growth (%)	*Fixed	1	0.921	0.352	0.097	0.759	4.218	0.247	0.485	0.497	0.021	0.887	0.827	0.377
Whitford tree condition measure	*Fixed	1	0.935	0.349	0.508	0.488	3.467	0.394	0.315	0.583	0.104	0.752	0.287	0.600
Tree leaf litter (%)	*Fixed	1	1.364	0.262	0.049	0.829	0.406	0.726	0.012	0.914	0.451	0.512	0.253	0.622
Proportion of dead branches (%)	*Fixed	1	0.007	0.933	0.679	0.424	2.545	0.482	0.758	0.398	0.110	0.745	0.829	0.377
Uncompacted live crown ratio (%)	Fixed	1	0.251	0.624	0.599	0.452	0.364	0.696	0.042	0.840	2.370	0.145	0.187	0.671
Sample event (1–10)	Random	9	**1.949**	**0.047**	**2.315**	**0.017**	1.316	0.239	**19.100**	**<0.001**	**4.250**	**<0.001**	**20.920**	**<0.001**
Site (1–24)	Random	15	**2.127**	**0.010**	1.614	0.072	0.431	0.731	**5.687**	**<0.001**	**4.940**	**<0.001**	**4.568**	**<0.001**

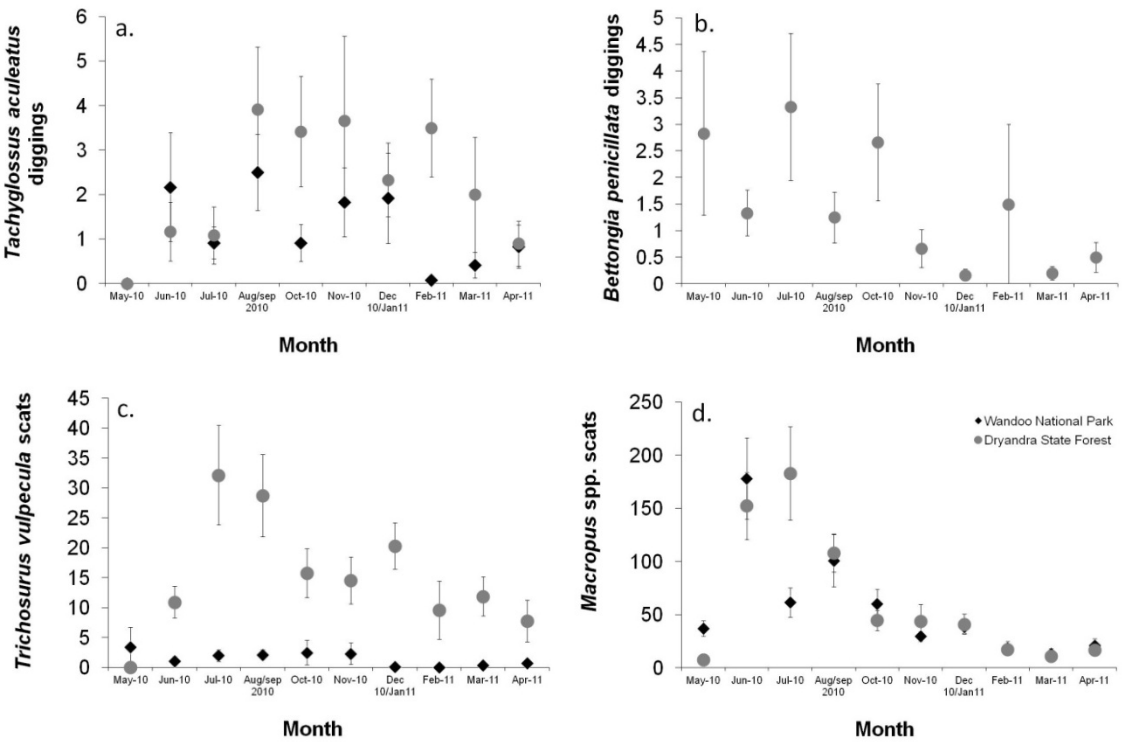

Figure 1: *Tachyglossus aculeatus* diggings (a), *Bettongia penicillata* diggings (b), *Trichosurus vulpecula* scats (c) and *Macropus* spp. scats (d) underneath 96 trees over 10 separate sampling events in 2010 and 2011 at Wandoo Conservation Park and Dryandra Woodland. Values are average number of diggings ± standard error. Note *Bettongia penicillata* diggings are from DW only.

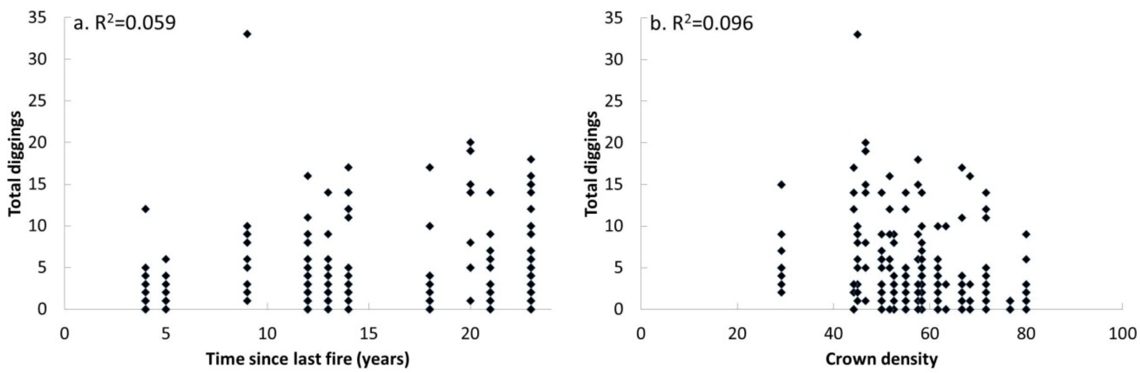

Figure 2: Relationships between total diggings and time since last fire a); and crown density b) underneath 96 trees over 10 sampling events in 2010 and 2011 at Wandoo Conservation Park and Dryandra Woodland. Each point represents diggings per site per sampling event.

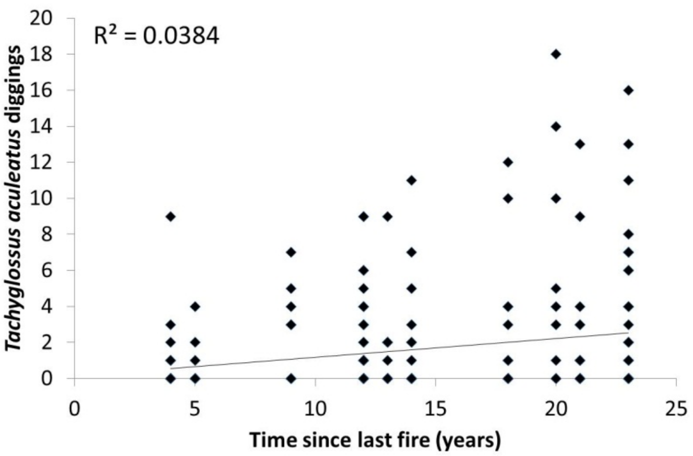

Figure 3: Relationships between *Tachyglossus aculeatus* diggings and time since last fire underneath 96 trees over 10 sampling events in 2010 and 2011 Wandoo Conservation Park and Dryandra Woodland. Each point represents diggings per site per sampling event.

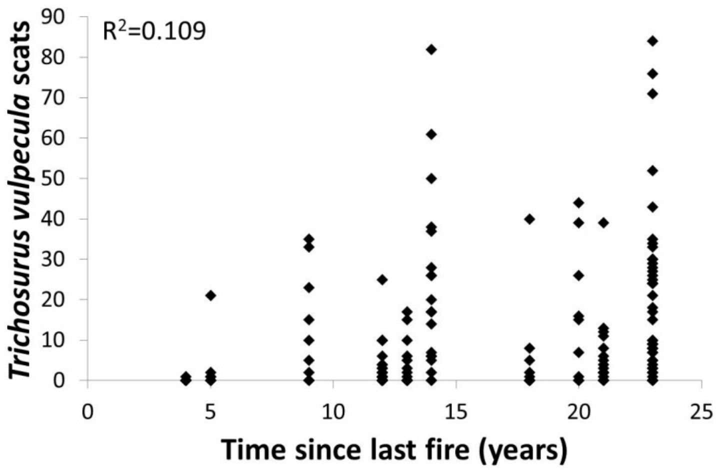

Figure 4: *Trichosurus vulpecula* scats and the relationship with time since last fire underneath 96 trees over 10 sampling events in 2010 and 2011 Wandoo Conservation Park and Dryandra Woodland. Each point represents scats collected per site per sampling event.