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# Termitaria are an important refuge for reptiles in the Pilbara of Western Australia

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**Abstract.** In all, 154 of 158 above-ground termitaria deconstructed in the Pilbara of Western Australia contained at least one vertebrate, and there was a mean of 30.4 (s.e. = 2.03) vertebrates and 4.5 (s.e. = 0.17) species in each mound. There was a significant difference in the relative abundance of species found in the termitaria and the 64 species found in the adjacent area. Termitaria were mostly occupied by eight species: *Gehyra pilbara* (66.3% of captures), *Heteronotia binoei* (13.7% of captures), *Furina ornata* (6.9%), *Antaresia stimsoni* (3.3%), *Cyclorana maini* (3.0%), *Gehyra variegata* (1.5%), *Suta punctata* (1.3%) and *Planigale* sp. (0.9%). It is likely that *F. ornata*, *A. stimsoni* and *S. punctata* used termitaria as a diurnal refuge and also prey upon reptiles living in the mound. If other termitaria in the Pilbara support a similarly high number of vertebrates, then these mounds provide an environmentally significant microhabitat and vertebrate fauna inhabiting the mounds should be captured and relocated before the termitaria are cleared or isolated as a result of development.

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## Introduction

The importance of termites in the diet of Australian arid-adapted lizards has long been recognised (Pianka 1986, 1989; Morton and James 1988). Pianka (1989) indicated that termites provided 1.5–53.2% of the diet for saurian fauna at nine sites in the semiarid parts of Western Australia, and Morton and James (1988) suggested that the major cause of lizard radiation in arid Australia was the abundance and diversity of termites. Although, more recently Colli *et al.* (2006) reported a positive correlation between termite and lizard richness in Cerrado, Brazil, they went on to suggest that termite abundance and richness was unable to drive lizard speciation but could maintain lizard species richness.

Termites are typically fossorial in arid Australia, but they also inhabit decaying logs, live and upright trees and above-ground termitaria. The above-ground termitaria can provide an important food resource for small vertebrates (Fleming and Loveridge 2003) and protection from wildfires. They also provide a thermal environment that modifies the external extremes and therefore provides a suitable diurnal retreat for animals (Korb and Linsenmair 2000; Vitt *et al.* 2007), nesting sites for birds and reptiles (Cowles 1930; Greene 1986; Green *et al.* 1999; King and Green 1999; Brightsmith 2000; Knapp and Owens 2008; Joseph *et al.* 2011) and protection from local flooding, as animals are elevated above the flood waterlevel.

Except for articles by Lynch (1986, 1988), Vitt *et al.* (2007) and Moro *et al.* (2014), which reported on vertebrates in termitaria in South Africa, Brazil and an island off the Western Australian coast, nothing is known of the residents of these refuges for small vertebrate fauna, particularly for the interior of Australia, where large above-ground termitaria are common in arid and semiarid areas. One of these studies (Lynch 1986, 1988) was on the ecology of the lesser dwarf shrew (*Suncus varilla*) that were found in these mounds and was presumably feeding on the small vertebrates in the termitaria. Fleming and Loveridge (2003) also trapped fauna around termitaria but did not open mounds, and Mahan (2009) and Heermans (2010) also compared the trapped vertebrate assemblage in the vicinity of termitaria with the assemblage in adjacent moundless areas.

Fleming and Loveridge (2003) trapped the vertebrate fauna in areas adjacent to very large *Macrotermes* sp. termitaria in Zimbabwe and reported that the mounds were a significant resource for small mammals, with an increase in their abundance and activity, but they observed no significant difference in reptile and amphibian abundance. Heermans (2010) similarly searched for, and trapped, vertebrate fauna around termitaria formed by *Macrotermes* sp. in Zimbabwe in areas that had been burnt or damaged by elephants to examine the potential importance of these mounds as a refuge for fauna. Although there were a greater number of reptiles and nearly twice as many species captured on mounds, the author concluded that there was no evidence that these termitaria were providing a significant refuge during fire or from the impact of elephants. Mahan (2009) searched for, using remote-controlled cameras, and trapped vertebrates in the vicinity of termitaria and non-termitaria control sites in Tsavo West National Park, Kenya. Overall, she found that there was no difference in the overall number of vertebrates and vertebrate species around mounds

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versus moundless sites; however, larger mounds had more vertebrate activity and significantly more reptiles were reported at mounds than at moundless sites.

The largest investigation of termitaria is the 477 dead mounds excavated by Lynch (1986, 1988). Lynch (1986) provided a checklist of vertebrate species encountered when examining dead termitaria as part of a study on *Suncus varilla*, which is the only mammal known to exclusively use dead mounds as a retreat and nesting site. This list included six species of frogs, a single species of gecko, a single species of blind snake, worm snake and viper, three species of elapids, 16 species of colubrids and three skink species. Lynch (1986) also reported that rodents had left stored fruit in three mounds and that *Mastomys natalensis* (African soft-furred rat) had built a nest in another. Lynch (1988) reported that most of these termitaria that contained reptiles harboured a single individual vertebrate (77%), with a small number (23%) containing two or more individuals.

In addition to pitfall and funnel trapping near termitaria, Vitt *et al.* (2007) opened 50 termitaria in Brazil, with 25 of these containing the gecko *Gymnodactylus carvalhoi*. Of the 25 mounds that contained a gecko, 14 contained a single individual, five contained two, three contained three and one contained four individuals. These geckos were seldom caught away from the mounds and were predominantly foraging on termites (91.8% by number and 77.8% by volume). More recently, Moro *et al.* (2014) reported on the vertebrate fauna in 407 termitaria from Barrow Island, Western Australia. A total of 265 individuals from 26 species was recorded, including four mammal species. Species most abundant in termitaria on Barrow Island were *Heteronotia binoei*, *Gehyra pilbara*, *Antaresia stimsoni* and *Morethia ruficauda exquisita.*

The thermal and air circulation properties (Darlington 1984) of some termitaria provide a suitable incubation environment for reptile eggs (Cowles 1930; Riley *et al.* 1985; Greene 1986; Green *et al.* 1999; King and Green 1999; Knapp and Owens 2008) and the altered composition of the soil around termitaria can lead to differences in the vegetation communities surrounding these mounds (Spain and McIvor 1988). This different vegetation can provide a different habitat and another niche for small vertebrate fauna. In Africa, termitaria provide an important food source for two mammalian termite eaters – aardvarks and pangolins (Bigalke 1968; Swart *et al.* 1999) – but other large mammalian species, namely the dwarf mongoose, warthogs, hyenas, porcupines and aardwolves (Melton 1973; Melton 1976; Anne and Rasa 1983; Knothig 2005) also utilise the burrows produced by aardvarks in these mounds. Of interest, Loveridge and Moe (2004) reported that above-ground termitaria supported almost twice as many species of trees than control sites, and megaherbivores (e.g. black rhino and elephant) browsing was significantly higher on mound plants compared with other woodland sites.

When areas are designated for development and the native vegetation is to be cleared, in almost all circumstances, all termitaria are cleared as part of the vegetation-clearing process. We took advantage of one of these vegetation-clearing programs south-west of Onslow (see Thompson and Thompson 2015) to systematically deconstruct each termitarium and to record all vertebrate fauna present. This is the first description of the reptilian and small mammalian fauna in termitaria in mainland Australia, and in particular the Pilbara of Western Australia. Moro *et al.* (2014) reported on vertebrate fauna in termitaria on an island off the Western Australian coast, which were also deconstructed as part of a vegetation-clearing program. Here we report on the abundance and diversity of amphibians, reptiles and small mammals caught during the systematic deconstruction of 158 termitaria. These termitaria were in a construction site and the vegetation was being cleared before infrastructure development.

## Methods

### *Site*

The study area is the Chevron Australia–operated Wheatstone LNG Project site, ~15 km south-west of Onslow in Western Australia. Between February 2012 and April 2014, ~1000 ha of vegetation were cleared for infrastructure development. The most northerly part of the development is on coastal dunes, with the area to the immediate south being coastal sand plain with low sand dunes interspersed by clay pans. There were two 'islands' in the study area. These were areas above the high-water mark that were surrounded by seawater during very high tides. When the water receded, the exposed mudflats had a fringing vegetation of low samphire shrubs.

The coastal vegetation consisted of mostly scattered *Acacia tetragonophylla* shrubs over *Triodia epactia* grassland or *Tecticornia* spp. low shrubland. Inland of this the vegetation was scattered tall *Prosopis pallida* shrubs over *A. tetragonophylla, Vachellia farnesiana* over low grasses or *A. tetragonophylla* shrubs over *T. epactia* grassland. The vegetation on one of the isolated island areas consisted mostly of scattered *A. tetragonophylla* shrubs over *T. epactia* grassland or *Tecticornia* spp. low shrubland or scattered *A. tetragonophylla* shrubs over *Scaevola pulchella* and *Indigofera monophylla* low shrubs over *T. epactia* grassland. The second isolated island area was mostly vegetated with tall scattered *P. pallida* over *A. tetragonophylla* and *V. farnesiana* over tussock grassland (Biota Environmental Sciences 2010*a*, 2010*b*).

### *Clearing termitaria*

All termitaria were deconstructed in a similar manner in accordance with a standard operating procedure. The time and location of the mounds being deconstructed was determined by the clearing contractors' schedule and was done at any time during the day and throughout the year. The location of each mound was recorded using a hand-held GPS. The mound height, circumference at the base, breast and head height of the person doing the measurement were measured and recorded. An apron around each termitarium was then cleared of all vegetation to a width of ~4 m. An excavator would then progressively remove large pieces of the mound and these would be carefully broken up by hand or hand-held hammers. All vertebrate fauna were captured and recorded in both 'live' and 'dead' (i.e. those that no longer contained termites) termitaria.

Surface soil temperatures in the mound were recorded using a Digitech Compact InfraRed Thermometer with Dual Laser Targeting (Model QM7221). The temperature in the crown was recorded immediately after the first large piece of the mound was removed, and again when the mound was half deconstructed and at ground level. Not all temperatures in all mounds were recorded.

Areas surrounding termitaria (~1000 ha) were cleared of vegetation for infrastructure development. Vertebrate fauna were collected by hand during this process and recorded. The distribution of mounds in the study area was uneven, and it was speculated that clumps of termitaria might have supported a higher abundance of vertebrates in each mound as the relative proximity to multiple other mounds would have enhanced the movement of fauna among termitaria. To examine this, we used multiple correlation analysis with two factors: height of the mound and the distance to its nearest termitarium.

## Results

### Termitaria

Termitaria varied in shape (i.e. tall and thin versus low and squat) and were devoid of vegetation. The mean height of 157 mounds was 200.3 cm (s.e. = 4.00, range = 100–330 cm). Mean circumference at the base, breast height and head height were 719.6 cm (s.e. = 15.52, $n = 157$, range = 210–1226 cm), 460.6 cm (s.e. = 14.81, $n = 147$, range = 90–975 cm) and 244.7 cm (s.e. = 10.62, $n = 124$, range = 42–740 cm) respectively (note that dimensions for all mounds were not recorded). In total, 158 termitaria were deconstructed, of which 154 contained at least one vertebrate. There was a mean of 30.39 (s.e. = 2.03) individual vertebrates and 4.46 (s.e. = 0.174) vertebrate species in each mound deconstructed.

Taller mounds contained significantly more vertebrates ($r^2 = 0.271$, $P < 0.001$), but proximity to the closest mound was unrelated to the number of vertebrates in the mound ($r^2 = -0.001$, $P = 0.925$). For termitaria for which we recorded temperature data at the crown, the middle and the base, the mean temperatures were 32.1°C ± 0.712°C ($n = 132$), 29.80°C ± 0.512°C ($n = 134$), and 30.23°C ± 0.500°C ($n = 134$) respectively. There was no significant correlation between mound height and crown, middle or base temperatures ($r^2 = 0.00$, $P = 0.86$; $r^2 = 0.007$, $P = 0.333$; $r^2 = 0.00$, $P = 0.81$ respectively).

There was a significant difference in the relative proportion of species found in termitaria (Table 1) and those salvaged during the vegetation-clearing program (Table 1) ($\chi^2 = 14121$, d.f. = 69, $P < 0.001$), indicating that some species had a preference of termitaria.

Approximately 90.6% of the small vertebrates found in termitaria were alive and were relocated without injury. Sixty-five species of vertebrates were caught in the adjacent area during the vegetation-clearing program.

### Amphibians

Only *Cyclorana maini*, a cocooning burrowing frog that has a preference for flat sandy-clay soils was recorded in termitaria, and always at the base. A small number of these frogs had burrowed into the soil adjacent to the base of termitaria, or had entered a hole at the base of the termitaria but none were found in the centre of the mound or in areas occupied by termites. None of the *C. mainii* were cocooned when found. Four other species of amphibians were recorded in the study area but were not recorded in termitaria (Table 1).

### Mammals

There are two undescribed species of planigale in the Pilbara, based on the external morphology (Gibson and McKenzie 2009); however, all planigales caught in the study area were the same species. Planigales either have an obvious preference for living in termitaria (i.e. 42 were caught in termitaria versus two caught during the vegetation-clearing program) or they were too small to be regularly seen and caught during vegetation clearing. Given their size, it is likely that some were missed during the vegetation clearing by heavy machinery, as they are easily buried, particularly if they retreated to a burrow. It is likely that the planigales caught in termitaria were using the mound as a diurnal retreat and possibly as a food source, as the mounds often contained invertebrates other than termites.

Of the 14 echidnas caught in the study area, four were in termitaria, with two in one mound. Echidnas often retreat to a burrow, crevice, or hollow log during the day (Augee 2008), and for these four individuals the hole in the base of the termitarium probably provided a suitable retreat site. Echidna diggings and scats were evident in areas vegetated with spinifex and grasses in the vicinity of where they were caught, but there was no obvious indication that echidnas had dug into termitaria in search of food, although this could be difficult to detect as mounds often had substantial openings at ground level, created by an unknown source.

### Dragon lizards

Six species of dragon lizards were present in the broader area, but the six individuals (three species) caught in termitaria had probably retreated into a hole in the base of the mound to avoid being seen or captured. It appears that dragon lizards do not preferentially retreat to termitaria, although *Pogona minor* and *Ctenophorus nuchalis* were recorded using termitaria as an elevated perch.

### Pythons

On average, one *A. stimsoni* was caught in every mound that was deconstructed, yet only 28 of these pythons were caught during the vegetation-clearing program in the adjacent area, providing evidence that termitaria are an important diurnal retreat for these snakes. McDonald *et al.* (2011) reported *A. stimsoni* in the MacDonnell Ranges of central Australia as habitat generalists with a preference for riparian woodlands, which was possibly related to prey availability, and close to rock-outcropping, which probably provided diurnal retreats. In the study area, termitaria instead of rocky outcrops were providing the diurnal retreat.

Four *Aspidites melanocephalus* were caught in termitaria and 19 were caught during other vegetation-clearing activities. *A. melanocephalus* is known to prey on lizards and snakes (Cogger 1992) but it is not known whether the animals caught in these termitaria were feeding on *A. stimsoni* and elapids or were just using the termitaria as a diurnal retreat.

### Elapids

Three species of elapid snakes appear to have a preference for using termitaria as a diurnal retreat – *Furina ornata, Suta punctata* and *Pseudechis australis*. *F. ornata* and *S. punctata* are

**Table 1. Vertebrates caught in termitaria and during the adjacent vegetation clearing**

| Family | Species | Vegetation clearing | | Termitaria | | | |
|---|---|---|---|---|---|---|---|
| | | No. | % | No. | % | Mean no. per mound | No. of mounds with at least one animal |
| Amphibia | | | | | | | |
| Hylidae | *Cyclorana maini* | 931 | 7.60 | 144 | 3.00 | 0.91 | 53 |
| | *Cyclorana platycephala* | 1 | 0.01 | | | | |
| Limnodynastidae | *Neobatrachus aquilonius* | 149 | 1.22 | | | | |
| | *Neobatrachus fulvus* | 185 | 1.51 | | | | |
| | *Neobatrachus* sp. | 23 | 0.19 | | | | |
| | *Notaden nichollsi* | 14 | 0.11 | | | | |
| Mammalia | | | | | | | |
| Dasuridae | *Dasykaluta rosamondae* | 73 | 0.60 | | | | |
| | *Dasyurus hallucatus* | 1 | 0.01 | | | | |
| | *Planigale* sp. | 2 | 0.02 | 42 | 0.87 | 0.27 | 23 |
| | *Sminthopsis macroura* | 7 | 0.06 | | | | |
| | *Sminthopsis youngsoni* | 2 | 0.02 | | | | |
| Muridae | *Mus musculus* | 39 | 0.32 | 1 | 0.02 | 0.01 | 1 |
| | *Notomys alexis* | 54 | 0.44 | | | | |
| | *Pseudomys desertor* | 1 | 0.01 | | | | |
| | *Pseudomys hermannsburgensis* | 10 | 0.08 | | | | |
| Tachyglossidae | *Tachyglossus aculeatus* | 10 | 0.08 | 4 | 0.08 | 0.03 | 3 |
| Reptilia | | | | | | | |
| Agamidae | *Ctenophorus femoralis* | 7 | 0.06 | | | | |
| | *Ctenophorus isolepis* | 78 | 0.64 | 1 | 0.02 | 0.01 | 1 |
| | *Ctenophorus nuchalis* | 92 | 0.75 | 3 | 0.06 | 0.02 | 3 |
| | *Ctenophorus rubens* | 28 | 0.23 | | | | |
| | *Ctenophorus* sp. | 1 | 0.01 | 2 | 0.04 | 0.01 | 1 |
| | *Diporiphora adductus* | 77 | 0.63 | | | | |
| | *Pogona minor* | 63 | 0.51 | | | | |
| Boidae | *Antaresia stimsoni* | 28 | 0.23 | 158 | 3.29 | 1.00 | 87 |
| | *Aspidites melanocephalus* | 19 | 0.16 | 4 | 0.08 | 0.03 | 3 |
| Elapidae | *Acanthophis pyrrhus* | 21 | 0.17 | | | | |
| | *Demansia psammophis* | 34 | 0.28 | | | | |
| | *Furina ornata* | 100 | 0.82 | 331 | 6.89 | 2.09 | 95 |
| | *Pseudechis australis* | 22 | 0.18 | 22 | 0.46 | 0.14 | 19 |
| | *Pseudonaja mengdeni* | 41 | 0.33 | | | | |
| | *Simoselaps anomalus* | 6 | 0.05 | | | | |
| | *Suta punctata* | 87 | 0.71 | 62 | 1.29 | 0.39 | 23 |
| Gekkonidae | *Gehyra pilbara* | 96 | 0.78 | 3185 | 66.34 | 20.16 | 152 |
| | *Gehyra variegata* | 343 | 2.80 | 70 | 1.46 | 0.44 | 30 |
| | *Heteronotia binoei* | 131 | 1.07 | 660 | 13.75 | 4.18 | 118 |
| Carphodactylidae | *Nephrurus levis* | 136 | 1.11 | 2 | 0.04 | 0.01 | 1 |
| Diplodactylidae | *Diplodactylus conspicillatus* | 1023 | 8.35 | 2 | 0.04 | 0.01 | 1 |
| | *Lucasium squarrosum* | 2 | 0.02 | | | | |
| | *Lucasium stenodactylus* | 18 | 0.15 | | | | |
| | *Strophurus jeanae* | 67 | 0.55 | | | | |
| | *Strophurus strophurus* | 104 | 0.85 | | | | |
| Pygopodidae | *Delma haroldi* | 35 | 0.29 | 2 | 0.04 | 0.01 | 2 |
| | *Delma* sp. | 122 | 1.00 | | | | |
| | *Delma tincta* | 1069 | 8.72 | 35 | 0.73 | 0.22 | 28 |
| | *Lialis burtonis* | 53 | 0.43 | | | | |
| | *Pygopus nigriceps* | 154 | 1.26 | 2 | 0.04 | 0.01 | 2 |
| Scincidae | *Ctenotus grandis* | 500 | 4.08 | 14 | 0.29 | 0.09 | 12 |
| | *Ctenotus hanloni* | 1537 | 12.54 | 7 | 0.15 | 0.04 | 6 |
| | *Ctenotus iapetus* | 495 | 4.04 | | | | |
| | *Ctenotus inornatus* | 376 | 3.07 | 11 | 0.23 | 0.07 | 9 |
| | *Ctenotus maryani* | 591 | 4.82 | 2 | 0.04 | 0.01 | 2 |
| | *Ctenotus pantherinus* | 392 | 3.20 | 8 | 0.17 | 0.05 | 6 |
| | *Ctenotus rufescens* | 35 | 0.29 | | | | |
| | *Ctenotus* sp. | 66 | 0.54 | | | | |

(*Continued*)

**Table 1. (Continued)**

| Family | Species | Vegetation clearing No. | Vegetation clearing % | Termitaria No. | Termitaria % | Termitaria Mean no. per mound | Termitaria No. of mounds with at least one animal |
|---|---|---|---|---|---|---|---|
| | *Eremiascincus pallidus* | 31 | 0.25 | 1 | 0.02 | 0.01 | 1 |
| | *Lerista bipes* | 1046 | 8.53 | 3 | 0.06 | 0.02 | 3 |
| | *Lerista clara* | 558 | 4.55 | 16 | 0.33 | 0.10 | 12 |
| | *Lerista onsloviana* | 47 | 0.38 | | | | |
| | *Lerista* sp. | 23 | 0.19 | | | | |
| | *Menetia greyii* | 71 | 0.58 | 2 | 0.04 | 0.01 | 2 |
| | *Tiliqua multifasciata* | 40 | 0.33 | | | 0.01 | 1 |
| Typhlopidae | *Anilios ammodytes* | 11 | 0.09 | | | | |
| | *Anilios grypus* | 18 | 0.15 | | | | |
| | *Anilios hamatus* | 79 | 0.64 | 1 | 0.02 | 0.01 | 1 |
| | *Anilios* sp. | 30 | 0.24 | | | | |
| Varanidae | *Varanus acanthurus* | 1 | 0.01 | | | | |
| | *Varanus brevicauda* | 541 | 4.41 | 3 | 0.06 | 0.02 | 3 |
| | *Varanus eremius* | 175 | 1.43 | | | | |
| | *Varanus gouldii* | 25 | 0.20 | | | | |
| | *Varanus panoptes* | 9 | 0.07 | | | | |
| Total | | 12256 | 100.00 | | | | |

small, predominantly nocturnal and eat small lizards (Cogger 1992; McDonald *et al.* 2013), which suggests that they are feeding on the geckos living in the termitaria as well as using it as a diurnal refuge. Multiple *F. ornata* were often found in the one termitarium, with the highest number recorded in a single mound being 21, but we also recorded 16 in another mound, nine in another, and two mounds with eight *F. ornata*.

Twenty-two *P. australis* were caught in termitaria and 22 were caught during other vegetation-clearing activities. *P. australis* is a widely foraging, diurnal and nocturnally active snake that preys predominantly on lizards and small mammals, but will eat bird eggs, birds and amphibians (Cogger 1992). It is likely that heavy machinery encourages *P. australis* to move from an area before it is cleared, with the consequence that the 22 individuals probably represents an underestimate of the number in vegetation-clearing areas before the presence of operating heavy machinery. It is not clear whether the *P. australis* in termitaria had retreated to that location as they fled from operating machinery or had retreated to this location to avoid the external heat or were searching for prey. *P. australis* were caught in the same termitarium as *A. stimsoni* on 13 occasions and on one occasion with two *A. melanocephalus*. The internal structure of termitaria enables animals to be in close proximity but separated by the many internal walls. Of interest, 42 *Pseudonaja mengdeni* and 34 *Demansia psammophis* were caught during vegetation clearing, but none were caught in termitaria, indicating that they are not retreating to cavities in termitaria during the day. Both of these snakes are widely foraging reptile feeders (Cogger 1992).

### *Geckos*

The most abundant vertebrate species in termitaria was *Gehyra pilbara*, with a total of 3185 (66.34%) individuals being caught in 152 of the 158 deconstructed mounds. In a mound in which 150 animals were caught, 109 of these were *G. pilbara*. This species is well known to frequent termitaria (Wilson and Knowles 1992) and probably preys mostly on termites. The second most abundant species in termitaria was another gecko, *Heteronotia binoei*. *H. binoei* represented 13.75% of all individuals caught in termitaria, which was far less than the 66.34% of *G. pilbara*, but twice that of *F. ornata* (6.9%) and four times more than any other species (Table 1). Pianka and Pianka (1976) and Pianka (2013) described *H. binoei* from inland Western Australia as ubiquitous and terrestrial and that it had a generalist diet that was predominantly spiders and other small insects, including isoptera. *H. binoei* was also caught during the vegetation-clearing program, but was in low abundance away from termitaria, which it was obviously using as a diurnal retreat. *G. variegata* was the third most abundant gecko in termitaria, but was more frequently caught during the vegetation-clearing program, often in the vicinity of *Prosopis pallida* (mesquite) that were being cleared. Pianka and Pianka (1976) described *G. variegata* from inland Western Australia as ubiquitous and arboreal, with a diet predominantly of termites and other small insects. This gecko was therefore using the termitaria as a refuge and termites probably as a source of prey.

*Delma tincta* was occasionally caught in termitaria, but was also frequently found during the vegetation-clearing program. Wilson and Knowles (1992) described its microhabitat as beneath rocks, logs, mats of dead vegetation, soil cracks, abandoned termitaria, ant nests and hummock grasses. *Lialis burtonis* was caught during the vegetation-clearing program, but not in termitaria. *Delma haroldi* was caught in low numbers during vegetation clearing and twice in termitaria, whereas *Pygopus nigriceps* was also caught twice (0.04%) in termitaria but represented 1.26% of all catches during vegetation clearing. None of these pygopods are known as termite- or reptile-eaters, so the individuals found in termitaria were using it as a refuge rather than as a food source.

A variety of skinks were abundant and frequently caught during vegetation clearing, particularly *Ctenotus hanloni*, *Lerista bipes*, *Ctenotus grandis*, *Lerista clara*, *Ctenotus maryani*, *Ctenotus iapetus*, *Ctenotus pantherinus* and *Ctenotus inornatus* (previously known as *Ctenotus saxatilis*: Rabosky *et al.* 2014). In contrast, skinks were infrequently caught in termitaria, and those that were, had well developed limbs. Skinks would readily flee from a disturbance, and were seen running into holes in termitaria, under rocks and into clumps of spinifex during the vegetation-clearing program. Termitaria therefore provide an infrequently used retreat site for skinks with well developed limbs, but it is not a habitat in which fossorial skinks were found.

## Discussion

There was a significant difference in the relative abundance of vertebrates caught in termitaria and in the adjacent vegetation during the vegetation-clearing program. Thirty-two species of vertebrates were caught in termitaria, whereas 65 species of vertebrate fauna were salvaged during the clearing of vegetation in the surrounding area (Table 1). Based on comparative abundance of species caught in termitaria and the adjacent area it appears that a few species use the mounds as a retreat or as a long-term residence.

The mass of each mound provided insulation and considerable thermal inertia, such that internal temperatures were generally higher than ambient temperatures early in the morning and cooler than those during the hottest part of the day, and would therefore have acted as a buffer on extremes in the external temperature variations (Korb and Linsenmair 2000; Vitt *et al.* 2007). There could have been a small variation between the measured and actual temperatures in the mound due to the small delay between opening the mound and measuring the temperature. The non-significant correlation between the temperature in the crown, middle and base of the termitarium with its height was probably due to seasonal and daily variations in ambient temperature in when the mounds were deconstructed and any relationship between temperature in the mound and mound mass was masked by these variations.

Vertebrate fauna, and specifically squamates, were generally much more diverse and abundant in the termitaria we examined than has been reported by others. Lynch (1988) reported a total of 26 squamate species in *Trinervitermes trinervoides* mounds in South Africa, with appreciable regional variations. A single gecko species dominated termitaria in the Bultfontein (e.g. *Pachydactylus capensis*), which is similar to that reported by Vitt *et al.* (2007) in Brazil, where only a single gecko species (*Gymnodactylus carvalhoi*) was utilising the termitaria. In Cecilia and Krugersdrift in South Africa, Lynch (1988) reported that the nocturnal snakes *Dasypeltis scabra* (an egg-eater) and *Aparallactus capensis* (a centipede-eater) were the dominant occupants of termitaria. It is interesting that both of these species are dietary specialists, with *D. scabra* preying on eggs of ground-nesting birds and the other eating centipedes, which presumably were caught while foraging at night. *D. scabra* was probably using termitaria as a diurnal retreat, in much the same way as *A. melanocephalus*, *S. punctata* and *A. stimsoni* are using termitaria around Onslow. *A. capensis* is similar in size and has a black head and nape similar to that of *F. ornata*, although there is no evidence to suggest that *F. ornata* has a preference for centipedes.

Moro *et al.* (2014) recorded many fewer animals per mound (265 animals in 407 mounds) than was recorded near Onslow (4801 in 158 mounds), but nearly as many species (4 mammals and 26 reptiles) compared with 32 species near Onslow (1 amphibian, 3 mammals and 28 reptiles). The most abundant species in termitaria on Barrow Island were *Heteronotia bineoi* (41.5%), *Gehyra pilbara* (9.06%), *Antaresia stimsoni* (8.7%) and *Morethia ruficauda exquisita.* (8.3%) compared with near Onslow where the predominant termitaria species were *Gehyra pilbara* (66.34%), *H. bineoi* (13.75%), *Furina ornata* (6.89%), *A. stimsoni* (3.29%), *S. punctata* (1.29%) and *Planigale* sp. (0.87%). Of interest, three species (*H. bineoi, G. pilbara* and *A. stimsoni*) were abundant in termitaria on Barrow Island and near Onslow. *F. ornata* and *Planigale* sp. are present on Barrow Island, but *F. ornata* was not caught in termitaria and only two *Planigale* sp. were recorded in termite mounds, which contrasts with captures reported in this study. It is not clear why the abundance of vertebrate fauna is significantly higher near Onslow than on Barrow Island; however, it could be due to a difference in the clearing protocol used.

Neither Lynch (1986, 1988) nor Vitt *et al.* (2007) indicated that termitaria were being used by large numbers of reptiles and were therefore important refuges for squamates. In this study, termitaria often contained large numbers of reptiles and were important refuge sites. If the abundance of vertebrate fauna in termitaria is relatively similar across the Pilbara, then the clearing of termitaria without capturing and relocating the individuals will result in the loss of a large number of small vertebrates. In recent years, developers and miners of their own volition or as an approval condition have captured and relocated fauna immediately before and during the vegetation-clearing process. These new management practices have resulted in numerous animals being saved from almost certain death during and immediately after the vegetation-clearing program. Approximately 90.6% of the small vertebrates found in termitaria were relocated without injury. The proportion of relocated individuals that survive the relocation program is largely unknown and is an area for future research, as there is little point in undertaking an expensive fauna relocation program if the animals fail to survive in the relocation area.

Riley *et al.* (1985) provided a comprehensive review of lizards and snakes that oviposit in ant and termite mounds. Although not systematically recorded during this study, gecko eggs or eggshells were found in many of the deconstructed termitaria. It is likely that these were mostly the eggs of *G. pilbara*, given its abundance in termitaria and the few that were caught away from termite mounds, but some of the eggs could have belonged to *G. variegata* and *H. binoei*, both of which lay eggs that are a similar size to those of *G. pilbara*.

Altered soil composition and condition around termitaria in Africa results in a different vegetation community around large mounds (Trapnell *et al.* 1976; Muvengwi *et al.* 2013). This vegetation attracts and influences the reptilian and mammalian fauna in the vicinity of mounds (Fleming and Loveridge 2003; Mahan 2009), particularly the large herbivores (Loveridge and Moe 2004) that are absent from the Australian native landscape. For example, Bigalke (1968) and Swart *et al.* (1999) reported the termite-eating aardvarks and pangolins in African termitaria, and others reported dwarf shrew, warthogs, hyenas, porcupines and aardwolves using these above-ground structures (Melton 1973; Melton 1976; Anne and Rasa 1983; Knothig 2005). The closest Australian equivalent to the African aardvarks and pangolins is probably the termite-eating specialist *Tachyglossus aculeatus* (echidna); however, we found no convincing evidence that *T. aculeatus* was digging into termitaria to access the termites, although many mounds had holes around their base. Two possible mammals that could use burrows in termitaria in the Onslow area are *Dasyurus hallucatus* (northern quoll) and *Felis catus* (feral cat), both of which have been reported in the area. Neither of these species is likely to dig a burrow into a termite mound, or feed on termites, but both would eat the small reptiles and mammals that occupy these mounds and could shelter in cavities created in the base of termitaria.

## Management recommendation

Deconstructing termitaria in a careful and systematic fashion in the Pilbara of Western Australia before land development activity can result in numerous fauna being relocated that would otherwise be lost. It is therefore recommended that government environmental regulators require industry proponents undertaking land development activity in areas that contain large above-ground termitaria, to carefully and systematically deconstruct all mounds with the specific purpose of catching and relocating the vertebrate fauna that are likely to be lost during the development program.

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