Earthworms on the Maret Islands and adjacent islands, north-west Kimberley region Western Australia

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Abstract

The Maret Islands in the Kimberley region of north-west Western Australia are the proposed site of onshore gas processing and shipping facilities and associated accommodation and airport infrastructure. Extensive parts of the islands will be within the he proposed development footprint. Terrestrial oligochaetes (earthworms) were noted by Harvey (2002) as examples of terrestrial invertebrate fauna exhibiting short range endemism. Investigation of earthworm assemblages on the islands proceeded within the scope of two hypotheses: *1. Earthworm species distribution and diversity is structured primarily by soil type and vegetation type; 2. The same set of earthworm species occurs on the islands to be sampled.*

Presence/absence samples were taken broadly over North and South Maret Islands, ensuring that principal geomorphic types and each vegetation type were assessed in proportion to their representation on each island. Surface soil conditions on the islands did not appear to favour earthworms at the time of the presence/absence survey. Subsequently in late February 2007 an earthworm was collected by Inpex staff beneath a rock on the laterite plateau of South Maret Island, and further specimens were collected during pitfall trapping excavations on South Maret Island (16 and 17 March 2007) and Berthier Island (5 April 2007). This material is mostly sexually immature specimens and requires specialist examination and dissection. None of the material conforms to the only described native species from the region, *Diplotrema macleayi*, although the most mature specimens are consistent, on the basis of external features, with the genus *Diplotrema*. In terms of the two hypotheses posed in the introduction, both remain as essentially unexaminable with the limited data collected. The sampling strategy described is suitable to test the hypotheses and it is recommended that further sampling take place when soil moisture is adequate.

Introduction

The Maret Islands are the proposed site of onshore gas processing and shipping facilities and associated accommodation and airport infrastructure. Extensive parts of the islands will be within the proposed development footprint.

Terrestrial oligochaetes (earthworms) were noted by Harvey (2002) as examples of terrestrial invertebrate fauna exhibiting short range endemism. They rely on seasonally moist soil, and seasonal soil moisture regimes are patchy at localised and landscape scales leading to patchy distribution of earthworm species (Wills and Abbott 2004). Earthworms collected from widely dispersed mainland patches of rainforest in the Kimberley region showed low diversity within rainforest patches but each patch contained a species unique to that patch (McKenzie and Dyne 1991).

Faunal studies on the islands have the principal aim of describing the faunal assemblages and habitats on the Maret Islands and to determine the significance of potentially impacted sites by comparison with non-impact areas and reference islands. For earthworm assemblages, investigation proceeded within the scope of two hypotheses:
1. Earthworm species distribution and diversity is structured primarily by soil type and vegetation type.
2. The same set of earthworm species occurs on the islands to be sampled.

Methods

Survey methods
Moist soil conditions were anticipated to be present in February 2007 and systematic sampling was conducted between 16 and 23 February 2007. The study applied sampling strategies that have proved successful in agricultural and forest regions of south-west Western Australia (Abbott & Parker 1980; Abbott 1982, 1985a,b; Abbott & Wills 2002; Wills & Abbott 2003).

Presence/absence samples were taken broadly over North and South Maret Islands, ensuring that principal landform types and each vegetation type (Appendices 1 and 2) were assessed in proportion to their representation on each island. For each site landform and vegetation context were noted as well as spade penetration, litter depth and coverage, litter and soil moisture conditions and presence of laterite pieces. Details for each sample site are listed in Appendix 3. Each sample consisted of a block of soil 19 cm by 19 cm by 15 cm depth (or to the depth present if < 15 cm). Some earthworm species feed at the interface between moist litter and mineral soil. Where litter was present, litter was scraped away to check litter conditions and reveal the underlying soil surface. The geographic location of each sample was determined by GPS. The block of soil was placed on a white surface and sorted *in situ*. Provision was made for any earthworms recovered to be retained and later preserved (washed in 40% ethanol for 5-10 min, fixed in 4% formalin for 1-2 h, and then stored in vials containing 70% ethanol).

It was intended that following recovery of earthworms in presence/absence surveys, transect based surveys would then be used to determine density, frequency of occurrence and biomass.

Landform/soil units searched
At the time of earthworm sampling a landform and soils survey of the island had not been undertaken, however, all primary landform elements on the island subsequently identified (RPSBBG 2007) were sampled for earthworms except cliffs and steep slopes (S1, S3 and S4 units), primary foredunes (D1) and beaches (Table 1).

The greater extent of both North and South Maret Islands is comprised of the of a lateritic plateau. Much of the plateau is laterite pavement (P1) or areas strewn with laterite cobble, stones and occasional boulders (P2). In some areas there are wind blown sand sheets covering laterite surfaces (P3). On the plateau above West Beach on South Maret Island there is a thin sand sheet apparently derived from dunes below the cliff. Where this sand has been trapped under vegetation it reaches a depth of about 20 cm. While the sand sheet on South Maret Island was sampled a similar sheet on North Maret island was not. Catchment areas and their associated weakly defined ephemeral water courses (P4) were sampled on both North and South Maret Islands.

Vegetation units searched
Within each landform type sampled, samples were taken from principal vegetation units under the assumption that local soil conditions influence vegetation composition (TcGp and AcS not sampled on North Maret, AcTb and PT not sampled on South Maret). Twenty three sites were sampled in vegetation units on the Lateritic Plateau (Table 2). The plateau was the most diverse in terms of vegetation units. Slopes and filled embayments were mantled in Monsoon forest and/or vine thicket (Mf/T) vegetation units. Particular attention was paid to investigating the Mf/T vegetation (see Appendix 1) since this has the tallest and densest foliage cover on both North and South Maret Islands.

Opportunistic collection of earthworm specimens
Earthworms were collected opportunistically by Inpex staff during later activities on the islands. Specimens were temporarily retained in moist soil in plastic bags and kept cool for later preservation. Specimens were washed and killed in 40% ethanol and then preserved in

70% ethanol for later examination. While this is not the optimal method of preservation, it is the least hazardous to non-specialist collectors.

Identification of collected material
The taxonomy of the Australian earthworm fauna is relatively well known despite large gaps in collection coverage. Extensive published faunas (Jamieson 2000; Blakemore 2002; Dyne and Jamieson 2004) allow identification to genus and species level of sexually developed native and non-native specimens. Material collected from the islands was compared with published descriptions. As yet undescribed earthworm material of the mainland regional earthworm fauna was previously collected from rainforest patches by McKenzie and Dyne (1991) and is lodged in the Australian National Insect Collection (ANIC) Canberra. These specimens were not examined.

Results

Surface soil conditions on the plateau did not appear to favour earthworms at the time of the presence/absence survey. Superficial soils were either absent, or dry at the time of sampling in the interstices between laterite fragments (Table 1). Soil and/or litter conditions were dry to touch at all sites and no free water was found on the islands. No earthworms were found on the islands in the general earthworm survey.

The Mf/T vegetation unit is most developed on fringing slopes and filled embayments to the plateau (Table 3). Soils in these contexts were dry, loose sands which spilled easily from the spade. No earthworms were found. Litter accumulation under this vegetation was markedly less than that under trees on the lateritic plateau (Table 4), indicating either lower rates of litterfall or higher rates of comminution and incorporation of the litter.

Most notable on the lateritic plateau were the accumulations of litter beneath trees (Table 4). This is probably indicative of a long absence of fire from both North and South Maret Islands. The interface between soil and litter is often habitat for earthworms, however, litter conditions were dry at the interface between mineral soil and litter (Appendix 3).

Berthier and Montalivet Islands were not sampled for earthworm in the presence/absence survey. It was considered appropriate to allocate the available sampling time to searching the Maret Islands more thoroughly until earthworms were found, or it became apparent that earthworms were not present.

Subsequently in late February 2007 an earthworm was collected by RPS staff beneath a rock on the laterite plateau of South Maret, and during pitfall trapping excavations on South Maret (16 and 17 March 2007) and Berthier (5 April 2007) islands (Table 5). This material is mostly sexually immature specimens (Table 5) and requires specialist examination and dissection. None of the material conforms to the only described native species from the region, *Diplotrema macleayi*, although the most mature specimens are consistent, on the basis of external features, with the genus *Diplotrema*. The earthworms were collected on South Maret Island from the P2b soil unit (Appendix 2), a unit found extensively on both North and South Maret Islands.

Discussion

Suitable soil conditions are necessary for the collection of earthworm specimens. Soils need to be moist so that earthworms are mobile and feeding, and sufficient time needs to have elapsed from rainfall so that earthworms are sexually active and exhibit mature sexual markings. In planning sampling, it was assumed that wet season rainfall prior to the sampling should have resulted in soil moisture levels suited to earthworm activity. Instead, surface soil and litter conditions during February were apparently too dry to allow mobility of earthworms in soils of the islands. The single specimen fortuitously collected in late February was found in moist gravelly soil beneath a boulder. Presumably the underside of the boulder provided a moist refuge. In dry tropical Queensland soils earthworms may aestivate at depth for

considerable periods before moving closer to the surface under moist conditions (Blakemore, Pers comm.)

McKenzie and Dyne (1991) noted for spade samples that where sample depth was limited by rocks or roots, density and biomass estimations would be underestimated. Similarly for samples on laterite plateau in this survey, limited spade penetration of the laterite may have influenced the detection of earthworms. Sampling by turning rocks and boulders was not used as a sample method in the general earthworm survey.

Tree height and foliage density is often an indicator of available soil moisture and nutrient resources. The most dense and tallest canopies on the islands are found in the Mf/T vegetation unit in the swales between dunes and slopes (Table 3, Fig. 1). However, no earthworms have yet been found been in this vegetation context. On South Maret Island earthworms have so far been found only on the lateritic plateau under PT, GcTb and CpATc vegetation units. These vegetation units have widely contrasting architecture, ranging from herb fields to woodlands, indicating that vegetation units are probably not a subtle enough indicator of suitable soil conditions for earthworms. By contrast, on the Swan Coastal Plain geomorphology at localised and landscape scales strongly influences both suitability for earthworms, and vegetation composition (Abbott and Wills 2002).

The presence of earthworms in woodlands and herb fields on the lateritic plateau of South Maret Island has significance for regional biodiversity of earthworms both on the mainland and other islands in the Bonaparte Archipelago. On the mainland, only remnant rainforest patches have been systematically sampled in the Kimberley region (McKenzie and Dyne 1991). These authors hypothesised that earthworms were patchy in distribution and that geographic ranges of species were about 20 km in diameter and overlapped a number of patches. Samples from widely dispersed patches (>10 km apart and mostly >40 km apart) showed a pattern of unique species in each patch. This pattern is not inconsistent with their hypothesis.

From the specimens recovered for South Maret Island it appears that earthworms in the Kimberley are not confined to rainforest patches, though some species may require conditions found only under rainforests, and that patches may be more extensive than isolated rainforest fragments. However, islands provide physical isolation of populations and genetic drift of separated populations can eventually lead to allopatric speciation. Islands in the vicinity of North and South Maret Islands are much closer than a few tens of kilometres and the relatedness of congeneric material found on nearby islands is at present unknown.

Soils apparently suitable for earthworms are extensive on both North and South Maret Islands however their collection in any but ideal soil moisture conditions requires deeper excavation. It is likely that earthworms are more extensively distributed on South Maret Island and are possibly present on North Maret Island.

Only limited amounts of earthworm material are available from the islands at present but most of that is immature or fragments. From examination of external features the material is not inconsistent with the native genus *Diplotrema*, a genus found extensively in northern Australia (McKenzie and Dyne 1991, McKenzie *et al.* 1995, Dyne and Jamieson 2004). *Diplotrema macleayi* is the only described species from the Kimberley region. *Dichogaster boulaui* and undescribed *Diplotrema* material collected from Koolan Island by McKenzie et al. (1995) is held at the Western Australian Museum (WAM), while undescribed *Diplotrema* material collected by McKenzie and Dyne (1991) is held at ANIC.

The material from South Maret and Berthier Islands is not consistent with introduced or cosmopolitan species known from the Kimberley region. Species that can be excluded are the littoral species *Pontodrilus litoralis* (dorsal pores present and non littoral habitat for S. Maret material), *Pontoscolex corethrurus* (genital markings not similar) and *Metaphire houlleti* (only 8 setae per segment for S. Maret material). Of other introduced genera in northern Australia, perhaps immature specimens of the some of the genus *Dichogaster* might superficially resemble the material collected from the islands.

Further resolution of the Maret Islands and Berthier Island material requires dissection and specialist consideration. However, the material may even then not be sufficient for formal description of new species. A better strategy is more timely sampling in conditions of suitable soil moisture and the collection of sexually mature specimens as this material would be more reliable for formal description for taxonomic purposes. Resolution of *Diplotrema* species and *Diplotrema* biogeography in the Kimberley region and adjacent islands remains an important priority given the suspected local endemism of this genus and isolation of populations on islands and possibly within relict rainforest patches.

The presence of an introduced species in gardens on Koolan Island (McKenzie *et al.* 1995) highlights the potential for exotic earthworms to be inadvertently introduced to The Maret Islands. Earthworms are regarded as “ecosystem engineers” and in some circumstances exotic earthworm invasions have the potential to profoundly affect ecosystem processes (Hendrix and Bohlen 2002).

In terms of the two hypotheses posed in the introduction, both remain as essentially untestable with the limited data collected. The sampling strategy described is suitable to test the hypotheses and it is recommended that further sampling take place when soil moisture is adequate.

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Table 1. Geomorphic and soil units sampled.

Landform	Soil unit	General description of landform/soils	Soil dryness	Litter dryness	Earthworms present?
Lateritic plateau (P)		Plateau surface			
	P1	Laterite pavements. No spade penetration. Some soil associated with termite mounds.	No soil or Dry	Scant litter	None found
	P2a	Laterite with surface floaters >5 cm. No spade penetration	No soil	Dry	None found
	P2b	Laterite with surface floaters >5 cm and some interstitial soil. Limited spade penetration in interstices	Dry	Dry	None found
	P2c P3a,b	Wind-blown sand sheet over laterite	Dry	Dry	None found
	P4				
Fringing cliffs and slopes	S1	Cliffs of massive laterite and steep slopes			Not sampled
	S2	Slopes with red sandy soil with laterite pieces >1 cm, surface boulders some sites. Some spade penetration	Dry	Dry	None found
Swales between dunes and slopes	S2	Red sands with laterite pieces >1 cm. Some spade penetration	Dry	Dry	None found
Swales between dunes and slopes	D2	Deep pale sands. Full spade penetration	Dry	Dry	None found
Dunes	D1	Low relief primary foredunes			Not sampled
	D2	Deep pale sands. Full spade penetration	Dry	Dry	None found
Beaches	Beaches	Deep pale sands.			Not sampled
		Sand and coral fragments.			Not sampled

Table 2. Number of sample sites in geomorphic units and vegetation types.

Landform unit	Vegetation unit			
	Mf/T	Non Mf/T shrublands and woodlands	Herbfields and grasslands	No vegetation
Lateritic plateau (P)	1	18	4	Veg. type not present
Fringing cliffs and slopes (S)	3	Veg. type not present	Not sampled	Not sampled
Swales between dunes and slopes (D2, S2)	4	Veg. type not present	Veg. type not present	Veg. type not present
Dunes (D)	4	Veg. type not present	Not sampled	Not sampled
Beaches	Veg. type not present	Veg. type not present	Veg. type not present	Not sampled

Table 3. Mean height in metres of covering vegetation. Height range in parentheses.

Geomorphic unit	Vegetation unit			
	Mf/T	Shrublands and woodlands: CpATc, GpTcS, Cp, CorN	Herbfields and grasslands: GcTb, AcTb	No vegetation
Lateritic plateau (P)	4	7 (3-11)	<0.5	Veg. type not present
Fringing cliffs and slopes (S)	9 (7-10)	Veg. type not present	Not sampled	Not sampled
Swales between dunes and slopes (D2, S2)	10 (8-12)	Veg. type not present	Veg. type not present	Veg. type not present
Dunes (D)	6 (5-8)	Veg. type not present	Not sampled	Not sampled
Beaches	Veg. type not present	Veg. type not present	Veg. type not present	Not sampled

Table 4. Mean litter depth in centimetres under covering vegetation. Depth range in parentheses.

Geomorphic unit	Vegetation unit			
	Mf/T	Shrublands and woodlands: CpATc, GpTcS, Cp, CorN	Herbfields and grasslands: GcTb, AcTb	No vegetation
Lateritic plateau (P)	2	10 (5-28)	<0.5	Not present
Fringing cliffs and slopes (S)	4 (3-5)	Veg. type not present	Not sampled	Not sampled
Swales between dunes and slopes (D2, S2)	2 (2-3)	Veg. type not present	Veg. type not present	Veg. type not present
Dunes (D)	4 (3-5)	Veg. type not present	Not sampled	Not sampled
Beaches	Veg. type not present	Veg. type not present	Veg. type not present	Not sampled

Table 5. Earthworm material examined.

Label details	WAM registration numbers	Comments	External features	Genus/species
South Maret Island, late February 2007, E714187, N8403030 {Hand captured under boulder}	WAM V 7338	Specimen distorted and in poor condition: delay in preservation.	8 rows of setae, ?genital markings in xvii, xviii and ?xix	Not determined.
South Maret Island, 16 March 2007, E714096, N8403064, upland, North Transect 10	WAM V 7330 WAM V 7332 WAM V 7333 WAM V 7334 WAM V 7335	Fragments and immatures	8 rows of setae, *ab* and *cd* rows closely paired, *dd* > 40%,	Not determined.
South Maret Island, 16 March 2007, E714096, N8403064, upland, North Transect 10. Specimen #1	WAM V 7331	See Fig. 2	Length: 40 mm (preserved) Width: 3.5 mm (preserved) Prostomium Epilobous closed Segments: Tripartite (= 3 bands within segments) Dorsal pores: Present Rows of setae: 8 rows in 4 closely paired sets Inter-setal ratios at segment *xiv*: aa:ab:bc:cd = 7:1:7:1, dd > 40% Clitellum: Not present Male pores: pair present in segment *xviii* slightly lateral to ab setal rows Female pores: Not visible Genital markings: pair with pores present in segment *viii*, pairs present in *xvii* and *xix* (carrying prostate pores?)	Possibly *Diplotrema sp.*
South Maret Island, 17 March 2007, E714513, N8402640, upland, Euc/acacia woodland	WAM V 7336	Immatures	8 rows of setae, *ab* and *cd* rows closely paired, *dd* > 40%,	Not determined.
Berthier Island, 05 April 2007, E714101, N8393996. hand captured in soil under vine thicket on basalt rocks on hill slope.	WAM V 7337	Immature or not recently sexually active? Specimen knotted. (Aestivating?)	8 rows of setae, *ab* and *cd* rows closely paired, *dd* > 40%, indefinite markings on and around xviii	Not determined.

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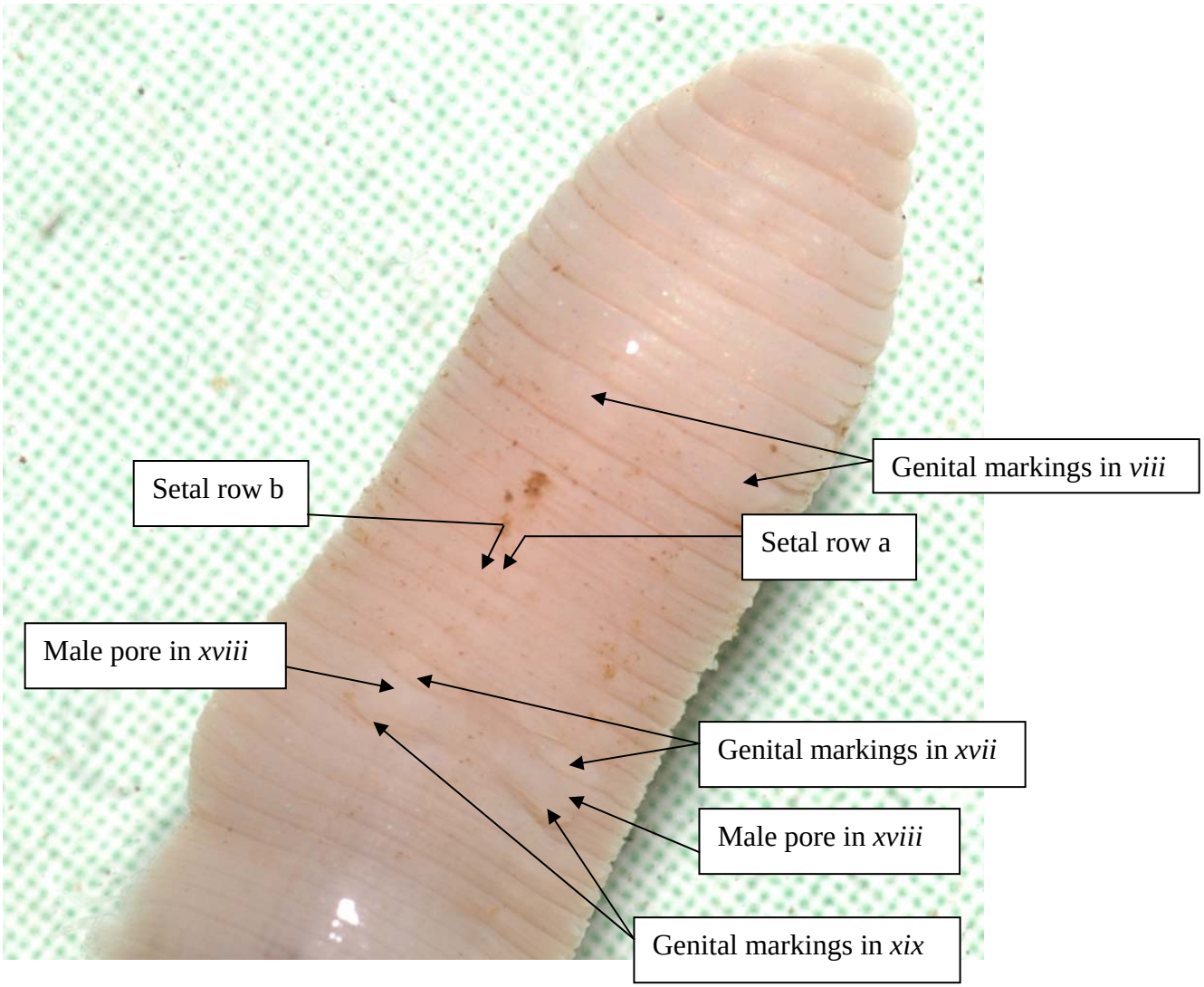

Fig. 1. Low resolution detail of specimen: South Maret Island, 16 March 2007, E714096, N8403064, upland, North Transect 10. Specimen #1. Maximum width of specimen 3.5 mm.

Appendices

Appendix 1: Description of vegetation types of North Maret and South Maret Islands (Courtesy of RPSBBG vegetation survey)

Appendix 2: Description of landforms and soils of North Maret and South Maret Islands (RPSBBG 2007)

Appendix 3: Earthworm presence/absence survey site details.

Appendix 1: Description of vegetation types (Courtesy of RPS BBG vegetation survey)

AcTb
Acacia retinervis Open Shrubland/Shrubland over *Triodia bynoei* Open Grassland over *Gomphrena canescens, Ptilotus ?corymbosus*. Open Herbland/Herbland.

AcS
Acacia retinervis Open Shrubland/Shrubland over *Sorghum timorense* Closed Grassland

CuG
Grevillea pyramidalis Open Shrubland over *Cullen badocanum* Low Open Shrubland/Low Shrubland over *Sorghum timorense* Closed Grassland

CorN
Corymbia ?clavigera Low Woodland/Low Open Forest over *Acacia retinervis* Shrubland over *Distichostemon hispidula* Scattered Low Shrubs over *Sorghum timorense, S. plumosum* Grassland/Closed Grassland

Cp
Corymbia polycarpa Low Open Forest over *Garuga floribunda, Terminalia petiolaris, T. canescens, Grevillea pyramidalis* Open Shrubland/Shrubland over *Sorghum timorense, S. plumosum* Closed Shrubland

CpAc
Corymbia polycarpa, C. ?clavigera Low Woodland/Low Open Forest over *Acacia retinervis* Shrubland over *Sorghum timorense, S. plumosum* Grassland.

CpATc
Corymbia polycarpa, C. ?clavigera Scattered Low Trees/Low Woodland over *Acacia retinervis, Terminalia canescens* Tall Scrub over *Tarenna pentamera*, *Clerodendrum tomentosum, Pavetta kimberleyana* Shrubland over *Ptilotus corymbosus* Very Open Herbland over *Sorghum timorense, Triodia bynoei* Grassland.

CpGTb
Corymbia polycarpa Scattered Low Trees over *Acacia retinervis* Tall Shrubland over *Buchnera ?asperata, Gomphrena canescens, Ptilotus corymbosus* Herbland over *Triodia bynoei* Open Hummock Grassland over *Fimbristylis trigastrocarya* Open Herbland.

CpTc
Corymbia polycarpa Scattered Low Trees over *Terminalia canescens* Tall Shrubland over *Acacia stigmatophylla* Open Heath over *Triodia bynoei* Closed Hummock Grassland

CTcAs
Corymbia polycarpa, C. ?clavigera, Terminalia canescens Low Open Woodland over *Acacia stigmatophylla* Open Shrubland over *Sorghum timorense (Triodia bynoei)* Grassland

CuG
Grevillea pyramidalis Open Shrubland over *Cullen badocanum* Low Open Shrubland/Low Shrubland over *Sorghum timorense, S. plumosum* Closed Grassland
On deeper sands and low dune ridges above the south-western beach of N Maret Island

GcTb
Gomphrena canescens, Ptilotus corymbosus, Buchnera ?asperata Herbland over *Triodia bynoei* Open to Closed Hummock Grassland over *Fimbristylis trigastrocarya* Very Open Sedgeland.

GpTcS
Grevillea pyramidalis, Terminalia canescens Open Shrubland/Tall Open Shrubland

over *Gomphrena canescens, Ptilotus* sp. Open Herbland over *Sorghum timorense, S plumosum* Closed Grassland.

NB. The two following veg descriptions are very similar and, while they are accurate to a degree they will be refined further during the next field trip. Technically they are both of Monsoon Forest, however the character changes in dominance from the slopes with presumably deeper soil to the plateaux with very little soil.

Mf/T
Monsoon forest or vine thicket.
Terminalia petiolaris, Mimusops elengi, Sterculia quadrifida, Exocarpos latifolius Closed Tall Scrub/Low Closed Forest over *Strychnos lucida, Diospyros maritima* Open Shrubland over *Sorghum plumosum, Cenchrus elymoides* Scattered Grasses/Open Grassland with lianes of *Sarcostemma viminale* subsp. *brunonianum, Cayratia maritima, Ampelocissus acetosa* and *Adenia heterophylla.*

PT
Plateau thicket. Almost impenetrable, needs more collecting.
Terminalia petiolaris, T. ferdinandiana, Corymbia polycarpa, C. ?clavigera Woodland/Closed Woodland over *Sterculia quadrifida, Strychnos lucida, Mimusops elengi, Diospyros maritima, D. ?humilis* Shrubland/Closed Shrubland over *Sorghum plumosum, Cenchrus elymoides* Scattered Grasses/Open Grassland with lianes of *Sarcostemma viminale* subsp. *brunonianum, Cayratia maritima, Ampelocissus acetosa* and *Adenia heterophylla.*

Appendix 2: Landforms and Soils of North and South Maret Islands (from RPSBBG 2007)

P Plateau surface (Laterite capped mesa)

Areas with massive laterite pavement.

P1 Flat to very gently inclined plateau surface with extensive open areas of massive laterite pavement and intervening areas of extremely shallow red or brown loam or clay loam soil occurring as interstitial material between coarse gravels and beneath a mantle of almost continuous lag gravel.

Areas strewn with laterite cobbles, stones and occasional boulders.

P2a Flat to very gently inclined plateau surface with abundant surface lateritic cobbles and stones and very shallow red or brown sandy loam soil with common gravel.

P2b Flat to very gently inclined plateau surface with abundant surface lateritic cobbles and stones and very shallow red or brown loam or clay loam soil with common gravel.

P2b Flat to very gently inclined plateau surface with occasional to locally-common surface lateritic cobbles and stones and moderately shallow red or brown loam or clay loam soil with minor gravel.

Areas with wind blown sands over lateritic surface.

P3a Very gently inclined margin of the plateau surface with moderately deep wind-blown sand deposits over buried laterite. Sands have 5-10 cm of light yellowish brown sand at surface over a reddish brown sandy subsoil with very minor gravel.

P3b Flat to very gently inclined plateau surface with moderately shallow wind-blown sand deposits over buried laterite. Occasional to locally-common surface lateritic cobbles and stones, and less than 5 cm of light yellowish brown sand at surface over a reddish brown sandy subsoil with minor gravel.

P3c Flat to very gently inclined plateau surface with moderately shallow wind-blown sand deposits over buried laterite. Common surface lateritic cobbles and stones, and only a thin veneer of yellow sand over reddish brown sandy subsoil with minor gravel.

Weakly incised drainage pathways (only seasonally active) within plateau surface.

P4 Gently inclined open linear drainage depressions with abundant surface lateritic cobbles and stones, and very shallow dark brown organic sands or loamy sands with common gravel.

S Slopes and cliffs fringing the plateau (with exposures of lower portions of lateritic profile as well as colluvium and scree).

S1 Steep slopes and precipitous cliffs with variable , extremely shallow to shallow soils and variable occurrence of laterite stones and boulders.

S2 Moderately steep vegetated lower sloes, with moderately thick to thick sands over buried lateritic colluvium or aeolianite. Soils beneath organic litter are grey/very pale brown to light yellowish brown, wind blown calcareous sands at the surface, over a reddish brown sandy subsoil.

S3 Steep sparsely vegetated portions of lower slopes where clayey saprolite and scree deposits are exposed. (NoteMany other areas of S3 occur within the S1 unit but have not been mapped).

S4 Moderately steep, sparsely vegetated slopes forming coastal promontories beyond the margins of the lateritic plateau.

D Dunes adjacent to beaches within protected embayments.

D1 Low relief, primary foredunes and very gently undulating relict foredune plain (not always present). Soils are predominantly deep grey to very pale brown, loose, calcareous sands with minimal vegetation cover. The sands are light fellowish brown at depth, in swales and lower portions of relict foredune plain.

D2 Moderate relief, secondary dunes with moderate to steep side slopes that are commonly vegetated with tall grasses. Soils are mainly deep grey to very pale brown, loose calcareous sands, underlain in places by weakly cemented aeolianite. The sand may be a darker brown near the harder aeolianite.

Appendix 3: Earthworm presence/absence survey site details

Field Number:	South Maret 1
Date:	16/2/2007
Easting UTM WGS 84:	714376
Northing UTM WGS 84:	8401856
Veg map unit:	Mf/T
Geomorphic unit:	Dune
Description of covering vegetation:	Tall thicket with vines
Estimated Vegetation Height:	5 m
Estimated litter coverage:	Not recorded
Estimated litter depth:	3 cm
Litter moisture:	Dry
Soil colour:	Pale
Soil texture:	Sand
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	None
Comments:	Full spade penetration

Field Number:	South Maret 2
Date:	16/2/2007
Easting UTM WGS 84:	714377
Northing UTM WGS 84:	8401890
Veg map unit:	Mf/T
Geomorphic unit:	Slope
Description of covering vegetation:	Tall thicket with vines
Estimated Vegetation Height:	10 m
Estimated litter coverage:	Not recorded
Estimated litter depth:	3 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Sand, Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	None
Comments:	Surface laterite boulders >50 cm,

Field Number:	South Maret 3
Date:	17/2/2007
Easting UTM WGS 84:	713689
Northing UTM WGS 84:	8401722
Veg map unit:	CpATc
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Isolated Eucalypt
Estimated Vegetation Height:	8 m
Estimated litter coverage:	100%
Estimated litter depth:	8 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Fine sand?, Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	229
Comments:	Almost no spade penetration

Field Number:	South Maret 4
Date:	17/2/2007
Easting UTM WGS 84:	713706
Northing UTM WGS 84:	8401914
Veg map unit:	CpATc
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Isolated Eucalypt
Estimated Vegetation Height:	7 m
Estimated litter coverage:	100%
Estimated litter depth:	8 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	No spade penetration

Field Number:	South Maret 5
Date:	17/2/2007
Easting UTM WGS 84:	713763
Northing UTM WGS 84:	8402102
Veg map unit:	CpATc
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Isolated Eucalypt
Estimated Vegetation Height:	7 m
Estimated litter coverage:	100%
Estimated litter depth:	5 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Fine sand?, Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	Limited spade penetration, 10cm laterite on surface.

Field Number:	South Maret 6
Date:	17/2/2007
Easting UTM WGS 84:	714061
Northing UTM WGS 84:	8402178
Veg map unit:	CpATc
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Isolated Corymbia
Estimated Vegetation Height:	9 m
Estimated litter coverage:	100%
Estimated litter depth:	12 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	Almost no spade penetration, 40cm laterite on surface.

Field Number:	South Maret 7
Date:	17/2/2007
Easting UTM WGS 84:	714201
Northing UTM WGS 84:	8402136
Veg map unit:	CpATc
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Isolated eucalypt
Estimated Vegetation Height:	11 m
Estimated litter coverage:	100%
Estimated litter depth:	12 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Fine sand? Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	Limited spade penetration

Field Number:	South Maret 8
Date:	17/2/2007
Easting UTM WGS 84:	714357
Northing UTM WGS 84:	8402194
Veg map unit:	CpATc
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Isolated eucalypt
Estimated Vegetation Height:	11 m
Estimated litter coverage:	100%
Estimated litter depth:	10 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	Almost no spade penetration. 50cm laterite on surface. Isopod in litter.

Field Number:	South Maret 9
Date:	17/2/2007
Easting UTM WGS 84:	713976
Northing UTM WGS 84:	8402101
Veg map unit:	GpTcS
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Sparse herbs and grasses
Estimated Vegetation Height:	<0.5 m
Estimated litter coverage:	Scant
Estimated litter depth:	Scant
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Massive laterite pavement
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	No spade penetration.

Field Number:	South Maret 12
Date:	19/2/2007
Easting UTM WGS 84:	714114
Northing UTM WGS 84:	8403554
Veg map unit:	Mf/T
Geomorphic unit:	Dune
Description of covering vegetation:	Thicket with vines
Estimated Vegetation Height:	6 m
Estimated litter coverage:	Not recorded
Estimated litter depth:	5 cm
Litter moisture:	Dry
Soil colour:	Pale
Soil texture:	Sand
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	324-327
Comments:	Full spade penetration

Field Number:	South Maret 13
Date:	19/2/2007
Easting UTM WGS 84:	714105
Northing UTM WGS 84:	8403510
Veg map unit:	Mf/T
Geomorphic unit:	Swale
Description of covering vegetation:	Tall thicket with vines
Estimated Vegetation Height:	8 m
Estimated litter coverage:	50%
Estimated litter depth:	2 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Sand, laterite pieces >1cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	324-327
Comments:	Full spade penetration, 5 cm laterite on surface

Field Number:	South Maret 14
Date:	19/2/2007
Easting UTM WGS 84:	714121
Northing UTM WGS 84:	8403470
Veg map unit:	Mf/T
Geomorphic unit:	Slope
Description of covering vegetation:	Tall thicket with vines
Estimated Vegetation Height:	10 m
Estimated litter coverage:	80%
Estimated litter depth:	3 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Sand, laterite pieces >1cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	Full spade penetration, 5 cm laterite pieces on surface

Field Number:	South Maret 15
Date:	19/2/2007
Easting UTM WGS 84:	714071
Northing UTM WGS 84:	8403644
Veg map unit:	Mf/T
Geomorphic unit:	Slope
Description of covering vegetation:	Thicket with vines
Estimated Vegetation Height:	7 m
Estimated litter coverage:	Not rcorded
Estimated litter depth:	3 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Sand, laterite pieces >1cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	Full spade penetration, 1.5 cm laterite pieces on surface

Field Number:	South Maret 16
Date:	21/2/2007
Easting UTM WGS 84:	713970
Northing UTM WGS 84:	8401944
Veg map unit:	GpTcS
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Sparse herbs and grasses
Estimated Vegetation Height:	<0.5 m
Estimated litter coverage:	Scant
Estimated litter depth:	Scant
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Massive laterite pavement with surface laterite 15-50 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	343-345
Comments:	No spade penetration

Field Number:	South Maret 17
Date:	21/2/2007
Easting UTM WGS 84:	714288
Northing UTM WGS 84:	8402082
Veg map unit:	CpATc
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Isolated Corymbia
Estimated Vegetation Height:	7 m
Estimated litter coverage:	100%
Estimated litter depth:	10 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Fine sand? Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	349-351
Comments:	Limited spade penetration

Field Number:	South Maret 18
Date:	21/2/2007
Easting UTM WGS 84:	714243
Northing UTM WGS 84:	8402170
Veg map unit:	CpATc
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Non Eucalypt thicket
Estimated Vegetation Height:	Not recorded
Estimated litter coverage:	100%
Estimated litter depth:	4 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Fine sand? Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	352-353
Comments:	Limited spade penetration. Surface laterite 20-40 cm

Field Number:	South Maret 19
Date:	21/2/2007
Easting UTM WGS 84:	714401
Northing UTM WGS 84:	8402314
Veg map unit:	GcTb
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Herbs and grasses
Estimated Vegetation Height:	<0.5 m
Estimated litter coverage:	Scant
Estimated litter depth:	Scant
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Massive laterite pavement
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	354-356
Comments:	No spade penetration.

Field Number:	South Maret 21
Date:	22/2/2007
Easting UTM WGS 84:	713500
Northing UTM WGS 84:	8402184
Veg map unit:	Mf/T
Geomorphic unit:	Swale
Description of covering vegetation:	Tall thicket with vines
Estimated Vegetation Height:	12 m
Estimated litter coverage:	70%
Estimated litter depth:	2 cm
Litter moisture:	Dry
Soil colour:	Pale
Soil texture:	Sand
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	364
Comments:	Complete spade penetration. Spider and web present. Drainage line?

Field Number:	South Maret 22
Date:	22/2/2007
Easting UTM WGS 84:	713700
Northing UTM WGS 84:	8402164
Veg map unit:	Mf/T
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Thicket with vines
Estimated Vegetation Height:	4 m
Estimated litter coverage:	20%
Estimated litter depth:	2 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Fine sand? laterite >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	365-366
Comments:	Almost no spade penetration. 8 cm laterite pieces on surface. Drainage line?

Field Number:	South Maret 23
Date:	22/2/2007
Easting UTM WGS 84:	713564
Northing UTM WGS 84:	8402298
Veg map unit:	GpTcS
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Non eucalypt thicket
Estimated Vegetation Height:	3 m
Estimated litter coverage:	100%
Estimated litter depth:	5 cm
Litter moisture:	Dry
Soil colour:	Red/Pale
Soil texture:	Fine sand, over laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	367-368
Comments:	Aeolian sand 20 cm deep over laterite.

Field Number:	South Maret 24
Date:	22/2/2007
Easting UTM WGS 84:	713607
Northing UTM WGS 84:	8402474
Veg map unit:	CpATc
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Isolated Eucalypt
Estimated Vegetation Height:	8 m
Estimated litter coverage:	100%
Estimated litter depth:	8 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Fine sand?, laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	371
Comments:	Limited spade penetration. Isopod and centipede in litter

Field Number:	South Maret 25
Date:	22/2/2007
Easting UTM WGS 84:	713785
Northing UTM WGS 84:	8402438
Veg map unit:	CpATc/GpTcS
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Isolated Corymbia
Estimated Vegetation Height:	6 m
Estimated litter coverage:	100%
Estimated litter depth:	28 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	372
Comments:	Almost no spade penetration

Field Number:	North Maret 4
Date:	18/2/2007
Easting UTM WGS 84:	713358
Northing UTM WGS 84:	8407058
Veg map unit:	Mf/T
Geomorphic unit:	Dune
Description of covering vegetation:	Thicket with vines
Estimated Vegetation Height:	7 m
Estimated litter coverage:	Not recorded
Estimated litter depth:	4 cm
Litter moisture:	Dry
Soil colour:	Pale
Soil texture:	Sand
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	Complete spade penetration

Field Number:	North Maret 5
Date:	18/2/2007
Easting UTM WGS 84:	713350
Northing UTM WGS 84:	8407196
Veg map unit:	Mf/T
Geomorphic unit:	Swale
Description of covering vegetation:	Tall thicket with vines
Estimated Vegetation Height:	10 m
Estimated litter coverage:	Not recorded
Estimated litter depth:	3 cm
Litter moisture:	Dry
Soil colour:	Dark
Soil texture:	Sand
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	Complete spade penetration

Field Number:	North Maret 6
Date:	18/2/2007
Easting UTM WGS 84:	713125
Northing UTM WGS 84:	8407438
Veg map unit:	Mf/T
Geomorphic unit:	Swale
Description of covering vegetation:	Tall thicket with vines
Estimated Vegetation Height:	12 m
Estimated litter coverage:	Not recorded
Estimated litter depth:	3 cm
Litter moisture:	Dry
Soil colour:	Dark
Soil texture:	Sand
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	Complete spade penetration

Field Number:	North Maret 7
Date:	18/2/2007
Easting UTM WGS 84:	713125
Northing UTM WGS 84:	8407438
Veg map unit:	Mf/T
Geomorphic unit:	Dune
Description of covering vegetation:	Tall thicket with vines
Estimated Vegetation Height:	8 m
Estimated litter coverage:	Not recorded
Estimated litter depth:	3 cm
Litter moisture:	Dry
Soil colour:	Dark
Soil texture:	Sand
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	Complete spade penetration

Field Number:	North Maret 8
Date:	20/2/2007
Easting UTM WGS 84:	713302
Northing UTM WGS 84:	8405944
Veg map unit:	Cp
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Isolated Eucalypt
Estimated Vegetation Height:	5 m
Estimated litter coverage:	Not recorded
Estimated litter depth:	6 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Fine sand? Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	328
Comments:	Limited spade penetration. Surface laterite 5-25 cm

Field Number:	North Maret 9
Date:	20/2/2007
Easting UTM WGS 84:	713171
Northing UTM WGS 84:	8405968
Veg map unit:	AcTb
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Grassland (10-20% cover)
Estimated Vegetation Height:	<0.5 m
Estimated litter coverage:	Scant
Estimated litter depth:	Scant
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Massive laterite pavement
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	329-333
Comments:	No spade penetration.

Field Number:	North Maret 10
Date:	20/2/2007
Easting UTM WGS 84:	713072
Northing UTM WGS 84:	8405960
Veg map unit:	CorN
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Eucalypt in woodland
Estimated Vegetation Height:	7
Estimated litter coverage:	100%
Estimated litter depth:	10 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Fine sand? laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	334-338
Comments:	Limited spade penetration. Surface laterite 30-80 cm

Field Number:	North Maret 11
Date:	20/2/2007
Easting UTM WGS 84:	713176
Northing UTM WGS 84:	8406568
Veg map unit:	Cp
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Isolated Corymbia with vines
Estimated Vegetation Height:	5
Estimated litter coverage:	100%
Estimated litter depth:	8 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	334-338
Comments:	Limited spade penetration. Surface laterite 20 cm

Field Number:	North Maret 12
Date:	23/2/2007
Easting UTM WGS 84:	713349
Northing UTM WGS 84:	8406936
Veg map unit:	Cp
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Isolated Corymbia
Estimated Vegetation Height:	4
Estimated litter coverage:	100%
Estimated litter depth:	8 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	Almost no spade penetration. Surface laterite 25-40 cm

Field Number:	North Maret 13
Date:	23/2/2007
Easting UTM WGS 84:	713562
Northing UTM WGS 84:	8407368
Veg map unit:	Cp
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Isolated Corymbia
Estimated Vegetation Height:	7
Estimated litter coverage:	100%
Estimated litter depth:	20 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	Almost no spade penetration.

Field Number:	North Maret 14
Date:	23/2/2007
Easting UTM WGS 84:	713349
Northing UTM WGS 84:	8407596
Veg map unit:	Cp
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Isolated Corymbia
Estimated Vegetation Height:	7
Estimated litter coverage:	100%
Estimated litter depth:	10 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	Almost no spade penetration. Surface laterite 25-50 cm

Field Number:	North Maret 15
Date:	23/2/2007
Easting UTM WGS 84:	712703
Northing UTM WGS 84:	8407924
Veg map unit:	CorN
Geomorphic unit:	Laterite plateau
Description of covering vegetation:	Eucalypt in woodland
Estimated Vegetation Height:	7
Estimated litter coverage:	100%
Estimated litter depth:	8 cm
Litter moisture:	Dry
Soil colour:	Red
Soil texture:	Laterite pieces >1 cm
Soil moisture:	Dry
Earthworms present?:	None found
Photo numbers:	
Comments:	Almost no spade penetration.