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Distribution and characteristics of mound-building termites (Isoptera) in Western Australia

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Abstract

We review here observations on mound-building in the Western Australian termite fauna, based on published data and the combined unpublished observations of the authors (M A-T 1987 – 1997, D H P 1950s to 1980s). We also examine the extent to which mounds of different species vary in shape and size across their geographic distribution and the major habitats where they build mounds, and give broad guidelines for identification of the mound-builder. Our observations cover all major regions of the State but are least comprehensive for the tropical Kimberley region.

A total of 153 described termite species, from 4 families and 26 genera, are known to occur in Western Australia. Of these, at least 21 species (14 % of species) from two families and seven genera build mounds. Nine species (43 %) are obligate mound-builders. Genera with mound-builders include the rhinotermitid *Coptotermes* (3 spp), and the termitid genera *Amitermes* (2 spp), *Drepanotermes* (6 spp), *Microcerotermes* (2 spp), *Nasutitermes* (2 spp), *Tumulitermes* (5 spp) and *Xylochomitermes* (1 sp). Three mound-building species are widely distributed north and south of the Tropic of Capricorn, seven species are restricted to parts or all of the south-west, three species are largely restricted to the arid centre, four species are largely restricted to the northern half of the State (including the Kimberley), and four species are west-coastal or near west-coastal in distribution. At least five additional species of *Amitermes*, *Macrognathotermes*, *Microcerotermes* (2 spp) and *Xylochomitermes* may construct mounds in northern-most Western Australia (Kimberley). Mounds range in height from pavement-like mounds barely rising above the soil surface, to mounds reaching over 4 m in the tropics. Materials used for mound-construction vary from almost pure clay to a mixture of sand and clay, soil and faecal material.

Introduction

Termite mounds (termitaria) are one of the most conspicuous features of many Australian landscapes, particularly in tropical regions which support the tallest of the termitaria (Calaby & Gay 1959; Gay & Calaby 1970; Andersen & Jacklyn 1993). Approximately one-fifth of the described Australian termite fauna construct mounds (Watson & Gay 1991). Mound-building termites often occur in great abundance, and more than 700 active mounds ha^{-1} have been recorded in Australia (Watson *et al* 1973; Spain *et al* 1983; Holt & Easey 1993). Lee & Wood (1971) record 65 tonnes ha^{-1} of above-ground mound material at one site, and estimate some of the mounds of *Nasutitermes triodiae* to weigh > 10 tonnes. In addition to the importance of mound-building termites to many ecological processes such as soil modification (Lobry de Bruyn & Conacher 1990) and energy flows (Abensperg-Traun 1994), mounds also provide important shelter and breeding sites for a considerable diversity of small- and medium-sized mammals, birds, reptiles, frogs, and invertebrates including other termite species (Calaby 1956; Spain & Brown 1979; Braithwaite 1990).

Mound-building (as well as subterranean) termites remain poorly known to most but specialist entomolgists, despite their functional importance and often high visibility over most of inland Australia. The aim of this review is to synthesize current knowledge of the mound-building termite fauna of Western Australia, particularly with regard to their geographic distribution, mound shapes and sizes, and the materials used for mound construction. We also provide guidelines for the identification of mound-building species, as opposed to termite species that inhabit the mounds of mound-builders as obligate or facultative (opportunistic) co-inhabitats.

Observations on mound-building behaviour

Mound-building species were probably amongst the first termites to be described for the Australian region because of the high visibility of most mound-building termites, relative to subterranean species. There are published observations on mound-building behaviour for most species but observations are widely scattered in the literature and they are inconsistent in detail and geographical emphasis. Published as well as unpublished observations contribute to our synthesis. Accumulated field observations from the early 1950s to the late 1980s (D H Perry) cover all parts of the state except the tropical Kimberley region where observations by J A L Watson on mound-building *Drepanotermes* species (Watson & Perry 1981), are used. We incorporate in this review observations on mound-building termites from the Kimberley that were reported elsewhere (*e.g.* Calaby & Gay 1956; Gay & Calaby 1970). Data for the central and southern wheatbelt are from studies of Abensperg-Traun and colleagues between 1987 and 1997 (*e.g.* Abensperg-Traun & De Boer 1990; Abensperg-Traun 1992; Abensperg-Traun *et al.* 1996 for the central wheatbelt; Abensperg-Traun & Milewski 1995 for the southern wheatbelt). Data on mound-building *Coptotermes* spp are supplemented by observations in Western Australia by Gay (1955) and Calaby & Gay (1956).

For each mound-building species we provide a map of its broad geographical distribution within Western Australia (from Watson & Abbey 1993), and observations on whether the species is 'obligate' (always builds mounds) or 'facultative' (builds mounds in only part of its geographical range). Mound shapes and common dimensions (height and width at base), the materials used for their construction, and major habitats where the species' mounds occur, are also included. Head-capsule morphology of soldier termites is generally used for species identification, and we provide dorsal views of the soldier caste for each species (redrawn from Hill 1942, Watson & Perry 1981, Perry *et al.* 1985 and Miller 1991).

We group mound-building species into five broad distributional patterns;

(i) species that occur over most areas of mainland Western Australia;

(ii) species largely restricted to parts or all of the south-west, arbitrarily defined by the 250 mm rainfall isohyet which incorporates all of the wheatbelt and eucalypt forests;

(iii) species largely restricted to the inland areas of the arid region (broadly delineated by the 250 mm rainfall isohyet north and south of the Tropic of Capricorn);

(iv) species occurring over most parts of the region north of the Tropic of Capricorn (but that are largely absent from the southern half of the State); and

(v) species restricted to coastal or near-coastal areas within any one of the above distributional categories.

Mound-building species

Of the 153 described termite species from 26 genera and four families known to occur in Western Australia (extracted from Watson & Abbey 1993), at least 21 species (14 %) from two families and seven genera are known to build mounds (Table 1). Nine species (43 %) are obligate mound-builders.

Widely-distributed species

• ***Coptotermes acinaciformis*** (Rhinotermitidae; obligate; Fig 1) is common in vegetation dominated by *Eucalyptus* but is generally absent where there are no eucalypts.

Table 1

Numbers of described termite species known to occur in Western Australia, numbers of Western Australian species known to build mounds, and additional species likely to construct mounds in the tropical north (see text). * = extracted from Watson & Abbey (1993). Number of obligate mound-builders are shown in parentheses

Family / *genus*	**Total number of species***	**Number of species known to build mounds**	**Number of additional species that may build mounds in the tropical north (Kimberley)**
Mastotermitidae			
Mastotermes	1	0	0
Kalotermitidae			
Bifiditermes	1	0	0
Cryptotermes	3	0	0
Kalotermes	2	0	0
Rhinotermitidae			
Coptotermes	5	3 (2)	0
Heterotermes	8	0	0
Schedorhinotermes	4	0	0
Termitidae			
Ahamitermes	2	0	0
Amitermes	48	2 (0)	1
Apsenterotermes	3	0	0
Cristatitermes	4	0	0
Drepanotermes	20	6 (3)	0
Ekphysotermes	3	0	0
Ephelotermes	3	0	0
Hapsidotermes	1	0	0
Hesperotermes	1	0	0
Incolitermes	1	0	0
Lophotermes	2	0	0
Macrognathotermes	3	0	1
Microcerotermes	7	2 (0)	2
Nasutitermes	8	2 (1)	0
Occasitermes	1	0	0
Occultitermes	2	0	0
Paracapritermes	1	0	0
Tumulitermes	14	5 (3)	0
Xylochomitermes	5	1 (0)	1

Mounds are "lean-to" slab nests of clay, usually up to ≈ 50 cm high (Fig 1, Plate 1). Mound / nest surfaces are characterized by an irregular network of superficial cracks which is typical for the clay-rich mounds / nests of *Coptotermes* species in general. Nests are commonly established around a fire scar at the base of eucalypt trees which provides access to the heartwood (as opposed to sapwood) upon which the species feeds. Such nests may also be built entirely on the inside of the tree, but with little or no external evidence. The heartwood of trees is progressively eaten out by the termites and is replaced by clay 'pipes' which run up the main trunk and may eventually penetrate all limbs and branches (Greaves 1962; Perry *et al.* 1985). This action creates the hollow trees and logs upon which a great variety of Australian birds and mammals depend for shelter and breeding (Saunders *et al.* 1982; Abensperg-Traun & Smith 1993). Where the host tree has collapsed (*e.g.* storm damage), nest reconstruction around the remaining stump may result in a broadly conical mound form up to ≈ 1.5 m in height. Less commonly, mounds may have no stump or wood inside them. Only one such mound has been recorded for the central wheatbelt (117° 45' E, 31° 24' S), for example, with a height and width at the base of 89 cm and 95 cm, respectively. Nest / mound walls are of clay; they may be 30-50 cm thick and are extremely hard (Calaby & Gay 1956; Perry *et al.* 1985). A single colony may contain well in access of one million individuals (Greaves 1967).

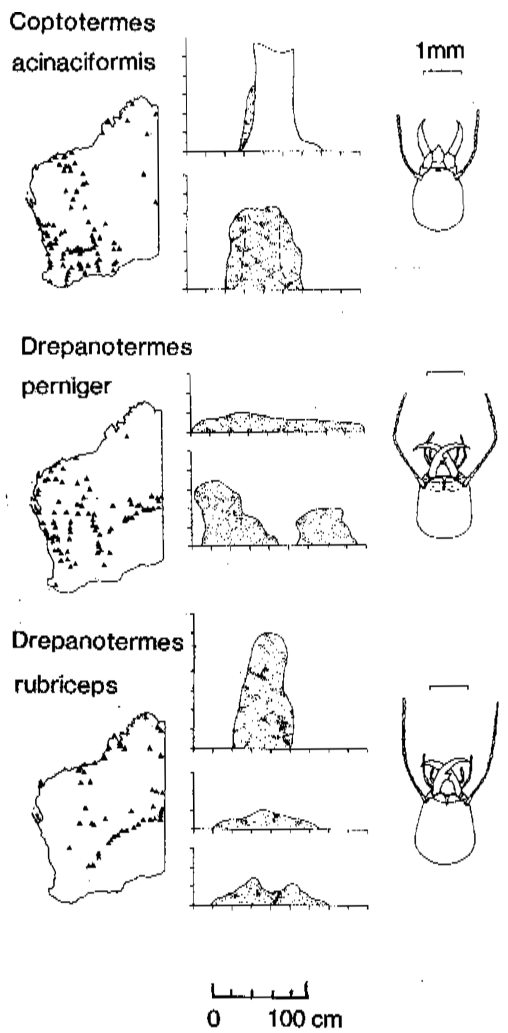

Figure 1. Western Australian mound-building termite species with a state-wide distribution, common mound shapes and dimensions, and a dorsal view (and dimension) of soldier head-capsules for respective species.

• ***Drepanotermes perniger*** (Termitidae; facultative; Fig 1) inhabits a wide variety of habitats; it can be locally common but is largely absent from heath / shrubland (on very sandy soils) and from forested (higher rainfall) areas of the south-west. Mounds are a mixture of sand and clay and are of variable shapes, flat and pavement-like to ≈ 20 cm high and ≈ 3 m wide, or broadly conical and irregular, to 1.5 m high and wide. Pavements are commonly ≈ 20 cm high but may be level with the surrounding soil surface and mound caps are several centimetres thick. Individual colonies frequently construct more than one mound to accommodate the growing colony (Holt & Easey 1985). Watson *et al.* (1973) estimate that moderately-sized colonies may contain ≈ 20 000 individuals. Population build-up of the species, particularly that expressed in the construction of new mounds, has been shown to correlate with long periods (years) of above-average rainfall, with an estimated longevity of individual mounds of up to 250 years (Watson *et al.* 1988). Mound construction following good years may result in up to 20% of the soil surface covered by the hard pavement-like mound surfaces which resist erosion and plant establishment, resulting in significant, detrimental and long-term effects on ecosystem function (Watson & Gay 1970; Watson *et al.* 1973). Mound-building does not occur, for example, in the central and southern wheatbelt but predominates in central parts of its Western Australian distribution. *Drepanotermes perniger* also takes over the mounds built by other species of *Drepanotermes* (Watson & Perry 1981).

• ***Drepanotermes rubriceps*** (Termitidae; obligate; Fig 1) is commonly associated with species of spinifex (hummock grass) of the genera *Triodia* and *Plectrachne* in mulga lands (Watson *et al.* 1973) but inhabits a range of habitats across large areas of the state. It is absent from the forested (higher rainfall) areas of the extreme south-west and extends slightly further into the central wheatbelt of the south-west (*e.g.* Kellerberrin, 31° 38' S, 117° 43' E) than is shown by Watson & Abbey (1993). In the central wheatbelt it is restricted to heath / shrublands on sandy soils where it can be particularly common in heath dominated by the sedge *Ecdeiocolea monostachya.* Mounds are of sand and clay, low and broadly rounded to a maximum height of ≈ 30 cm (arid regions), or flat, pavement-like averaging ≈ 20 cm in height (central wheatbelt). Pavement mounds may be covered by loose soil and are then difficult to detect. In the Kimberley region, mounds may be taller, as high or higher than wide, and are sometimes built in areas subject to seasonal flooding (Watson & Perry 1981). Mound densities of ≈ 200 mounds ha^{-1} have been recorded. *Drepanotermes rubriceps* also takes over the mounds of other species, and then modifies their internal structure (Watson & Perry 1981). Individual colonies may construct several mounds (Holt & Easey 1985).

South-west species

• ***Amitermes obeuntis*** (Termitidae; facultative; Fig 2) occurs throughout the south-west. Mounds are of highly variable shapes, symmetrical and domed to irregular, most commonly ≈ 20–30 cm high and wide at the base but rarely up to ≈ 50 cm high, invariably with a pitted surface, usually of dark grey colour and very high in clay content (Fig 2, Plate 2). Mounds often incorporate wood lying on the soil surface and may also be constructed against the bases of eucalypts. In such instances, they can resemble the slab-like nests of *Coptotermes acinaciformis* (Fig 1) but are generally darker in colour and lack the cracked exterior surface typical of *Coptotermes* mound / nest surfaces. Mound densities of up to 39 mounds per 0.25 ha^{-1} have been recorded for mallee-heath on granitic soils at south-coastal Fitzgerald River National Park (34° 04' S, 119° 26' E; Abensperg-Traun & Milewski 1995). Nests without mound structures were also located under rocks. In some places, colonies are housed below a flat shield of hard clay just below the soil surface (Fig 2). In wandoo (*Eucalyptus capillosa*) woodland of the central wheatbelt, *A. obeuntis* commonly attaches its nest to the surface of *Drepanotermes tamminensis* mounds; such nests rarely exceed 25 cm in diameter and 10 cm in depth and are readily distinguishable from the mound-proper by their darker (grey) colour. Although rare, *A. obeuntis* does occur on sandy soils that are low in clay content (heaths, some shrublands) where the species usually foregoes mound-building by attaching its nests onto the pavement mounds of *Drepanotermes rubriceps*. Mounds of *A. obeuntis* frequently provide a shelter for other termite species and at least seven species have been collected from such situations (Gay & Calaby 1970). *Amitermes obeuntis* also frequently inhabits abandoned *Drepanotermes tamminensis* mounds without attaching nests onto external mound surfaces.

• ***Coptotermes frenchi*** (Rhinotermitidae; facultative; Fig 2) occurs throughout the south-west with exception of the Swan Coastal Plain. It is locally common in eucalypt woodlands and mallee but also occurs in shrublands where emergent, mallee-type eucalypts are common. Mound-building occurs only in the eastern and south-eastern part of the species' range. Mounds are symmetrical, conical or domed, of clay, most commonly 20–30 cm high but rarely up to a maximum of ≈ 60 cm, and to 1.2 m wide at the base, with irregular networks of superficial cracks. Often mounds are built in the centre of mallee clumps (multi-stemmed eucalypts), with mallee stems protruding through the mound structure. Over 600 000 individual termites have been collected from an average-sized colony (Greaves 1967).

• ***Drepanotermes tamminensis*** (Termitidae; obligate; Fig 2) is endemic to the Western Australian wheatbelt and its distribution is restricted to the area confined by the 300 and 600 mm rainfall isohyets (Watson & Perry 1981). In the central wheatbelt, it is common on duplex soils supporting salmon gum *Eucalyptus salmonophloia* / wheatbelt wandoo *E. capillosa* woodland and in shrublands on gravelly soils where mound densities may be particularly high (Park *et al.* 1994; M Abensperg-Traun, unpublished data). Park *et al.* (1994) give average numbers of termite individuals within single mounds of

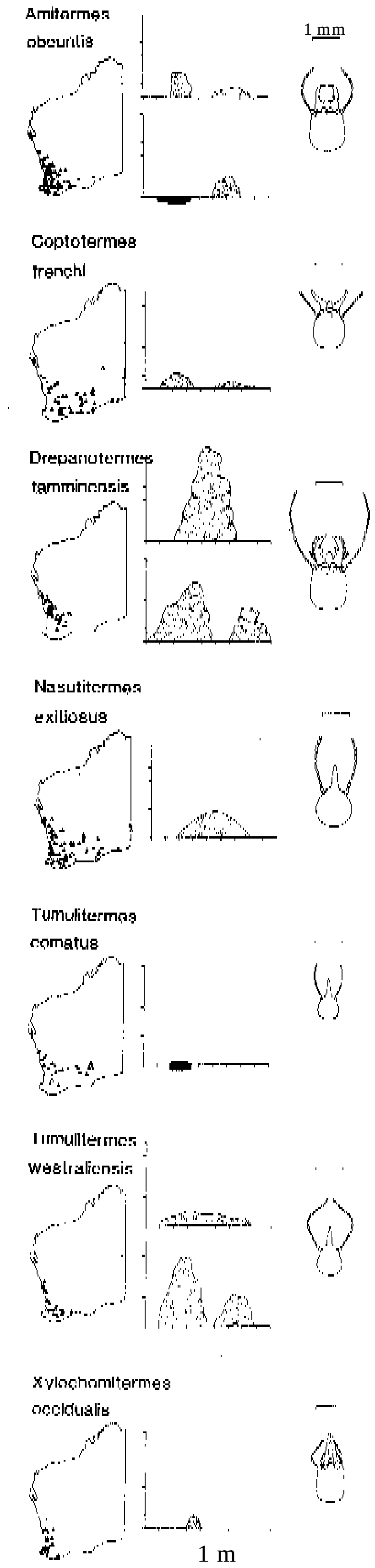

Figure 2. Western Australian mound-building termite species that are restricted to all or parts of the south-west, common mound shapes and dimensions, and a dorsal view (and dimension) of soldier head-capsules for respective species.


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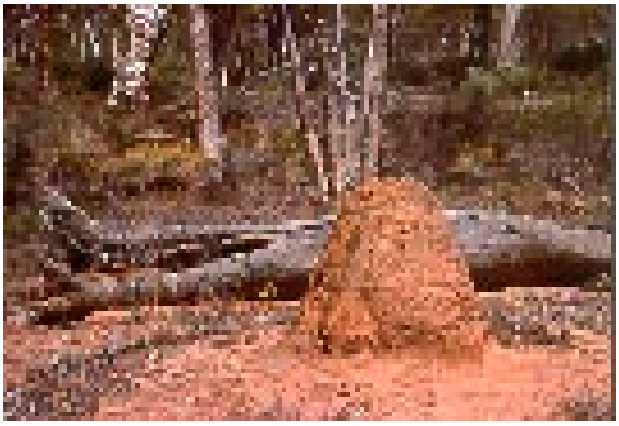
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Plate 1. 'Lean-to' slab nest of *Coptotermes acinaciformis* (wandoo *Eucalyptus capillosa* woodland, Kellerberrin, central wheatbelt).

Plate 2. Mound of *Amitermes obeuntis* (wandoo *Eucalyptus capillosa* woodland, Kellerberrin, central wheatbelt).

Plate 3. Mound of *Drepanotermes tamminensis* (wandoo *Eucalyptus capillosa* woodland, Kellerberrin, central wheatbelt).

Plate 4. Mounds of *Drepanotermes tamminensis* (wandoo *Eucalyptus capillosa* woodland, Kellerberrin, central wheatbelt).

Plate 5. Characteristic surface of *Drepanotermes tamminensis* mound (Kellerberrin, central wheatbelt).

Plate 6. *Nasutitermes exitiosus* mound (wandoo *Eucalyptus capillosa* woodland, Kellerberrin, central wheatbelt).

Plate 7. *Nasutitermes triodiae* mound (spinifex *Triodia* spp. grassland, Exmouth).

29 000 (wandoo woodland) and 22 000 (shrubland on gravelly soils). This suggests differences in habitat suitability between these two vegetation types. The species is largely absent from gimlet *Eucalyptus salubris* woodland (on heavier soils in lower-lying areas), mallee, york gum *E. loxophleba* / jam *Acacia acuminata* woodland and from vegetation on deep sands where the pavement mounds of *D. rubriceps* may be common (see above; M Abensperg-Traun, personal observations). Mounds are a mixture of sand and clay, irregularly conical or rounded, 0.5–1.5 m high and wide at the base (Plate 3). As is the case for most species, their mounds may vary markedly in colour depending on soil type (Plate 4). The aggregated nature of mounds suggests that, as is the case for *D. perniger* and possibly other species of mound-building *Drepanotermes*, individual colonies may construct several mounds to house the growing colony. With the exception of young mounds, mound-surfaces are characteristically 'spotty', with dark patches of approximately 2–3 cm in diameter covering varying proportions of the mound surface (Plate 5). These represent chambers eroded by wind and rain where termite workers deposit waste material such as feces and dead termites. Mound extensions cover eroded chambers with a new surface which is usually creamy-grey in color but depending on soil type. In old and / or senescent colonies, eroded chambers may cover a high proportion of the mound surface.

• ***Nasutitermes exitiosus*** (Termitidae; facultative; Fig 2) occurs throughout the south-west and is common in eucalypt forests, eucalypt woodlands and mallee. In the Fitzgerald River National Park along the south-coast, it also occurs in shrublands where emergent ('mallee-form') eucalypts are common. In the central wheatbelt it is rare or absent from sandy soils (mixed shrublands, heath) and from shallow soils supporting york gum *E. loxophleba* / jam *Acacia acuminata* woodlands. Mounds are usually symmetrical, dome-shaped and smooth (Plate 6). The species requires no clay for mound-building, constructing soft exterior mound walls of earthy material ≈ 2-4 cm thick, protecting a hard, blackish carton nest core (composed of fecal material). Mounds are generally ≈ 20–30 cm high and wide, but may reach ≈ 70 cm in height and width in higher rainfall regions. Large mounds frequently have steeper sides than is shown in Fig 2 and may then become somewhat less symmetrical. Mounds become progressively smaller with decreasing rainfall (and increasing temperature extremes) where nests may be entirely below ground level. Where the colony has died, the earthy mound cover is progressively eroded, exposing the dark and brittle carton nest core. In areas of heavy rocky outcropping where soil is scarce, mounds may lack the outer layer of soil. Gay & Whetherly (1970) collected more than 2.5 million individuals from a single large mound. In contrast to the mounds of most other species, no other termite species has been found to co-inhabit mounds of *N. exitiosus* until the death of the mound builder.

• ***Tumulitermes comatus*** (Termitidae; facultative; Fig 2) occurs throughout most of the south-west. Mound-building is largely restricted to coastal areas such as the heath / shrublands between Yanchep (31° 33' S, 115° 41' E) and Dongara (29° 15' S, 114° 56' E). The sand and clay mounds may protrude slightly above the soil surface but are generally level with the soil surface and to ≈ 25 cm wide.

• ***Tumulitermes westraliensis*** (Termitidae; obligate; Fig 2) is endemic to Western Australia with its distribution broadly defined by the 400 mm rainfall isohyet. A single (questionable?) record locates the species at the Giles Meteorological Station in the Simpson Desert (25° 02' S, 128° 18' E; Watson & Abbey 1993). The species is also common on the sandy Swan Coastal Plain and on the Darling Range (Ratcliffe *et al.* 1952). Mounds are of sand and clay and of two principal shapes; wide and flat (pavement-like) and ≈ 10–30 cm high (south-coastal) (and thus resembles some of the mounds of *Drepanotermes rubriceps* and *D. perniger*), or up to ≈ 100 cm high and broadly conical in northern parts. In Fitzgerald River National Park, up to 31 mounds per 0.25 ha^{-1} have been recorded for mallee-heath on granitic soils. Here, only pavement-like mounds were built and the species was absent from heath (on sands), and from coastal marlock *Eucalyptus platypus* and flat-topped yate *E. occidentalis* woodlands (Abensperg-Traun & Milewski 1995).

• ***Xylochomitermes occidualis*** (Termitidae; facultative; Fig 2) occurs throughout the forested regions of the south-west, extending into the central wheatbelt near Kellerberrin (not shown by distributional data of Watson & Abbey 1992). The mounds are usually blackish or brownish, of carton and soil, symmetrical, domed and ≈ 10–15 cm high and wide. Mound-building has been observed in southern eucalypt forests of the extreme south-west (Perry *et al.* 1985), and near Mundaring Weir east of Perth (31° 58' S, 116° 10' E), but not elsewhere in the region.

Arid centre species

• ***Drepanotermes columellaris*** (Termitidae; facultative; Fig 3) is endemic to Western Australia where its habitats are dominated by mulga (*Acacia aneura*) woodland / shrubland. The sand and clay mounds of "northern" populations are pillar-like structures 1–2 m high and 0.5–1 m wide at the base and cylindrical or tapered to the top. Some mounds fork in upper parts, forming two or more turrets up to 0.5 m long. Mounds are often situated under tall vegetation. Southern populations rarely build mounds (Watson & Perry 1981).

• ***Microcerotermes boreus*** (Termitidae; facultative; Fig 3) is found in the predominantly arid western half of the State extending south of the Tropic of Capricorn to an area approximately level with Lake Moore north-east of Dalwallinu (30° 17' S, 116° 40' E). An apparently isolated population has been recorded for a small area in the tropical Kimberley region near the Mitchell Plateau (14° 44' S, 125° 44' E). Mound-building has been observed only in tropical areas of its Western Australian distribution where it constructs small, rounded, blackish carton-nests approximately 25 cm high and wide at the base (Gay & Calaby 1970).

• ***Tumulitermes tumuli*** (Termitidae; facultative; Fig 3) is predominantly a species of the mulga lands of the arid interior although south-western populations extend into the agricultural region as far south as Moora (30° 39' S, 116° 00' E). Mounds are made of sand and clay, broadly symmetrical, spire-like and to ≈ 60–70 cm high, with a

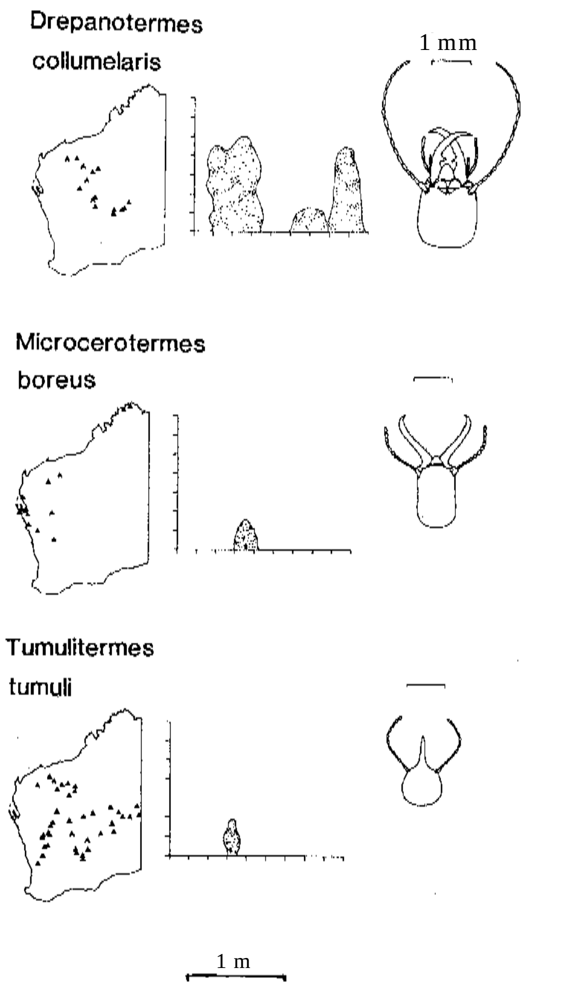

Figure 3. Western Australian mound-building termite species that are largely restricted to the central arid region, common mound shapes and dimensions, and a dorsal view (and dimension) of soldier head-capsules for respective species.

pronounced constriction at the base where it is ≈ 15–20 cm wide. Sheep frequently rub against mounds which readily snap off at the base, but these are commonly rebuilt by the colony.

Northern species

• ***Microcerotermes nervosus*** (Termitidae; facultative; Fig 4) builds small, pointed mounds, composed of predominantly dense woody carton with a thin outer layer of soil particles, in northern parts of their range (Kimberley). Mounds are frequently constructed over dead stumps or against the base of a tree (Gay & Calaby 1970). Mound-building has not been observed in more southerly populations.

• ***Nasutitermes triodiae*** (Termitidae; obligate; Fig 4, mound in upper position redrawn from Ratcliffe *et al.* 1952) is predominantly a species of spinifex (hummock) grasslands (*Triodia* spp). Its sand and clay mounds are the largest of any species in Western Australia (to ≈ 4 m high). Mounds are of variable shapes with rounded or pointed tops, dome- or mushroom-shaped, and are often

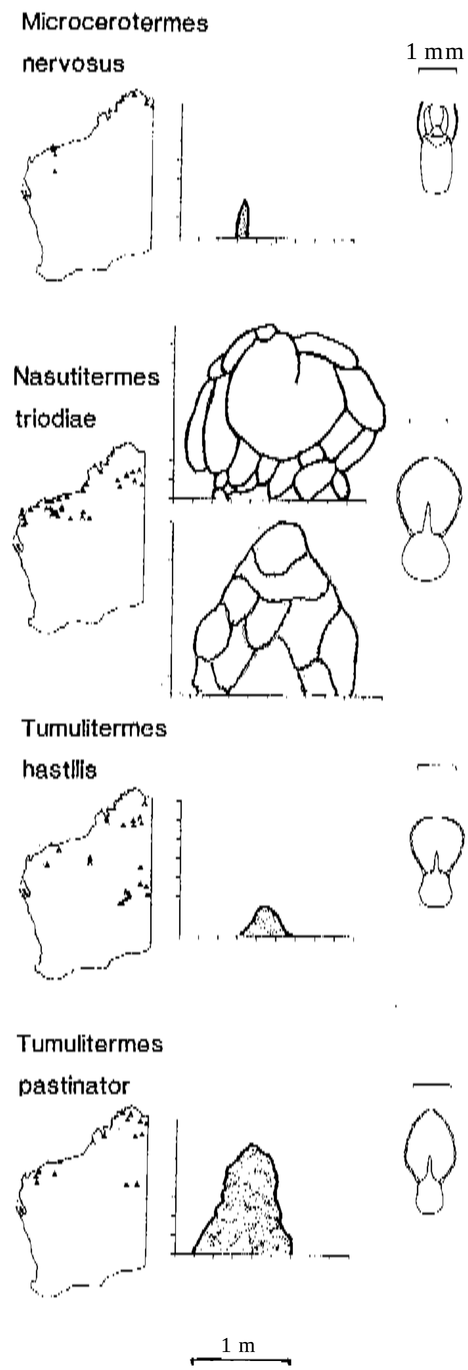

Figure 4. Western Australian mound-building termite species that are largely restricted to the area north of the Tropic of Capricorn, common mound shapes and dimensions, and a dorsal view (and dimension) of soldier head-capsules for respective species.

constricted at the base. Mounds may be smooth or covered in bulbous lobes, each lobe representing an individual (nocturnal) mound extension effort (Plate 7).

• ***Tumulitermes hastilis*** (Termitidae; obligate; Fig 4) inhabits predominantly mixed scrub/ grasslands. The sand and clay mounds are up to ≈ 40 cm high and wide at the base. Mounds may reach high local densities.

• ***Tumulitermes pastinator*** (Termitidae; obligate; Fig 4) occurs in grass/scrubland and is particularly common on the poorest soils, sandy gravel to stony country (Gay & Calaby 1970). Mounds are of sand and clay, broadly conical and commonly ≈ 60–80 cm high and wide but can reach a maximum height of ≈ 2 m. Individual colonies may construct several mounds which are termed polycalic (Holt & Easey 1985).

Coastal or near-coastal species

• ***Coptotermes brunneus*** (Termitidae; obligate; Fig 5) is restricted to a near-coastal strip north of the Murchinson River inhabiting sclerophyll woodland and mallee scrub. Its distribution closely matches that of its obligate inquiline (co-inhabitant) *Ahamitermes inclusus* (see below). Mounds are symmetrical, conical or domed, of clay and to a maximum of ≈ 2.5 m high and 1.5 m wide at the base. In mature mounds (>≈ 1.5 m high), the mound interior may almost entirely be a mass of clay, with most of the actual nest below ground level; the mound interior may also be cavernous (Calaby & Gay 1956; Calaby & Gay 1959). Gay & Calaby (1970) report that the upper portion of the mound interior may contain small pools of free water. One of us (DHP) found internal walls of some very large, old mounds to be lined with elongate "collecting cups" of clay, 2–3 cm wide and 10–20 cm long, holding small amounts of water that has condensed off the inside walls.

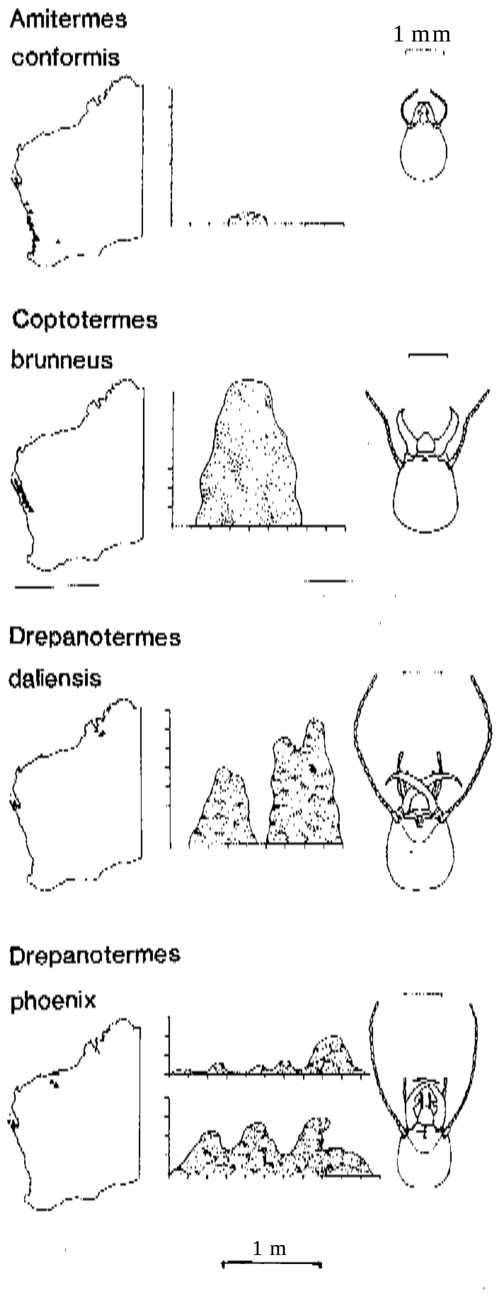

Figure 5. Western Australian mound-building termite species that are restricted to coastal or near-coastal regions, common mound shapes and dimensions, and a dorsal view (and dimension) of soldier head-capsules for respective species.

• ***Amitermes conformis*** (Termitidae; facultative; Fig 5) is restricted to a coastal strip from approximately Busselton in the south (33° 39' S, 115° 20' E) to just north of Kalbarri (27° 43' S, 114° 10' E). A single record also places the species in the southern wheatbelt south of Merredin (31° 29' S, 118° 17' E). Mounds are found only in eucalypt woodland and forest in southern-most areas of its distribution and are of sand and clay, 5 – 10 cm high and ≈ 20 cm wide at the base.

• ***Drepanotermes daliensis*** (Termitidae; facultative; Fig 5) shows a very restricted distribution around the coastal town of Broome (17° 58' S, 122° 14' E). Mounds (of sand and clay) are columnar to 1.5 m high, or broadly conical and rounded, 0.5–1 m high and wide at the base. Mounds may have more than one turret, similar to the mounds built by *D. columellaris* (Watson & Perry 1981).

• ***Drepanotermes phoenix*** (Termitidae; obligate; Fig 5) is endemic to Western Australia and inhabits a restricted area of predominantly spinifex grasslands near the coastal town of Roebourne (20° 47' S, 117° 09' E). Mounds are of sand and clay, pavement-like and 1–3 m in diameter from which rise a series of irregular hummocks up to ≈ 80 cm in height (Watson & Perry 1981).

Kimberley species

Tropical regions are known for the large size and abundance of its termite mounds (*e.g.* Andersen & Jacklyn 1993), and in the tropical Kakadu National Park of the Northern Territory, 16 species (about 30% of all known species in the region) build mounds (Braithwaite *et al.* 1988). This compares with six species (8%) for the termite fauna in the Western Australian wheatbelt. We therefore expect that the incidence of mound-building in the tropical Kimberley of Western Australia, for which our observations are least comprehensive, will increase as more data become available. For example, five other (termitid) species whose distributions overlap that of the Kimberley region are known to build mounds in the adjacent northern tropics of the Northern Territory (Braithwaite *et al.* 1988), and may therefore also build mounds in the Kimberley region. These species include *Amitermes vitiosus, Macrognathotermes sunteri, Microcerotermes nanus, M. serratus* and *Xylochomitermes melvillensis* (Table 1). Of these, *Macrognathotermes sunteri, Microcerotermes nanus* and *Xylochomitermes melvillensis* are largely restricted to the Kimberley region of their Western Australian distribution (Watson & Abbey 1993).

Identification of the original mound builder

As the above observations indicate, the presence of a termite species within a mound does not necessarily imply its role as the mound-builder. Not only are mounds sometimes taken over by other termite species, but mounds are commonly inhabited simultaneously by several species although without sharing galleries and chambers.

Subterranean (non-mound-building) termite species living in the mounds of other (mound-building) termites are referred to as ‘inquilines’. This behaviour is common; it has been observed in a wide range of species and inquilines may occur in the presence or absence of the colony of the original mound builder. Old colonies, or those weakened by disease, predation (*e.g.* ants, echidnas) or low food availability, are likely to be more susceptible to invasion by inquilines (or predaceous ants) than healthy colonies. Low food availability may occur during drought (especially through competition with livestock for grass, Watson & Gay 1970) or following fire (*e.g.* Abensperg-Traun *et al.* 1996). Benefits to the inquiline may include greater protection from environmental fluctuations (temperature and moisture extremes) afforded by mound-walls, possibly reduced predation by ants, the obvious reduction of energy expenditure involved in mound construction and maintenance, and being able to feed on nest content, especially in nests that contain carton (faecal) material. Several wood-eaters such as *Macrognathotermes sunteri* are known to feed on carton material from *Coptotermes* mounds (Miller 1991). Other species may invade mounds of grass-eaters for the food stores that they contain. All three species of the Australian endemic *Ahamitermes* (*A. hillii*, *A. nidicola*, *A. inclusus*) are obligate inquilines in the nests of *Coptotermes* spp (Calaby 1956). Of these, *A. hillii* and *A. inclusus* are endemic to Western Australia. The distribution of *Ahamitermes hillii* matches that of *Amitermes obeuntis* (Fig 2), while that of *Ahamitermes inclusus* closely resembles that of its host *Coptotermes brunneus* (Fig 5, Watson & Abbey 1993). Most other inquilines are opportunistic (facultative) mound inhabitants. For north-east Queensland, Spain & Brown (1979) report up to 81 % and 52 % of *Amitermes laurensis* and *A. vitiosus* mounds, respectively, housing one or more inquiline. We have made similar observations for Western Australian species involving subterranean opportunists as well as mound-builders inhabiting the mounds of other species (*e.g.* some *Drepanotermes* spp). In the central wheatbelt, subterranean opportunists frequently found in the mounds of *Drepanotermes tamminensis* include *Heterotermes occiduus*, *Microcerotermes newmani*, *Tumulitermes petilus*, *T. peracutus*, *Amitermes neogermanus* and several species of the *Termes-Capritermes* complex such as *Ephelotermes argutus* and *Xylochomitermes occidualis* (M Abensperg-Traun, unpublished data). *Amitermes obeuntis* is a mound-builder that commonly inhabits *D. tamminensis* mounds.

The presence of inquilines may make it difficult to correctly identify the original mound builder. Structural integrity of mounds, which can generally be used as a rough indicator of colony vigour, is maintained through mound extension to accommodate the growing colony. Mounds housing healthy colonies rarely show extensive invasions by other termite species. However, following the decline of the original colony, mound expansion is likely to cease. The mound then falls into increasing disrepair and structural degradation which is generally reflected by a crumbly outer surface covered to varying degrees by lichen, and usually by extensive ant invasion (*e.g. Iridomyrmex greensleidi* and *I. rufoniger* in the central wheatbelt). Such mounds frequently house several species of termites (and ants) which may occupy the bulk of the mound interior.

Correct identification of the original mound builder involves identification of the species occupying most of the mound interior, as well as those of other mounds in the close vicinity, and by comparing physical mound characteristics with those given in this review (with regard for geographic location). Entry into the mound to collect specimens for later identification may require a pick-axe, crow-bar and/or spade. Using forceps and taking great care to avoid damage to specimens, a minimum of ten soldiers and workers each should be collected for species identification from each individual mound, and from all co-inhabiting species. Specimens should be immediately stored in vials containing ≈ 75% alcohol for subsequent identification. Each individual collection (soldiers and workers of one species) must be stored in separate vials, labelled for location and any other relevant detail (*e.g.* longitude/latitude, mound shape and dimensions, vegetation and soil type). For more detailed taxonomy, see Hill (1942), Watson & Perry (1981), Perry *et al.* (1985) and Miller (1991).

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References

Abensperg-Traun M 1992 The effects of sheep-grazing on the subterranean termite fauna (Isoptera) of the Western Australian wheatbelt. Australian Journal of Ecology 17:425–432.

Abensperg-Traun M 1994 The influence of climate on patterns of termite-eating in Australian mammals and lizards. Australian Journal of Ecology 19: 65–71.

Abensperg-Traun M & De Boer E S 1990 Species abundance and habitat differences in biomass of subterranean termites (Isoptera) in the wheatbelt of Western Australia. Australian Journal of Ecology 15:219–226.

Abensperg-Traun M & Milewski A V 1995 Abundance and diversity of termites (Isoptera) in unburnt versus burnt vegetation at the Barrens in mediterranean Western Australia. Australian Journal of Ecology 20:413–417.

Abensperg-Traun M & Smith G T 1993 Predictable effects of agricultural development on the long-term availability of hollows for animals: observations from the Western Australian wheatbelt. Pacific Conservation Biology 1:78–79.

Abensperg-Traun M, Steven D & Atkins L 1996 The influence of plant diversity on the resilience of harvester termites to fire. Pacific Conservation Biology 2:279–285.

Andersen A N & Jacklyn P 1993 Termites of the Top End. CSIRO, Melbourne, Australia.

Braithwaite R W 1990 More than a home for white ants. Australian Natural History 23:306–313.

Braithwaite R W, Miller L & Wood J T 1988 The structure of termite communities in the Australian tropics. Australian Journal of Ecology 13:375–391.

Calaby J H 1956 The distribution and biology of the genus

Ahamitermes (Isoptera). Australian Journal of Zoology 4:111–124.

Calaby J H & Gay F J 1956 The distribution and biology of the genus *Coptotermes* (Isoptera) in Western Australia. Australian Journal of Zoology 4:19–39.

Calaby J H & Gay F J 1959 Aspects of the distribution and ecology of Australia termites. In: Biogeography and Ecology in Australia (eds A Keast, R L Crocker & C S Christian). Dr W Junk, The Hague, 211–223.

Gay F J 1955 A new *Coptotermes* and *Ahamitermes* (Isoptera) from Australia. Proceedings of the Linnaean Society of New South Wales 79:177–181.

Gay F J & Calaby J H 1970 Termites of the Australian region. In: Biology of Termites (eds K Krishna & F M Weesner). Academic Press, New York, 393–448.

Gay F J & Whetherly A 1970 The population of a large mound of *Nasutitermes exitiosus* (Hill)(Isoptera: Termitidae). Journal of the Australian Entomological Society 9:27–30.

Greaves T 1962 Studies of foraging galleries and the invasion of living trees by *Coptotermes acinaciformis* and *C. brunneus*. Australian Journal of Zoology 10:630–651.

Greaves T 1967 Experiments to determine the populations of tree-dwelling colonies of termites (*Coptotermes acinaciformis* (Froggatt) and *C. frenchi* Hill). Division of Entomology Technical Paper 7, CSIRO, Melbourne.

Hill G F 1942 Termites (Isoptera) from the Australian Region. CSIRO, Melbourne.

Holt J A & Easey J F 1985 Polycalic colonies of some mound-building termites (Isoptera: Termitidae) in northeastern Australia. Insectes Sociaux 32:61–69.

Holt J A & Easey J F 1993 Numbers and biomass of mound-building termites (Isoptera) in a semi-arid tropical woodland near Charters Towers, North Queensland, Australia. Sociobiology 21:281–286.

Lee K E & Wood T G 1971 Physical and chemical effects on soils of some Australian termites, and their pedological significance. Pedobiologia 11:376–409.

Lobry de Bruyn L A & Conacher A J 1990 The role of termites and ants in soil modification: a review. Australian Journal of Soil Research 28: 55–93.

Miller L R 1991 A revision of the *Termes-Capritermes* branch of the Termitinae in Australia (Isoptera: Termitidae). Invertebrate Taxonomy 4:1147–1282.

Park H C, Majer J D & Hobbs R J 1994 Influence of vegetation and soil types on the wheatbelt termite, *Drepanotermes tamminensis* (Hill), in the Western Australian wheatbelt. Ecological Research 9:151–158.

Perry D H, Watson J A L, Bunn S E & Black R 1985 Guide to the termites (Isoptera) from the extreme south-west of Western Australia. Journal of the Royal Society of Western Australia 67:66–78.

Ratcliffe F N, Gay F J & Greaves T 1952 Australian Termites. CSIRO, Melbourne.

Saunders D A, Smith G T & Rowley I 1982 The availability and dimensions of tree hollows that provide nest sites for cockatoos (Psittaciformes) in Western Australia. Australian Wildlife Research 9:541–556.

Spain A V & Brown A J 1979 Aspects of the biology of harvester termites in a grassland environment (Isoptera). In: Proceedings of the 2nd Australasian Conference on Grassland Invertebrate Ecology (eds T K Crosby & R P Pottinger). Government Printer, Wellington, 141–145.

Spain A V, Okello-Oloya T & Brown A J 1983 Abundance, above-ground masses and basal areas of termite mounds at six locations in tropical north-eastern Australia. Revue d'Ecologie et de Biologie du Sol 20:547–566.

Watson J A L & Abbey H M 1993 Atlas of Australian Termites. CSIRO, Division of Entomology, Canberra.

Watson J A L & Gay F J 1970 The role of grass-eating termites in the degradation of a mulga ecosystem. Search 1:43.

Watson J A L & Gay F J 1991 Isoptera. In: The Insects of Australa, Vol 1. Melbourne University Press, Melbourne.

Watson J A L, Barrett R A & Green J P 1988 Growth of mounds of the Australian harvester termite, *Drepanotermes perniger* (Froggatt) (Termitinae). Sociobiology 14:217–244.

Watson J A L, Lendon C & Low B S 1973 Termites in mulga lands. Tropical Grasslands 7:121–126.

Watson J A L & Perry D H 1981 The Australian harvester termites of the genus *Drepanotermes* (Isoptera: Termitinae). Australian Journal of Zoology (Supplementary Series) 78:1–153.