

## SECTION 7: SOIL MACROFAUNA

### GROUND-DWELLING ANTS, TERMITES, OTHER MACROARTHROPODS AND EARTHWORMS.

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#### 7.1 Introduction:

The Humid Forest Zones (HFZ) of the tropics cover about 8% of the Earth's land surface, of which about 20% occurs in SE Asia. The present forest is a mosaic of different types of land use: patches of logged-over forest in varying states of regrowth, secondary forest and fallow vegetation, some tree plantations including forms of agroforestry and significant remnants of primary vegetation, as well as degraded grasslands exhausted of almost all arable potential (Swift & Mutsaers, 1992; van Noordwijk *et al.*, 1997). The dominant soils are acidic (oxisols and ultisols derived from low activity clays), commonly exhibiting Al toxicity, low cation-exchange capacity, low base saturation and low P availability. Consequently, they have low inherent fertility and, in many cases, low structural stability if soil organic matter is excessively depleted. The traditional food-production systems of the HFZ are those of shifting cultivation (slash and burn) and (increasingly) recurrent fallow rotation, with rice, plantain, cocoyam (Taro), maize, Cassava and groundnut as typical staples, the last two of these having relatively low fertility requirements. In recent years, socioeconomic factors (including changing world prices for cocoa, oil-palm, rubber latex and other cash crops), population growth, the restriction of urban employment opportunities and legal uncertainties over title to timber revenue, have led to an increase in the clearance of forest for food or cash-crop production and, concomitantly, an accelerated decline in the fertility of soils under cultivation as fallow periods have shortened (Woomer & Swift, 1994). Agricultural research for the HFZ has therefore been directed towards the improvement of sustainability, for example, by the conservation of soil organic matter and the provision of better mulching regimes. Added to this is the development of flexible mixed cropping systems, for example, the combination of marketable tree crops with field-planted staples, or mixtures of commercially valuable trees such as rubber and natural secondary regrowth (Scholes *et al.*, 1994; van Noordwijk, 1997). Multistrata systems provide an opportunity for the simultaneous production of timber (and/or other tree crops) and food, with a sustained supply of organic matter and nutrients to soil and the stabilization of structure.

The importance of macrofauna to the promotion of tropical soil fertility has been stressed in recent reviews (Fragoso *et al.*, 1993; Lavelle *et al.*, 1997; Garnier-Sillam & Harry, 1995; Nash and Whitford, 1995; Brussaard & Jumas, 1996; Wood, 1996). The distribution, protection and stabilization of organic matter, the genesis of soil structure (macroaggregates), humification, the release of immobilized N and P, the improvement of drainage and aeration, and the increase in exchangeable cations have all been demonstrated in soils modified by termites and earthworms (e.g. Mulongoy & Bedoret, 1989; Lavelle *et al.*, 1992; 1998). Soil ants and other macrofauna represent predators, herbivores (granivores) and bioturbators, bringing about important changes in the physical and chemical properties of soils, as well as dispersing plant propagules. Networks of galleries and chambers increase the porosity of the soil, increasing

drainage and aeration (Cherrett, 1989) and reducing bulk density (Baxter and Hole, 1967). Ant-plant communities are much more species-rich in the tropics than elsewhere; a pattern associated with habitat heterogeneity (Davidson and McKey, 1993; Folgarait, 1996).

Depletion of termite abundance and diversity is now a well-established effect of forest clearance (Wood *et al.*, 1982; Eggleton *et al.*, 1995; 1996). Effects on earthworms also include the loss of typical forest species, but also possible invasion by exotic species, with adverse consequences for soil structure (Reddy & Dutta, 1984; Barros *et al.*, 1996). Information on ants is limited, but Belshaw and Bolton (1994) found similar levels of leaf litter ant diversity in secondary forest, primary forest and cocoa plantations in Ghana. A more recent study in Cameroon by Watt *et al.* (1997), showed that moderate forest disturbance, for example, by enrichment planting after partial clearance, increased species numbers and overall ant abundance in both leaf-litter and canopy-dwelling ants. Complete clearance reduced abundance severely, although diversity was comparable to that in closed canopy forest. There is a general consensus that the conservation of indigenous invertebrate biodiversity should be an integral part of land-management strategies in the HFZ, if the goal of increased crop-yield sustainability (and concomitant forest conservation) is to be realized (e.g. Smith *et al.*, 1993; Lavelle, 1996; Lavelle *et al.*, 1998).

The soil biota (and hence soils as a whole) respond to human-induced disturbance such as agricultural practices, deforestation, pollution and global environmental change with many negative consequences including loss of primary productivity, loss of cleansing potential for wastes and pollutants, disruption of global elemental cycles, feedbacks on greenhouse gas fluxes and erosion. At the same time, global food supply depends on intensive agriculture. As intensification proceeds, above-ground biodiversity is reduced, one consequence of which is that the biological regulation of soil processes is altered and often substituted by the use of mechanical tillage, chemical fertilizers and pesticides. This is assumed to reduce below-ground diversity as well, which, if accompanied by the extinction of species, may cause losses of function and reduce the ability of agricultural systems to withstand unexpected periods of stress and bring about undesirable effects. Scientists have begun to quantify the causal relationship between i) the composition, diversity and abundance of soil organisms, ii) sustained soil fertility, and iii) environmental effects such as greenhouse gas emission and soil carbon sequestration.

Large numbers of farmers in the tropics have limited access to soil inputs (i.e. fertilizer and pesticides) but are nonetheless forced by circumstances to drastically reduce the complexity of their agroecosystems in an attempt to intensify production. An alternative solution is to intensify while at the same time retaining a greater degree of above-ground diversity. The maintenance of diversity of crops and other plants in cropping systems is widely accepted as a management practice which buffers farmers against short-term risk. Enhanced biodiversity and complexity above-ground contributes to the re-establishment or protection of the multiplicity of organisms below-ground able to carry out essential biological functions. This can be considered at both the field and the landscape level to enhance structural complexity and functional diversity, especially in degraded lands.

In this paper, we report quantitative and qualitative sampling in 7 representative land uses in or close to the Pasir-Mayang Forest Reserve, Jambi Province, central Sumatra, using rapid assessment methods which enabled most sites to be examined in 1-2 days. Ants and other macrofauna were sampled qualitatively by the use of pitfall traps and quantitatively from standard soil monoliths.





An expanded version of Table 1, incorporating botanical, soil physio-chemical data and additional site information is given as Annex III, Table 12.1.

### 7.3 Aims and objectives:

- To provide data on species richness, numerical density and biomass density for ground-dwelling ants, with estimates of population variance for numerical density and biomass density, in 7 LUTs.
- To provide data on numerical density and biomass density of earthworms and termites, with estimates of population variance, in 7 land uses.
- To provide an estimate of species richness of earthworms.
- To provide an estimate of taxonomic richness (to the best level of resolution possible) for other macrofauna (in addition to earthworms, ants and termites).
- To give pooled (i.e. overall) data for numerical density and biomass density for other macrofauna.
- To allocate basic functional attributes to macrofauna.

The objectives were developed to test the following hypotheses:

- Agricultural intensification results in a reduction of soil biodiversity, leading to a loss of ecosystem services detrimental to sustained productivity.
- Above-ground and below-ground biodiversity are interdependent across scales of resolution from individual plant communities to the landscape.
- Agricultural diversification (at several scales) promotes soil biodiversity and enhances sustained productivity.
- Sustainable agricultural production in tropical forest margins is significantly improved by enhancement of soil biodiversity.

### 7.4 Methods:

#### 7.4.1 Review of existing methods:

General approaches to the sampling of invertebrate animals, and the advantages and disadvantages of particular methods, are described by Murphy (1962), Phillipson (1971) and Southwood (1978).

Soils differ greatly in composition, particle size, structure, depth and compaction, and whether they are under trees, grassland or cultivation. Since the soil fauna is incorporated closely into the soil structure, the assessment of populations of these organisms is extremely difficult and laborious, and generally necessitates a wide range of specialized techniques if animals in the three major size categories (macrofauna, mesofauna and microfauna) are to be assessed (Edwards, 1991).

The basic options are a) hand soil *sifting* and sorting (including litter layer dissection), b) *trapping* with or without baits, and c) *extraction* methods. In the last category are techniques based on *flotation*, which separates buoyant animals from the inert soil particles with water-based solutions (for example brine or sugar solutions) or organic solvents, or enables them to escape from the particle matrix by swimming (for example enchytraeids and nematodes in wet funnel methods), or *dry heat* extraction in which litter or soil samples suspended above funnels

are slowly dried, causing animals to migrate out of the litter into the funnels, from which they can be recovered, preserved and concentrated in alcohol (Bater, 1996). For ants, which are exceptionally mobile and respond rapidly to desiccation, a special modification of the extraction principle can be employed through the use of Winkler bags. These are narrow-mesh closed fabric bags forming a double-pyramid shape and enclosing suspended samples of soil or litter; the bags are hung up in a dry place for 6-8 days while the samples dry out naturally and any ants they contain are eventually captured in pots of alcohol fitted into the lower apex.

However, extraction methods like this are generally slow and usually require some kind of laboratory base, so for rapid assessment focussed on the larger soil animals, it is normally sufficient to use just *hand sorting*; i.e. a measured quantity of soil or litter (usually delimited by a quadrat) is gradually crumbled over a sheet of plastic or other material and the invertebrates collected with forceps or pooter as they are released and stored in a suitable preservative (5% formalin for earthworms and gastropods; 70% alcohol for other invertebrates). Samples tend to accumulate faster than they can be sorted, so it is permissible to store samples in plastic bags (but out of direct sunlight) for up to 12 hours for later sorting. The efficiency of hand-sorting is generally high for animals which can be seen with the naked eye, as long as field assistants are adequately trained, but some authors have reported making allowances of up to 12% for lost or undiscovered specimens (e.g. Wood *et al.*, 1982).

Trapping methods can be used to exploit accidental encounter by invertebrates, but baiting is not usually employed for ants, as attractants may introduce bias by selecting for some species more than others. Pitfall traps, containers sunk into the soil flush with the soil surface, containing either a preservative or some other immobilizing fluid and with raised covers to prevent flooding by rain, are probably the most commonly used method of catching invertebrates (Bater, 1996). The main variations are in the size of container and the use, or otherwise, of guiding fins or other corralling devices to increase interception. The limitations of pitfall traps are largely in the interpretation of data, since the numbers of animals trapped are related both to overall numbers present and their activity, and so may not sample each population entirely. There is a tendency for such traps to accumulate ants, beetles, crickets, isopods, myriapods and spiders (all of which are active on the surface of the ground, particularly at night). The optimum period for capture is about 24 hours, after which traps are often disturbed by vertebrates and birds. There are methods available to convert the numbers of invertebrates trapped to populations, usually based on physically delimiting sampling areas with some form of barrier or using mark-recapture techniques.

#### **7.4.2 Functional classification of soil fauna:**

(after Lavelle, 1988; Anderson and Ingram, 1993).

Soil invertebrates can be classified according to their feeding habits and distribution in the soil profile as follows:

***Epigeic species*** which live and feed on the soil surface. These may act as litter transformers or the predators of litter transformers, but do not actively redistribute plant material.

***Anecic species*** which remove litter from the soil surface through their feeding, redistributing it to other horizons or locations, accompanied by effects on soil structure and hydraulic properties.

*Endogeic species* which live entirely within the soil, feeding on organic matter and dead root materials, which are mixed with other components of the soil, creating mineral-humus complexes and influencing a large suite of soil properties. The quantification of these effects on soil processes requires detailed study, but a simple characterization of macrofauna can assist in assessing their role in different landuses and under various regimes of management (Table 7.2).

**Table 7.2**  
**Functional classification of common soil fauna**

<b>Taxon</b>	<b>Category</b>
Ants	Epigeic and anecic
Arachnids (esp. spiders)	Epigeic
Beetle adults	Epigeic and endogeic
Beetle larvae	Epigeic
Cockroaches	Epigeic
Centipedes	Epigeic
Cicada larvae	Endogeic
Crickets	Epigeic
Earthworms (pigmented)	Epigeic and anecic
Earthworms (unpigmented)	Endogeic
Millipedes	Epigeic
Slugs and snails	Epigeic
Wood-feeding termites	Epigeic and anecic
Soil-feeding termites	Endogeic
Fungus-growing termites	Anecic
Woodlice	Epigeic

#### **7.4.3 Sampling design:**

Sampling in each land use is based on a single quadrat of 40x5 m, which is compatible with concurrent botanical and other pedological sampling exercises (Gillison and Liswanti, this volume). The recommendation is for a minimum of 5 soil monoliths, each 25x25x30cm spaced along the mid-line of the transect at approximately 8m intervals, accompanied by at least 10 pitfalls (using 14cm diameter glass or plastic containers) arranged in a flanking line parallel to the transect or along its long edge. The choice of the starting point for the transect should be random, but its direction is normally determined by the line of best visual habitat homogeneity.

#### **7.4.4 Procedure:**

Procedures follow Anderson and Ingram (1993) closely:

- a. 5 sampling points (for monoliths) are located and marked within the transect.
- b. 10 pitfall traps are fitted at roughly 4m intervals along one flank of the transect. The traps are put in during the afternoon or early evening and emptied 24 hours later. Each trap contains a little water, with a few drops of detergent added, to immobilize specimens by drowning.

- c. At each sampling point litter is removed from within a 25cm quadrat and hand-sorted at the site.
- d. Isolate the monolith by cutting down with a spade a few centimetres outside the quadrat and then digging a 20cm wide and 30cm deep trench around it. NB. In a variant of the method not adopted in Pasir Mayang, all invertebrates longer than 10cm excavated from the trench are collected; these will be mainly large millipedes and earthworms with very low population densities but representing an important biomass. Their abundance and biomass can be calculated on the basis of 0.42 m<sup>2</sup> samples, i.e. the width of the block plus two trench widths, squared.
- e. Divide the delimited monolith block into three layers, 0-10cm, 10-20cm and 20-30cm. This can be done conveniently using a parang or machete held horizontally and grasped at both ends. Hand-sort each layer separately. If time is short or the light poor (sorting in closed canopy forest is usually difficult after about 3.30pm), bag the soil and remove to a laboratory. Ants can be extracted by gently brushing small (handful) quantities of soil through a coarse (5mm) sieve into a tray: the sieve retains the ants.
- f. Record the number and fresh (preserved, after blotting) weight of all animals and identify to at least the taxonomic and functional levels indicated in Table 7.2 (but preferably further). The presence and weight of termite fungus combs (if any) should also be noted.

#### 7.4.5 Analysis:

The following steps should be followed:

- i) Make a list of species, if possible grouped into subfamilies or families. Use generic names to generate alphabetical orders. Use the results from pitfall traps and monoliths to compile this list.

Fully identified species should be listed with the full binomial and descriptive authority:

e.g. *Dorylus laevigatus* Smith

Morphospecies should be listed by number:

e.g. *Crematogaster* sp. 1  
*Crematogaster* sp. 2  
 ..... etc.

Species identified only to genus should be listed without numbers:

e.g. *Colobopsis* sp.

Incorporate the species list into a table showing the sites where each occurred.

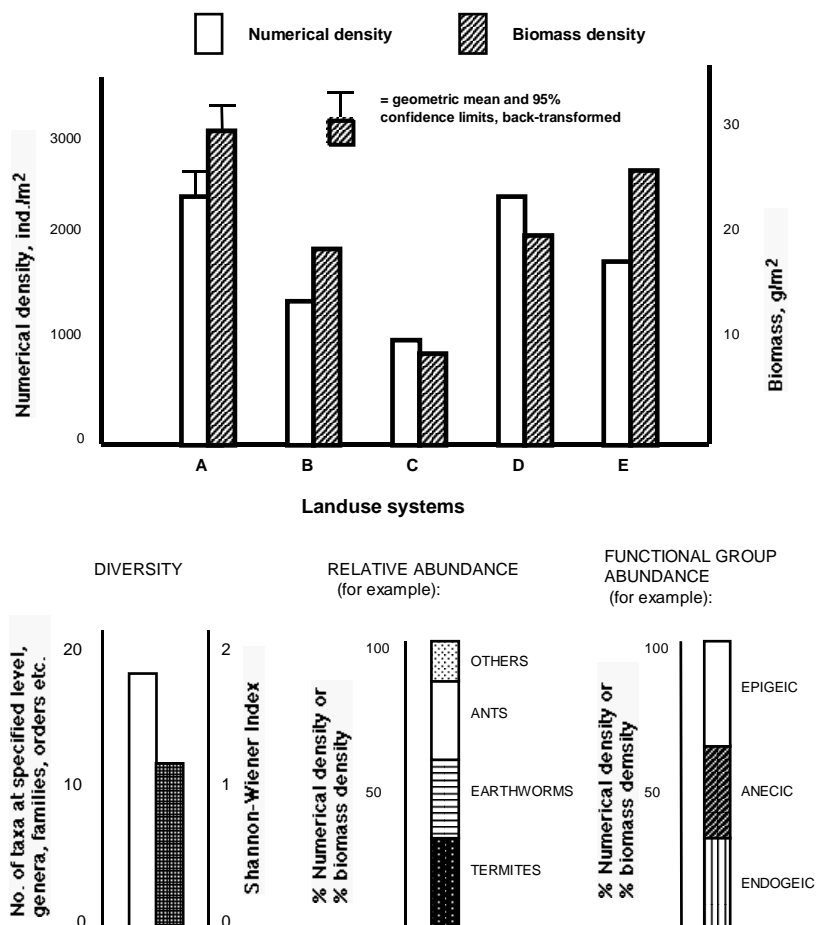
- ii) Estimate abundance as numbers m<sup>-2</sup> from each monolith (multiply the raw number per monolith by 16 (except earthworms and millipedes, see above), combining data for all species.

Calculate an arithmetical mean. To estimate the 95% confidence limits the primary data should be transformed as  $\log_{10}(x+1)$ . If there are not too many zeros, this should roughly normalize the data and produce homogeneous variances from group to group. In difficult cases, a log-log transformation can be tried. Apply descriptive statistics to the transformed dataset, including 95% confidence limits, and back transform to obtain a geometric mean. Quote means for untransformed data, together with the geometric mean and confidence limits for  $\log(x+1)$  transformed data. The transformed data can be used for histograms and site-to-site comparisons.

Estimate biomass as  $\text{g m}^{-2}$  in a similar way. Use fresh weight or the mass of blotted preserved specimen, if possible. Avoid the use of dry weight because of the different oven temperatures used by different scientists and the variable water content of different types of organism. Where insect specimens in a range of sizes are available, an alternative method is to calibrate live biomass against head width in representative specimens covering the whole size range. The weight of unknowns can then be estimated from the curve. For log transformations of data, it is most convenient to work in  $(\text{mg} + 1)$ , then back-transform and express as g.

iii) Results should be presented as species/taxa lists, plus the standard histograms as illustrated below:

**Figure 7.1. Graphical summaries of biodiversity data – some examples**



iv) An overall quantitative synthesis of data for macrofauna can be attempted using the following matrix:

**Table 7.3**  
**Synthesis matrix for macrofauna**

Region	Landuse System				
	A = natural control site	B	C	D	E
e.g. Pasir Mayang	x = 80	x = 67 p = 0.1 % = -16	x = 50 p = 0.04 % = -38	x = 95 p = 0.11 % = +19	x = 57 p = 0.05 % = -29

where, x = average of monoliths

p = level of significance for a comparison with the control site by an appropriate statistical test.

% = percentage difference between the mean of each landuse and the control site, with an indication (+/-) of the direction of change (increase or decrease).

The control site is selected as the least disturbed local land use; in most cases this would be a tropical forest, preferably primary, or else old growth secondary or disturbed primary forest. Arrangement of sites in rank order to form a disturbance gradient may be somewhat arbitrary, especially if site histories are incompletely known, but disturbance intensity, management intensity and time since the imposition of disturbance are the usual criteria employed.

Matrices can be prepared for the following data:

- total numerical density
- total biomass density
- earthworm numerical density
- earthworm biomass density
- earthworm species richness
- termite numerical density
- termite biomass density
- termite species richness
- ant numerical density
- ant biomass density
- ant species richness
- all macroarthropod numerical density
- all macroarthropod biomass density

v) A qualitative synthesis can be given by answering the following questions:

- what is the effect of each landuse system on biodiversity?
- which groups change the most with disturbance and along the land use gradient?
- what is the relationship between the functional group changes and the degree of sustainability of each land use?

#### **7.4.6 Data analysis:**

Carry out a non-parametric ANOVA (Kruskal-Wallis) on each dataset to see if there is a significant difference across the sites (or treatments). This can be followed by pairwise comparisons between sites using the Mann-Whitney U test. Parametric ANOVA can be performed on log transformed data.

### **7.5 Results:**

#### **7.5.1. Ants:**

The total number of subfamilies sampled was 8:

- Dorylinae: BS10 only
- Formicinae: all sites
- Myrmecinae: all sites
- Ponerinae: all sites except BS14
- Leptanillidae: BS 8 only
- Pseudomyrmicinae: BS 6 and BS 10 only
- Cerapachyinae: BS 8 only
- Dolichoderinae: BS 6, BS 10, BS 12 and BS 14 only

The species lists for each site are available in Annex III, Table 12.11 . Details of ant numerical density and biomass density by site and by stratum are given in Annex III, Table 12.2 and 12.3 , respectively. The following figures summarize ant diversity and abundance:

Figure 7.2. Ant species richness

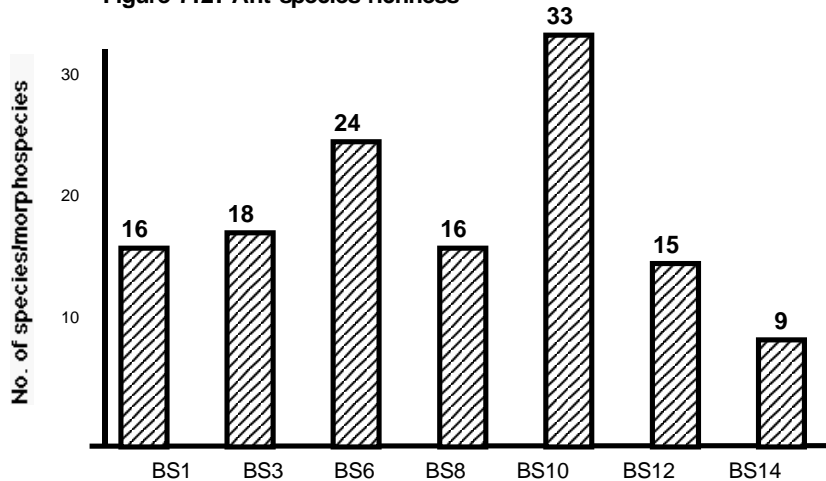
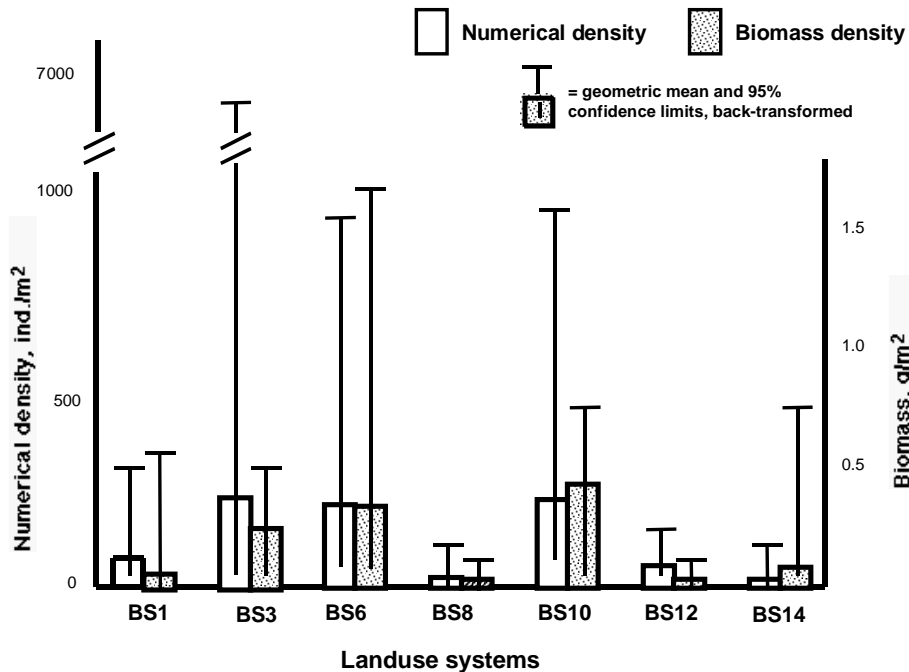


Figure 7.3. Ant abundance and biomass



Abundance and biomass were totalled for each monolith and assessed by the non-parametric one-way Kruskal-Wallis ANOVA, using arithmetic data. Abundance and biomass did not vary significantly across the sites ( $p > 0.05$ ). One-tailed pairwise comparisons of ant abundance between sites were, however, carried out by the Mann-Whitney test (Table 7.10). These generally showed significant differences between some of the richer sites (BS3, BS6, BS10) and those that were highly disturbed (BS12, BS14).

BS3, BS6 and BS10 all had more ants than either BS12 or BS14 ( $p < 0.025$  in all comparisons). BS10 had more ants than BS 8 ( $p < 0.025$ ). All other site comparisons were non-significant (see Table 7.10 and Annex III, Table 12.10).

BS3 had a higher biomass of ants than BS8 ( $p=0.05$ ) and BS12 ( $p=0.025$ ). BS6 and BS10 also had a higher biomass than BS12 ( $p<0.025$ ). All other site comparisons were non-significant (see Table 7.11 and Annex III, Table 12.10).

Untransformed abundance and biomass data from each soil stratum were summed across all sites. Transformed data were used to compute geometric means and 95% confidence limits, using the average of each monolith (numbered 1-5) across all 7 sites (Table 7.8). ANOVA tests on these data showed no significant differences between strata.

In a further analysis of abundance and biomass, all 140 data points (5 monoliths X 4 strata X 7 sites) were transformed and subjected to a parametric two-way ANOVA in which the variables were site and stratum (Table 7.9). This showed a significant variation across sites (abundance:  $p<0.025$ ; biomass:  $p<0.05$ ) and between strata (abundance:  $p<0.001$ ; biomass:  $p<0.025$ ). However the interactions between site and stratum were not significant for either abundance or biomass ( $p>0.5$ ).

Functional group allocation (epigeic, anecic, see Figure 7.11) was made from information in Holldobler and Wilson (1990) and by anecdote (E. Widodo and M. Maryati, personal communications).

All three measures of ant activity (species richness, abundance and biomass) were consistent in showing BS3, BS6 and BS10 as sites of high ant activity. On abundance data BS10 was significantly different from two other sites and on biomass data different from one. In statistical analysis, biomass differences were more weakly supported by pairwise comparisons between sites. BS3, BS6 and BS10 had no zero samples from monoliths.

**Table 7.4**  
**Abundance and biomass totals (arithmetic data)**

<b>Site</b>	<b>Total no individuals sampled from monoliths.</b>	<b>Total biomass of ants sampled from monoliths, mg</b>
BS1, primary forest	110	109
BS3, logged over	163	83
BS6, <i>Paraserianthes</i>	172	1583
BS8, rubber	39	32
BS10, jungle rubber	169	268
BS12, alang-alang	25	12
Bs14, Cassava	15	105

Table 7.4 gives some indication of the real quality of the data; a small amount of material from which to extrapolate to the landscape level. Nevertheless, it is instructive in illustrating the way in which this group of insects does not have its highest species richness, abundance or biomass in the primary forest, but in two disturbed sites of somewhat different character.

Trends across the sites relative to the control site (BS1, primary forest) are given in Table 7.5, in standard format. The literature contains few data for comparison. Belshaw and Bolton (1994)

give average litter-ant abundance across several woodland sites in Ghana as 117 m<sup>-2</sup>. Watt *et al.* (1997) examined a range of forest sites in Cameroon representing a disturbance gradient similar to that observed in Pasir Mayang, but give figures in the range 20-80 m<sup>-2</sup>. However, the lightly and heavily disturbed sites were towards the lower end of this range, while sites with intermediate disturbance yielded the higher abundances. Stork and Brendell (1993) give 3 g m<sup>-2</sup> as the biomass of all non-social insects in the forest system of Seram, Indonesia.

**Table 7.5**  
**Trends across the sites relatives to the control sites (BS1)**

Parameter	Landuse System						
	Natural control site = BS1	BS1	BS6	BS8	BS10	BS12	BS14
<b><u>Numerical density</u></b>							
Arithmetical average of monoliths, nos m <sup>-2</sup>	352	522	550	134	541	80	48
p value for comparison with control site (transformed data)	0	ns.	ns.	ns.	ns.	ns.	ns.
% difference of means from control site	0	+48%	+56%	-62%	+54%	-77%	-86%
<b><u>Biomass density</u></b>							
Arithmetical average of monoliths, nos m <sup>-2</sup>	0.346	0.285	4.889	0.102	0.857	0.03	0.336
p value for comparison with control site (transformed data)	0	ns.	ns.	ns.	ns.	ns.	ns.
% difference of means from control site	0	-18%	+1400%	-71%	+248%	-92%	-1%

ns. = not significant (p > 0.05)

### 7.5.2. Termites:

The species lists for each site are available in Section 8 of this report. Details of termite numerical density and biomass density by site and by stratum are given in Annex III, Table 12.4 and 12.5, respectively. Figures 7.4 and 7.5 summarize termite diversity and abundance.

Abundance and biomass were totalled for each monolith and assessed by the non-parametric one-way Kruskal-Wallis ANOVA, using arithmetic data. Abundance and biomass were found to vary significantly across the sites (Tables 7.9; p<0.025). One-tailed pairwise comparisons of ant abundance between sites were carried out by the Mann-Whitney test (Tables 7.10 and 7.11).

These generally showed significant differences between the richest site (intact rainforest, BS1) and others. In addition, sites BS3 and BS6 were significantly greater in abundance and biomass than site BS12 (the *Imperata* grassland;  $p$  varies between  $<0.05$  and  $<0.005$ ). There were no other significant differences between sites. Untransformed abundance and biomass data from each soil stratum were summed across all sites. Transformed data were used to compute geometric means and 95% confidence limits, using the average of each monolith (numbered 1-5) across all 7 sites (Table 7.8). ANOVA tests on these data showed that vertical biomass distribution varied significantly across the sites (Table 7.9;  $p<0.05$ ). For both abundance and biomass, all 140 data points (5 monoliths X 4 strata X 7 sites) were transformed and subjected to a parametric two-way ANOVA in which the variables were site and stratum. This showed a significant variation across sites ( $p<0.001$ ) and between strata ( $p<0.001$ ). The interactions between site and stratum were significant for abundance ( $p<0.05$ ) and biomass ( $p<0.01$ ). Termites generally showed highest numerical and biomass densities in the top 10 cm of the soil.

Functional group allocation (anecic, endogeic, see Figure 7.11) was made from knowledge of termite natural history (see Jones, 1999 in preparation). Generally, species nesting arboreally and feeding on the surface were designated anecic, those building epigeal nests and subterranean nests but feeding on the surface anecic, and those feeding within the soil endogeic, wherever the nesting site. The epigeic category was not recognized for termites.

Overall, termite abundance and biomass were heavily reduced by forest disturbance. This confirms their status as sensitive indicators of forest quality (Eggleton *et al.*, 1995; 1996; Watt *et al.* 1997). Diversity remained relatively high in two disturbed sites (BS3, logged over forest; BS10, jungle rubber), but this was not matched by a corresponding retention of abundance and biomass.

Figure 7.4. Termite species richness

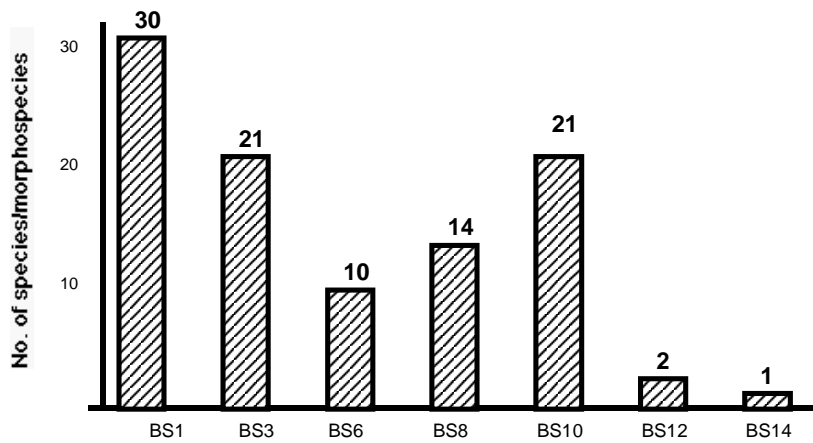
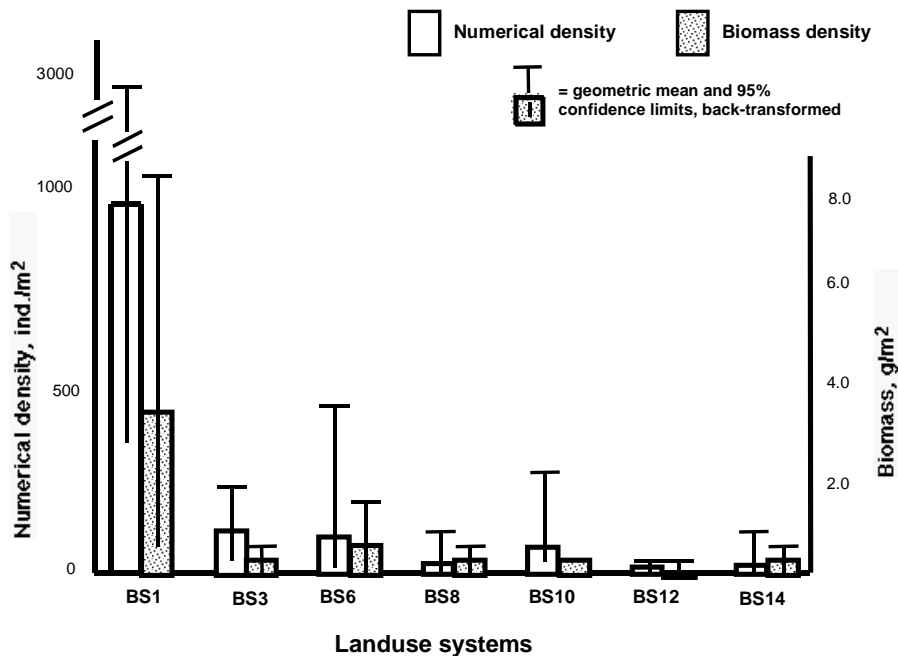


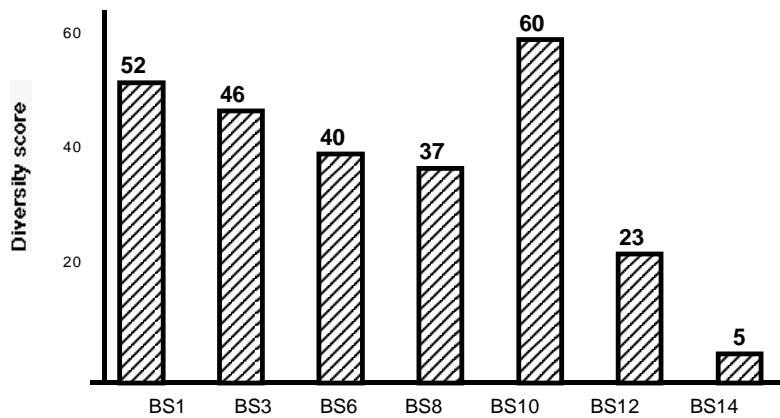
Figure 7.5. Termite abundance and biomass



### 7.5.3. All macroarthropods:

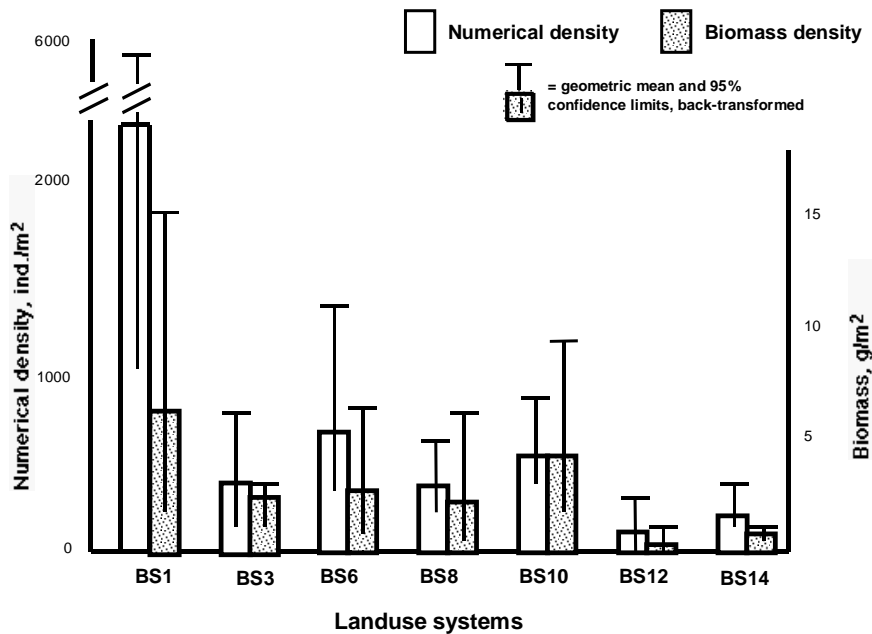
Macroarthropods other than ants and termites were recovered from monolith dissections and pitfall traps. These were predominantly Coleoptera, Diptera, Hemiptera, Dictyoptera Orthoptera, Isopoda, Myriapoda and Arachnida, including many juvenile forms. In most, cases identification was made at class and ordinal level only, more rarely to family, but abundance and biomass were determined as for ants and termites. To make use of the resulting data, they were added to those of ants and termites to make a composite dataset representing all macroarthropods. This is summarized in Figs. 7.6 and 7.7 below, with detailed information in Annex III, Table 12.6 and 12.7.

Figure 7.6. All macroarthropods taxonomic richness



Diversity score = ant species + termite species + other groups at ordinal level or above (earthworms not included)

Figure 7.7. All macroarthropods abundance and biomass



A crude diversity index for macroarthropods was obtained by summing ant and termite species richness, then adding other groups at the level of taxonomic resolution obtained. This shows a more even decline across the gradient, with the exception of BS10 (jungle rubber), which scored a higher diversity than any other site. However, it must be borne in mind that groups with inherent very high diversity, e.g. Coleoptera, Diptera, Arachnida, are almost certainly inaccurately represented (i.e. underestimated) by this method.

Abundance and biomass were totalled for each monolith and assessed by the non-parametric one-way Kruskal-Wallis ANOVA, using arithmetic data. Abundance and biomass were found to vary significantly across the sites (Tables 7.9; abundance,  $p < 0.005$ ; biomass,  $p < 0.025$ ). One-tailed pairwise comparisons of ant abundance between sites were carried out by the Mann-Whitney test (Tables 7.10 and 7.11). For abundance, these generally showed significant differences between the richest site (intact rainforest, BS1) and others. In addition, sites BS6, BS8 and BS10 were significantly greater in abundance and biomass than heavily degraded sites

(BS12 and BS14;  $p$  varies  $<0.025$  to  $<0.005$ , except BS6 vs BS14, which is not significant). For biomass, BS1 was significantly greater than BS3, BS12 and BS14. Biomass in BS12 and BS14 was also exceeded by that in BS10 and that in BS12 by BS6 and BS8. Untransformed abundance and biomass data from each soil stratum were summed across all sites. Transformed data were used to compute geometric means and 95% confidence limits using the average of each monolith (numbered 1-5) across all 7 sites (Table 7.8). ANOVA tests on these data showed that vertical abundance and biomass distribution varied significantly across the sites (Table 7.9; abundance,  $p<0.01$ ; biomass,  $p<0.005$ ). For both abundance and biomass, all 140 data points (5 monoliths X 4 strata X 7 sites) were transformed and subjected to a parametric two-way ANOVA in which the variables were site and stratum. This showed a significant variation across sites ( $p<0.001$ ) and between strata ( $p<0.001$ ). The interactions between site and stratum were not significant. The data are, of course, heavily influenced by ant and termite distributions, but for macroarthropods as a whole, the highest numerical and biomass densities were found in the top 10 cm of the soil.

Functional group allocations for macroarthropods other than ants and termites (engineers, litter transformers, macropredators, see Figure 7.10 and epigeic, anecic, endogeic, see Figure 7.11) were made from knowledge of natural history and by reference to Anderson and Ingram (1993; Table 7.2). Animals which did not fit any of these categories, for example sap-feeders, were excluded from the subsequent analysis of functional group distribution across sites.

Few, if any, published studies of soil macroarthropod communities are available for comparison with these data. The inclusion of data for arthropods other than ants and termites appears useful in providing some additional resolution between sites, not obtained from scrutiny of the ants and termites alone. This may be a consequence of the well-known patchiness of soil animal distributions, since individual groups may show very large variance between replicate samples in a single site, but a composite category of macroarthropods may show less overall variation. The category "macroarthropods", however, disguises group to group turnovers which may characterize disturbance gradients.

#### **7.5.4. Earthworms:**

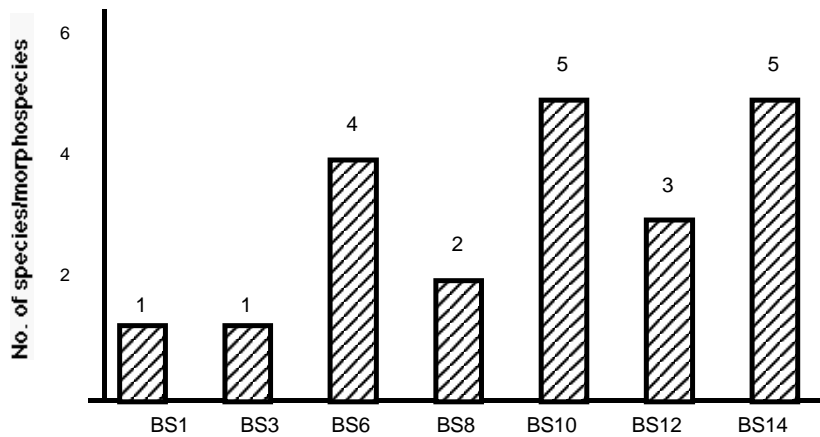
Earthworms were recovered from monolith dissections, but were only rarely present in pitfall traps. Summary data on diversity, abundance and biomass are given in Figs. 7.8 and 7.9, with further details in Appendices 7.8 and 7.9. Overall earthworm diversity was low, with only a single morphospecies recognized from the forested BS1 and BS3 sites. However, very high abundance and biomass were associated with sites BS6 and BS10.

Abundance and biomass were totalled for each monolith and assessed by the non-parametric one-way Kruskal-Wallis ANOVA, using arithmetic data. Abundance and biomass were found to vary significantly across the sites (Tables 7.9;  $p<0.005$ ). One-tailed pairwise comparisons of ant abundance between sites were carried out by the Mann-Whitney test (Tables 7.10 and 7.11). For abundance, these showed significant differences between the richest site (jungle rubber, BS10;  $p<0.005$ ) and all others. In addition, site BS6 was significantly greater than BS1, BS3, BS8 and BS12. BS14 (Cassava garden) was relatively abundant, exceeding BS1 and BS3 ( $p<0.025$ ). For biomass, BS10 exceeded BS8 and BS12 ( $p$  variable  $<0.05$  to  $<0.005$ ), while BS6 exceeded BS1, BS3, BS8, BS12 and BS14. ( $p$  variable  $<0.05$  to  $<0.005$ ). This somewhat anomalous result reflects the large confidence interval associated with site BS10.

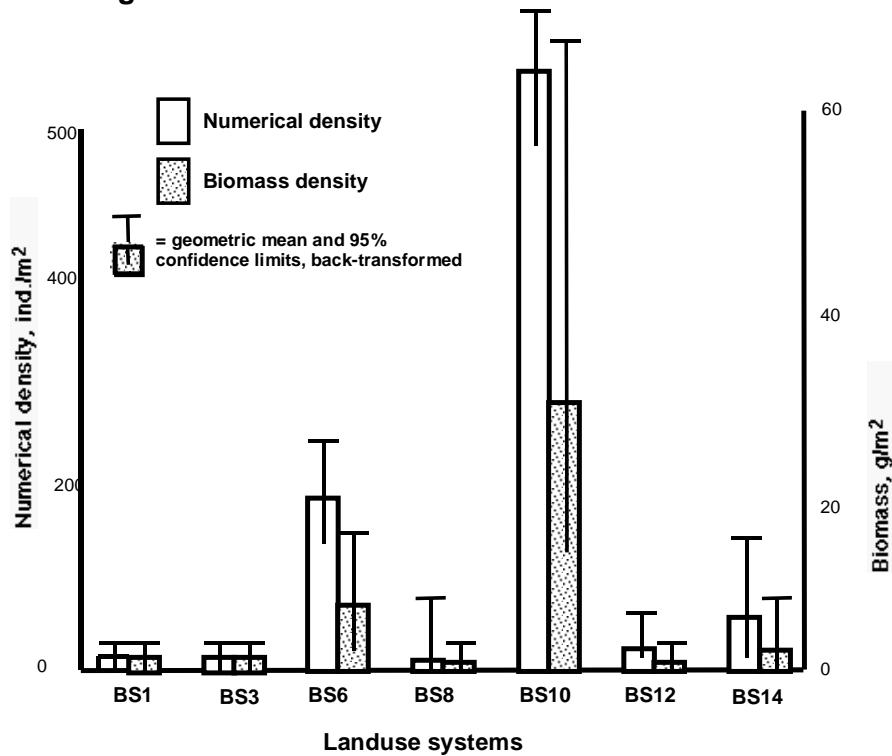
Untransformed abundance and biomass data from each soil stratum were summed across all sites. Transformed data were used to compute geometric means and 95% confidence limits, using the average of each monolith (numbered 1-5) across all 7 sites (Table 7.8). ANOVA tests on these data showed that vertical abundance and biomass distribution varied significantly across the sites (Table 7.9;  $p < 0.001$ ). For both abundance and biomass, all 140 data points (5 monoliths X 4 strata X 7 sites) were transformed and subjected to a parametric two-way ANOVA in which the variables were site and stratum. This showed a significant variation across sites ( $p < 0.001$ .) and between strata ( $p < 0.001$ ). The interactions between site and stratum were significant for both abundance ( $p < 0.001$ ) and biomass ( $p < 0.001$ ). Earthworms generally showed highest numerical and biomass densities in the top 10 cm of the soil, with only a few specimens recovered below this level and none in the litter.

Functional group allocation (epigeic, anecic, endogeic, see Figure 7.11) was made from pigmentation (see Lavelle, 1988 and Lavelle et al., 1997). Anecic and endogeic earthworms were considered engineers.

**Figure 7.8. Earthworms taxonomic richness**



**Figure 7.9. Earthworms abundance and biomass**



Few data exist documenting the responses of tropical forest earthworms to disturbance gradients, but increases in population size and biomass following conversion of natural forest to plantation have been observed (Lavelle *et al.*, 1997). The alternative explanation that disturbed sites have abundant dead wood and litter, thereby supporting increased earthworm populations, is not supported by measurements of the actual resources available at BS6 and BS10 (Annex III, Table 12.1 ).

**7.6. Synthesis:**

Tables 7.6 and 7.7 summarize soil faunal abundance and biomass (respectively) across the 7 sites. Arithmetic totals (the sum of means of each group) are included for illustrative purposes, although it is not suggested that these totals are useful population parameters. It can be seen that the relative contributions of the groups to overall abundance and biomass is not the same in

all sites. Ants were the most abundant group in 5 sites (BS3, BS6, BS8, BS10 and BS12), but not at the extremes of the disturbance gradient, where termites (BS1) and earthworms (BS14) predominated. The rank order of macrofaunal abundance was BS1>BS6>BS10>BS3>BS8>BS14>BS12, broadly indicating that the more severe and the more recent disturbances reduced numbers. Earthworms had the highest biomass in 4 sites (in rank order BS10, BS6, BS14 and BS12), whereas termites made the greatest contribution in BS, and macroarthropods other than ants and termites in BS3 and BS8. The rank order of total biomass was BS10>BS6>BS1>BS14>BS8>BS3>BS12. Two disturbed sites, jungle rubber and *Paraserianthes* plantation, therefore, exceeded the intact rainforest in macrofaunal biomass, in both cases due to the development of large earthworm populations. The overall picture that emerges from these data is of the dominance of termites in intact primary rainforest, and their progressive replacement by other groups, especially ants and earthworms, in disturbed sites. BS12, the alang-alang grassland is clearly the most impoverished site by all measures.

Table 7.8 summarizes the vertical distribution of the soil macrofauna across the 7 Jambi sites. Abundance and biomass are notably concentrated in the top 10 cm of the mineral soil, so that the particular effects of disturbance at this level, whether positive or negative, may be the primary factor determining the responses of soil animals. Sample sizes were considered too small to permit site by site comparisons of the vertical distribution of each group; however, the data are available for such an analysis (not shown). Two ways ANOVA after log transformation indicates a significant interaction between sites and strata for termites and earthworms (Table 7.9).

Table 7.9 shows the results of all ANOVA tests carried out on the soil macrofaunal data. *Post hoc* pairwise comparisons of abundance and biomass between sites are shown in Tables 7.10 and 7.11, respectively. No widely accepted method of statistical testing exists for soil macrofaunal data, indeed such data are relatively rarely presented even with confidence limits or other indications of variance. Table 7.9 demonstrates a reasonable correspondence between the results of non-parametric and parametric analyses; however, ant abundance and biomass were not significantly different between sites or strata in one-way ANOVAs. Other groups differed overall between sites and strata in both abundance and biomass.

Pairwise comparisons of macrofaunal abundance in sites by Mann-Whitney showed significant differences in 19 out of the 21 possible pairings. Termites were significantly different in 7 comparisons, ants in 7 (of which 1 was unique, i.e. not reflected by other groups), all macrofauna in 10 (of which 2 were unique) and earthworms in 13 (of which 4 were unique). This suggests that earthworm abundance and total macroarthropod abundance were more sensitive in discriminating between sites than ant or termite abundances alone. Pairwise comparisons of macrofaunal biomass showed significant differences in 18 of the possible 21 pairings. Termite biomass was significantly different in 7 comparisons (of which 2 were unique), ant biomass in 4 comparisons (of which 1 was unique), all macrofauna in 8 comparisons (of which 2 were unique) and earthworm biomass in 5 comparisons (of which 5 were unique). Total macroarthropod and earthworm biomass, therefore, were also more sensitive site discriminators than ant or termite biomass alone.

**Table 7.6**

**Summary of abundance data for soil macrofauna across a forest disturbance gradient in Jambi Province, Central Sumatra. Numerical densities are given as nos. m<sup>-2</sup>, based on 5 monoliths per site, spaced along a 40 m transect. For geometric means, data are transformed as log<sub>10</sub>(x+1), then back-transformed. 95% confidence limits (C.Ls.) are given for the geometric means. Arithmetic total is the sum of means.**

Abundance parameters	BS 1 Primary forest	BS 3 Logged-over forest	BS 6 <i>Paraserianthes</i> tree plantation	BS 8 <i>Hevea</i> (rubber) plantation	BS 10 Jungle rubber	BS 12 Degraded <i>Imperata</i> grassland	BS 14 Cassava garden
<b>Ants</b>							
Arithmetic mean	352	522	550	134	541	80	48
Geometric mean	23	239	223	17	226	15	6
95% C.Ls.	1-1348	28-2004	24-2065	1-529	24-2123	1-833	1-131
<b>Termites</b>							
Arithmetic mean	2892	163	512	128	211	3	26
Geometric mean	971	65	47	11	25	2	10
95% C.Ls.	190-4966	12-364	1-1923	2-201	2-1107	0-8	0-124
<b>All macroarthropods</b>							
Arithmetic mean	3668	713	1312	397	830	86	160
Geometric mean	2455	331	630	346	512	30	148
95% C.Ls.	630-9120	86-788	184-2152	177-679	219-1202	2-429	86-253
<b>Earthworms</b>							
Arithmetic mean	3	6	195	35	576	26	102
Geometric mean	2	2	186	6	565	14	53
95% C.Ls.	1-8	1-14	116-297	1-123	428-743	2-103	12-228
Arithmetic total	3671	619	1507	432	1406	112	262

**Table 7.7**

**Summary of biomass data for soil macrofauna across a forest disturbance gradient in Jambi Province, Central Sumatra.**

**Biomass densities are given as  $\text{g m}^{-2}$ , based on 5 monoliths per site, spaced along a 40 m transect. For geometric means, data are transformed as  $\log_{10}(\text{mg}+1)$ , then back-transformed. 95% confidence limits (C.Ls.) are given for the geometric means.**

**Arithmetic total is the sum of means.**

Biomass parameters	BS 1 Primary forest	BS 3 Logged-over forest	BS 6 <i>Paraserianthes</i> tree plantation	BS 8 <i>Hevea</i> (rubber) plantation	BS 10 Jungle rubber	BS 12 Degraded <i>Imperata</i> grassland	BS 14 Cassava garden
<b>Ants</b>							
Arithmetic mean	0.35	0.29	4.89	0.10	0.86	0.03	0.34
Geometric mean	0.02	0.19	0.35	0.02	0.24	0.01	0.022
95% C.Ls.	<0.01-1.43	0.05-0.72	0.01-9.86	<0.01-0.43	0.02-3.09	<0.01-0.16	<0.01-1.22
<b>Termites</b>							
Arithmetic mean	5.59	0.09	0.59	0.07	0.49	<0.01	0.02
Geometric mean	2.77	0.10	0.47	0.06	0.35	<0.01	0.02
95% C.Ls.	0.09-14.67	0.01-0.26	0.01-1.50	0-0.22	0-1.38	0-0.012	0-0.06
<b>All macroarthropods</b>							
Arithmetic mean	8.99	1.89	5.79	2.27	6.08	0.64	0.67
Geometric mean	5.08	1.82	2.13	1.55	3.99	0.44	0.66
95% C.Ls.	1.23-20.68	1.09-2.80	0.12-7.79	0.01-5.61	0.67-13.89	0.01-1.76	0.38-1.00
<b>Earthworms</b>							
Arithmetic mean	0.03	0.06	11.42	0.77	60.16	0.83	4.67
Geometric mean	0.01	0.06	8.40	0.53	33.59	0.12	2.79
95% C.Ls.	<0.01-0.05	<0.01-0.09	2.21-26.49	<0.01-2.18	11.92-91.81	0.04-1.22	1.11-11.03
Arithmetic total	9.02	1.95	17.21	3.04	66.24	1.47	5.34

**Table 7.8**

**Summary of vertical distribution of invertebrate soil macrofauna in a forest disturbance gradient in Jambi province, Central Sumatra, with statistical analysis of transformed data by parametric analysis of variance (ANOVA). For geometric means data are transformed as  $\log_{10}(x+1)$  for abundance and  $\log_{10}(mg+1)$  for biomass, then back-transformed. 95% confidence limits (C.Ls.) are given for the geometric means. ns, not significant.**

Population parameter	Litter layer	0-10 cm	10-20 cm	20-30 cm	ANOVA between strata	
					F <sub>(3,16)</sub>	p
<b>ABUNDANCE, nos m<sup>-2</sup></b>						
<b>Ants</b>						
Geometric mean	52	136	24	4	2.39	ns
95% C.Ls.	20-134	81-230	8-68	2-75		
<b>Termites</b>						
Geometric mean	15	80	44	4	2.30	ns
95% C.Ls.	3-64	43-148	24-78	1-50		
<b>All macroarthropods</b>						
Geometric mean	184	343	77	38	5.60	<0.01
95% C.Ls.	143-237	153-767	52-119	14-111		
<b>Earthworms</b>						
Geometric mean	0	82	1	0	36.47	<0.001
95% C.Ls.	-	47-138	1-7	-		
<b>BIOMASS, g m<sup>-2</sup></b>						
<b>Ants</b>						
Geometric mean	0.04	0.21	0.03	0.04	1.28	ns
95% C.Ls.	0.01-0.12	0.05-0.92	0.01-0.12	0.01-0.12		
<b>Termites</b>						
Geometric mean	0.06	0.43	0.06	0.03	3.94	<0.05
95% C.Ls.	0-0.14	0.11-1.45	0.03-0.11	0-0.08		
<b>All macroarthropods</b>						
Geometric mean	1.12	1.17	0.23	0.18	8.45	<0.005
95% C.Ls.	0.62-1.97	0.57-2.28	0.12-0.34	0.09-0.32		
<b>Earthworms</b>						
Geometric mean	0	9.67	0.04	0	489.9	<0.001
95% C.Ls.	-	7.82-11.88	0-0.10	-		

**Table 7.9**  
**Summary of parametric and non-parametric ANOVA on invertebrate soil macrofaunal abundance and biomass**  
**from 4 horizon levels and 7 sites in a forest disturbance gradient. ns, not significant.**

Population parameter	One-way parametric ANOVA between sites <sup>a</sup>	One-way parametric ANOVA between strata <sup>b</sup>	Two-way parametric ANOVA <sup>c</sup>			Kruskal-Wallis non-parametric ANOVA <sup>d</sup> between sites
			Between sites	Between strata	Interaction of sites and strata	
Ant abundance	ns	ns	p<0.025	p<0.001	ns	ns
Ant biomass	ns	ns	p<0.05	p<0.025	ns	ns
Termite abundance	p<0.005	ns	p<0.001	p<0.001	p<0.05	p<0.025
Termite biomass	p<0.025	p<0.05	p<0.001	p<0.001	p<0.01	p<0.025
All macroarthropods abundance	p<0.005	p<0.01	p<0.001	p<0.001	ns	p<0.005
All macroarthropods biomass	p<0.05	p<0.005	p>0.001	p<0.001	ns	p<0.025
Earthworm abundance	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	P<0.005
Earthworm biomass	p<0.001	p<0.001	p<0.001	p<0.001	p<0.001	P<0.005

<sup>a</sup>all strata combined for each monolith and data log transformed.

<sup>b</sup>each stratum averaged across 7 sites and data log transformed.

<sup>c</sup>strata treated as replicate samples in each site and data log transformed.

<sup>d</sup>untransformed data.

**Table 7.10**

**Matrix summary of differences between treatments (sites) for invertebrate soil macrofaunal abundance across a forest disturbance gradient in Jambi Province, Central Sumatra. Groups are shown which are significantly different in pairwise comparisons of sites by one-tailed Mann-Whitney. \* p<0.05; \*\* p<0.025; \*\*\* p<0.005. Numbers in brackets indicate the site with the greater abundance.**

BS1						
BS3	Termites <sup>**</sup> (1) Macroarthropods <sup>**</sup> (3)					
BS6	Earthworms <sup>***</sup> (6)	Earthworms <sup>***</sup> (6)				
BS8	Termites <sup>**</sup> (1) Macroarthropods <sup>**</sup> (1)	-	Earthworms <sup>**</sup> (6)			
BS10	Termites <sup>**</sup> (1) Macroarthropods <sup>**</sup> (1) Earthworms <sup>***</sup> (10)	Earthworms <sup>***</sup> (10)	Earthworms <sup>***</sup> (10)	Ants <sup>*</sup> (10) Earthworms <sup>***</sup> (10)		
BS12	Termites <sup>***</sup> (1) Macroarthropods <sup>***</sup> (1) Earthworms <sup>*</sup> (12)	Ants <sup>*</sup> (3) Termites <sup>**</sup> (3)	Ants <sup>*</sup> (6) Termites <sup>*</sup> (6) Macroarthropods <sup>**</sup> (6) Earthworms <sup>***</sup> (6)	Macroarthropods <sup>**</sup> (8)	Ants <sup>*</sup> (10) Macroarthropods <sup>**</sup> (10) Earthworms <sup>***</sup> (10)	
BS14	Termites <sup>***</sup> (1) Macroarthropods <sup>***</sup> (1) Earthworms <sup>**</sup> (14)	Ants <sup>*</sup> (3) Earthworms <sup>**</sup> (14)	Ants <sup>*</sup> (6)	Macroarthropods <sup>**</sup> (8)	Ants <sup>*</sup> (10) Macroarthropods <sup>***</sup> (10) Earthworms <sup>***</sup> (10)	-
	BS1	BS3	BS6	BS8	BS10	BS12

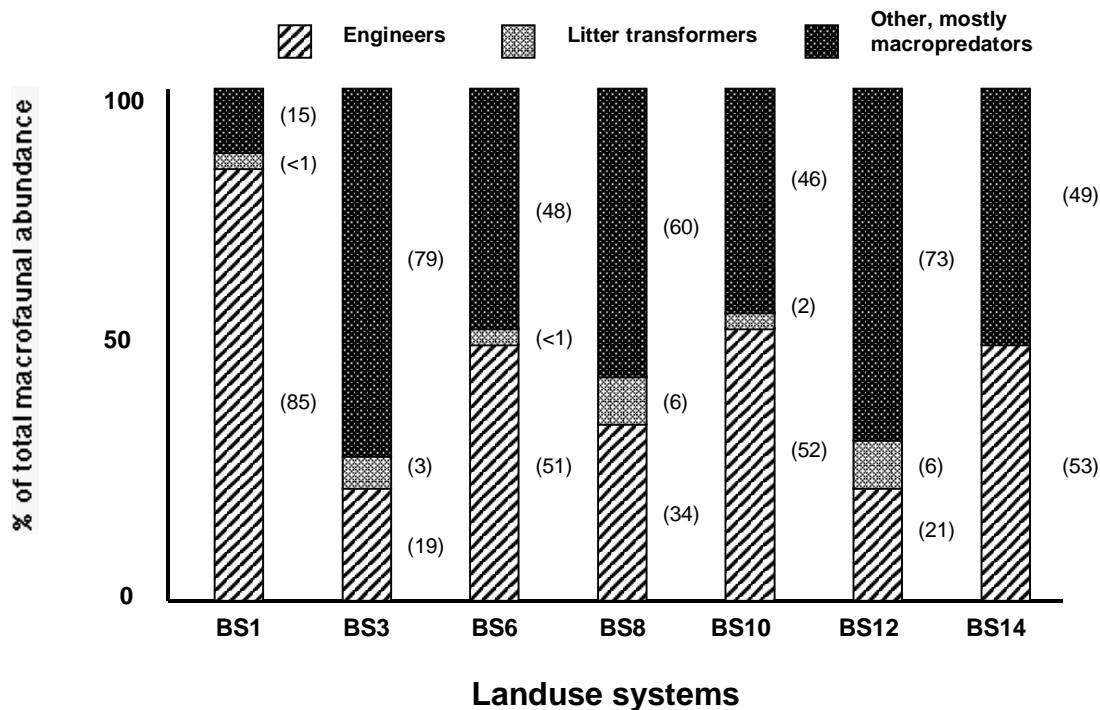
**Table 7.11**

**Matrix summary of differences between treatments (sites) for invertebrate soil macrofaunal biomass across a forest disturbance gradient in Jambi Province, Central Sumatra. Groups are shown which are significantly different in pairwise comparisons of sites by one-tailed Mann-Whitney. \* p<0.05; \*\* p<0.025; \*\*\* p<0.005. Numbers in brackets indicate the site with the greater biomass.**

BS1						
BS3	Termites <sup>**</sup> (1) Macroarthropods <sup>*</sup> (1)					
BS6	Earthworms <sup>***</sup> (6)	Earthworms <sup>***</sup> (6)				
BS8	Termites <sup>***</sup> (1)	Ants <sup>*</sup> (3)	Earthworms <sup>***</sup> (6)			
BS10	Termites <sup>*</sup> (1)	-	-	Earthworms <sup>***</sup> (10)		
BS12	Termites <sup>***</sup> (1) Macroarthropods <sup>**</sup> (1)	Ants <sup>**</sup> (3) Termites <sup>***</sup> (3)	Ants <sup>*</sup> (6) Termites <sup>*</sup> (6) Macroarthropods <sup>*</sup> (6) Earthworms <sup>***</sup> (6)	Macroarthropods <sup>*</sup> (8)	Ants <sup>*</sup> (10) Macroarthropods <sup>*</sup> (10) Earthworms <sup>***</sup> (10)	
BS14	Termites <sup>***</sup> (1) Macroarthropods <sup>***</sup> (1)	Macroarthropods <sup>**</sup> (3)	Earthworms <sup>*</sup> (6)	-	Macroarthropods <sup>***</sup> (10) Earthworms <sup>**</sup> (10)	Earthworms <sup>*</sup> (14)
	BS1	BS3	BS6	BS8	BS10	BS12

Figs. 7.10 and 7.11 represent attempts to examine the functional composition of the soil macrofauna across the seven sites, made on the basis of abundance data means. Unfortunately, we do not have biomass totals for macroarthropods other than ants and termites itemized by taxon, so it is not possible to make the same classifications based on biomass. In Figure 7.10 (Scheme 1) animals are allocated to one of three functional groups reflecting feeding and ingestion habits: engineers, litter transformers and macropredators. Unpigmented worms and termites were designated as engineers; pigmented earthworms, diplopods, crickets, woodlice and cockroaches as litter transformers; and the rest (including all ants) as macropredators. This is a fairly easy classification to make from the available data, but it does involve some over-simplification for certain groups (for example not all ants are predatory). Generic names were available for some earthworms recovered from monoliths, which assisted the allocation of specimens between the engineer and litter transformer category.

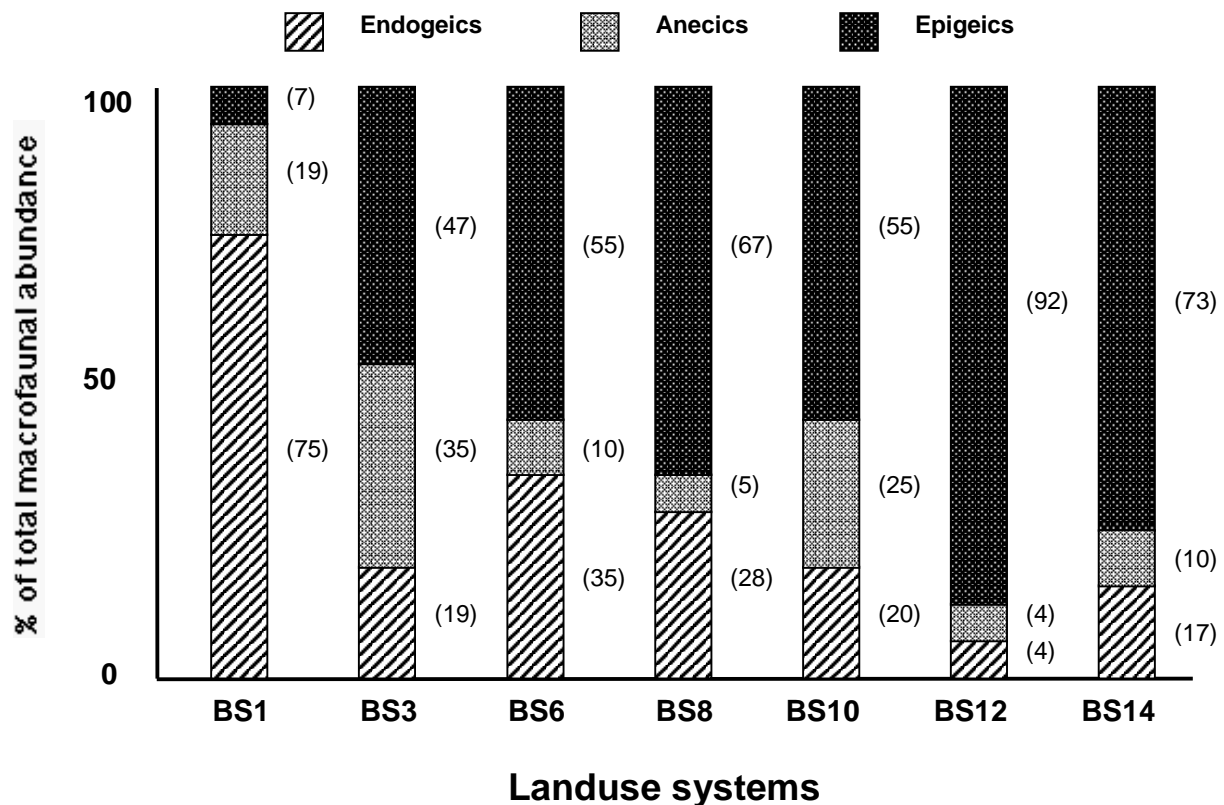
**Figure 7.10. Proportion (by abundance) of macrofaunal functional groups 1**



In this scheme there is no clear trend across the gradient, except that disturbed sites are relatively richer in macropredators and impoverished in engineers. In Figure 7.11 (Scheme 2), animals are allocated to one of three functional groups reflecting feeding habits and nesting/burrowing sites: epigeic (non-burrowing, living on the surface), anecic (burrowing but feeding on the surface) and endogeic (burrowing and feeding underground). Allocation is more difficult, as it requires making distinctions between different types of termites and ants, the two groups generally with the greatest abundance. Termites from the monoliths were not identified to species, so it is assumed that those found feeding in the litter are anecic and those feeding in the soil itself are endogeic. The epigeic category is not recognized for termites. For ants, all specimens were identified at least to genus level, and allocation of each to nesting type (above-ground or below-ground) was done anecdotally (by consulting experts) or from a literature search. Above-ground nesters are considered epigeic and below-ground nesters anecic. The endogeic category is not recognized in ants. For this scheme, Figure 7.11 clearly shows an

increase in the relative abundance of epigeic forms across the gradient, with the concomitant reduction of endogeics. Overall, disturbance diminishes the proportion of engineers and increases the proportion of epigeic invertebrates. Some amelioration of these trends is evident in the recovering forested sites BS6, BS8 and BS10.

Figure 7.11. Proportion (by abundance) of macrofaunal functional groups 2.



## 7.7. Synopsis

Figure 7.12 shows means for taxonomic diversity score (defined as in Figure 7.6, with the addition of the number of earthworm species and morphospecies), total abundance and total biomass of soil macrofauna across the seven sites (abundance and biomass presented as geometric means). The trend of diminishing diversity, ameliorated only for BS10, jungle rubber, is the most obvious feature. Surges of abundance and biomass are associated with sites BS6, *Paraserianthes* plantation and BS10, jungle rubber, reflecting large earthworm populations and/or an abundance of ants. A biomass mean of almost 40 g m<sup>-2</sup> (geometric mean) is a feature of the jungle rubber site, and easily exceeds the biomass of any other site. Abundance is greatest in intact rainforest, reflecting the high numerical density of termites, and their reduction in other sites.

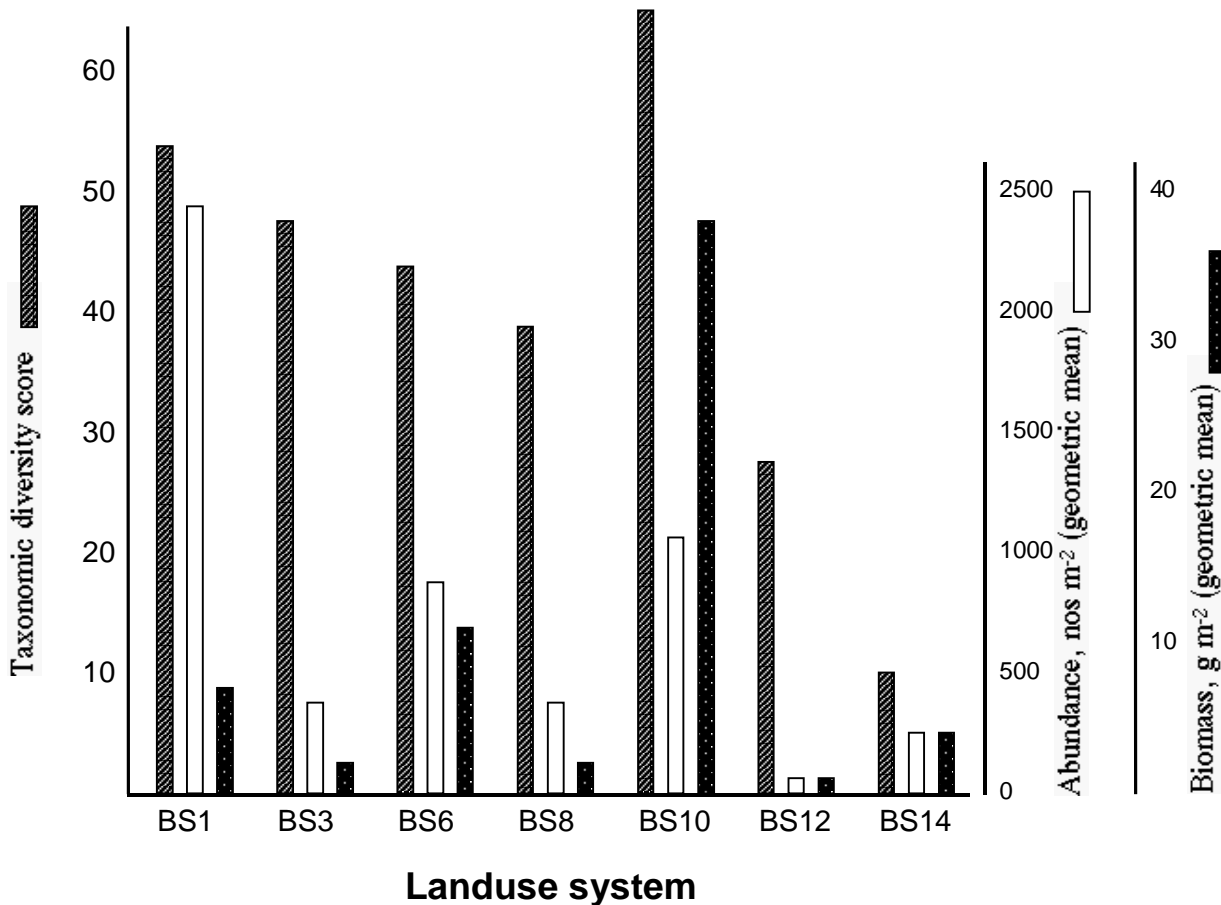
## 7.8 Discussion:

### 7.8.1 Methods and relevance to Rapid Biodiversity Assessment:

The sampling methods represent the consensus of best practice agreed in 1997 by the Below-Ground Working Group of the Alternatives to Slash-and-Burn Project (ASB). As far as

possible, the sampling addresses groups which are known ecosystem engineers (termites, ants and earthworms) and litter transformers (millipedes, woodlice, some coleopterous larvae), rather than surrogate groups or so-called "indicators" with dubious predictive value (see Lawton *et al.*, 1998). In the case of termites, ants and earthworms, the objective is to obtain resolution at species level, and thus contribute elements of true biodiversity to the dataset. The addition of pitfalls is a recent revision of ASB methodology and should assist the achievement of a more representative sampling of ants. Termite species richness is addressed through 100 x 2m qualitative transects (see report by Jones *et al.*, section 8), which take account of the known spatial heterogeneity of termites in forest or forest-derived systems and help to mitigate the variability of data from shorter transects on groups with typically patchy distributions.

**Figure 7.12. Biodiversity summary (earthworms included)**



Monolith dissection is still the only approach to the sampling of earthworms, and the disturbance involved is known to result in the escape of deep-burrowing species (James, 1996). The various other techniques of earthworm sampling available, for example chemical extraction, vibrational displacement and electrical shocking are considered too cumbersome or environmentally unacceptable for Rapid Biodiversity Assessment, but estimates based on cast frequency and density may have some potential (Hauser *et al.*, 1997; Norgrove *et al.* 1998; Hauser and Asawalam, 1998). Dry heat extractions, for example, using Berlese, Tullgren or Kempson funnel systems, are suitable for a wide variety of macrofauna (including earthworms) and mesofauna, but are limited by the time required for drying (24-48 hours) and the relative bulkiness and lack of portability of the equipment required, and, thus are not suited for concurrent or sequential rapid assessments over a large geographical range. There is a notable learning-curve effect in the digging of soil monoliths, so that 5 pits can normally be completed

comfortably in one day, though sorting extends the time required for each landuse to two days. Similarly, the qualitative termite transect requires 20 man-hours of effort, which usually translates into two days of sampling per land use, including sorting and cleaning of specimens. Neither monoliths nor termite transects can be completed in heavy rain, so a two-day sampling period is really the minimum that can be allocated per land use. The wisdom of starting work early in the day, when light is generally good and downpours less frequent is self-evident. ASB recommends 10 monoliths per transect, but there must be some doubt whether this is a realistic target, since the sorting of the resulting soil samples is a rate-limiting step. It is normally satisfactory to have 2-4 people working on the monolith digging and sorting; a larger number adds to the disturbance of the site and may interfere with other sampling activities taking place concurrently. ASB has now standardized the size of monoliths at 25x25x30cm. 30cm is considered a satisfactory depth, as only a relatively small component of the macrofauna is assumed active below this level in tropical forest zones. However, it should be noted that the assumption will not necessarily be valid in savanna systems.

Macrofauna are only one of five groups of soil organisms which ASB now recommends should be sampled for an adequate assessment of ecosystem function; the others are nematodes, nitrogen-fixing bacteria, mycorrhizal fungi and "decomposers" (i.e. microorganisms having a significant role in the nutrient cycling). Field sampling for these other groups is normally straightforward and rapid, consisting of coring and digging operations of various kinds, but subsequent extraction, cultivation, bioassay and strain-typing procedures impose severe constraints on technical and financial resources (Swift and Bignell, 1999). ASB recognizes that there will be variation in the degree of resolution of taxonomic identity and functional group allocation between the five major target groups of soil biota. This is not considered a problem as long as comparisons are made at the same level of resolution. Standard units have been agreed for expressing data at various levels and this report reflects those agreed for macrofaunas (basically by taxonomic group, functional group, abundance, biomass and biodiversity indices). In the latest (1997) revision of below-ground methods, ASB recommends new functional group classifications for the soil biota as a whole and for termites in particular:

**Table 7.12**  
**Functional Group Classifications for the Soil Biota and Termites**

<u>Soil biota</u>	<u>Termites</u>
ecosystem engineers	soil-feeders
litter transformers	wood-feeders
macropredators	wood/soil interface feeders
micropredators	grass-feeders
microsymbionts	lichen-feeders
decomposers	fungus-growers

Additional new functional group classifications are to be considered for taxa where the current classifications are considered unsatisfactory, especially earthworms and beetles.

### **7.8.2 Significance of results at regional and global level:**

The literature contains a few reports of tropical ant abundance and biomass (see above). The data obtained from Pasir Mayang are broadly in agreement with expectations. The study of soil

fauna on Mount Mulu (Sarawak) by Collins (1980) gave ant abundance in the lowland forest control site at 130 m elevation as 509 m<sup>-2</sup> (cf. 352 in the present study) and ant biomass as 0.445 g m<sup>-2</sup> (cf. 0.346 in the present study).

Globally, estimates of termite abundance for savannas (>50 to <4000 m<sup>2</sup>) overlap with those for agricultural systems (>1500 to <6000 m<sup>2</sup>), secondary forests/plantations (>100 to <10,000 m<sup>2</sup>), and primary forests (>1000 to <7000 m<sup>2</sup>). The reliability of individual estimates depends on the rigour of the sampling protocols, but the highest numerical densities are clearly associated with tropical forests. Regional/habitat biomass estimates follow abundance estimates closely, and vary from less than 1 g fresh weight m<sup>-2</sup> to a maximum value of 130 g in a near-primary site of the Mbalmayo Forest Reserve (Eggleton *et al.*, 1996). Most site values, however, are less or much less than 10 g m<sup>-2</sup>, with the highest values in forest systems. Broadly, the numerical and biomass densities of termites are matched with species diversity. Relatively few studies have compared termite abundance and biomass with that of other soil invertebrates in the same systems, but the conclusions of Collins *et al.* (1984) are probably typical of tropical forests: ants and termites have greater abundance than all other macrofauna put together, and also greater biomass than other macrofauna, excepting earthworms in particularly favourable conditions such as base-rich or neutral soils with high organic content (see also Fogden, 1977; Collins, 1980;1989; Marsh and Wilson, 1981; Lavelle *et al.*, 1997). Given these data, termites may constitute as much as 10% of all animal biomass in the tropics (Wilson, 1993), and as much as 95% of soil insect biomass (Watt *et al.*, 1997). Estimated termite biomass in different biomes is given by Bignell *et al.* (1997). The relative biomass contribution of termites depends on where they are sampled, as the absolute biomass in African forests is considerably higher than in Asian forests (Table 7.1), declining on a rough longitudinal gradient to <1 g m<sup>-2</sup> in rainforests in Australia and Papua New Guinea .

Termite abundance, biomass and species richness are generally reduced when forest is cleared (Collins, 1980; Wood *et al.*, 1982; Eggleton *et al.*, 1995; 1996). However, in some cases temporary nutrient enrichment from cut and abandoned vegetation (Eggleton *et al.*, 1995; 1996; 1997), as well as the availability of termite species from adjacent savannas to colonize disturbed areas (Wood *et al.*, 1982; cf. Eggleton *et al.*, 1996) may obscure overall diversity reductions, as true forest species are replaced with others (i.e. the so-called “trash species”). Less extreme disturbances, such as foraging and hunting by local people, selective logging, conversion to tree plantation, or small-scale subsistence agriculture or agroforestry produce smaller effects on abundance and biomass (and in some cases no effects), but there may be a turnover of species with a tendency for wood-feeding forms to replace soil-feeders. In addition, there may be a lag between the onset of moderate disturbance and noticeable changes in assemblage composition, as colonies can survive for a number of years after disturbance (Eggleton *et al.*, 1996;1997). Feeding group shifts are probably mostly due to changes in canopy cover, with concomitant effects on soil humidity, but both organic C and total N in soils may be reduced along disturbance gradients (Eggleton *et al.*, 1996). Lawton *et al.*, (1998) calculated a modified form of Whittaker’s  $\beta$  index of species turnover (the  $\beta$ -2 index, see Harrison *et al.*, 1992) for termites in five sites along a disturbance gradient in the Mbalmayo Forest Reserve ranging from near primary forest to an area completely cleared by bulldozer. This index varies from 0 (no turnover) to 100 (every site has a unique set of species). The value for termites was 28.8, lower than for beetles and canopy ants, but above butterflies, birds, litter ants and soil nematodes.

### **7.8.3 Needs for further work:**

Further sampling in sites at both the light and heavy end of the disturbance gradients would be helpful to confirm the apparent benefit to ants and earthworms conferred by intermediate levels of disturbance. Transects with 6, 8 and 10 monolith dissections should also be attempted to see whether slightly or substantially larger sample sizes assist the descriptive and hypothesis-testing statistics, and therefore provide better site-to-site resolution.

## **7.9 Summary:**

### **7.9.1 Assessments of species richness, abundance and biomass:**

These were compared across of range of forest and forest-derived sites representing a disturbance gradient in or adjacent to the Pasir Mayang Forest Reserve, Jambi Province, Sumatra in November 1997. A combination of pitfall traps, dissected soil monoliths (to 30 cm depth) and transects of 100x2 m was used (variously) to assess species richness of ants, termites, other macroarthropods and earthworms; abundance and biomass of these groups were estimated from 5 monoliths (only) arranged along a 40 m transect.

### **7.9.2 Species richness, abundance and biomass according to land-use type:**

#### *Ants*

57 species (including some morphospecies) from 8 subfamilies were sampled overall, with the highest species richness (33) and taxonomic richness (6 subfamilies) associated with the jungle rubber site (BS10). Highest abundance (arithmetical mean 550 ants m<sup>-2</sup>) and highest biomass (arithmetical mean 4.889 g m<sup>-2</sup>) were recorded in the *Paraserianthes* tree plantation (BS6). Rubber plantation (BS8), alang-alang grassland (BS12) and Cassava garden (BS14) were generally poor sites for ants. Primary forest (BS1) and logged-over forest (BS3) were sites of intermediate species richness, abundance and biomass.

#### *Termites*

48 species (including some morphospecies) from 5 subfamilies were sampled overall, with the highest species richness (30) associated with the intact rainforest (BS1), which also had the highest abundance (2892 m<sup>-2</sup>) and biomass (5.59 g m<sup>-2</sup>), Rubber plantation (BS8), alang-alang grassland (BS12) and Cassava garden (BS14) were generally poor sites for termites, with jungle rubber (BS10), logged-over forest (BS3) and *Paraserianthes* tree plantation intermediate for species richness, abundance and biomass. See section 8 of this report.

#### *Other macroarthropods*

Arthropods other than ants and termites were of some significance in abundance and biomass totals in several sites, notably intact forest (BS1), logged-over forest (BS3), rubber plantation (BS8) and Cassava garden (BS14).

## Earthworms

Earthworms had low diversity in Jambi sites, but were numerous and had high biomass in *Paraserianthes* tree plantation (BS6) and jungle rubber (BS10). In the latter site, numerical density was 576 m<sup>-2</sup> and biomass density 60.16 g m<sup>-2</sup> (both arithmetic means).

### 7.9.3 Variability in data collection:

This was high. Transformation of data as log<sub>10</sub> (x+1) and the use of non-parametric statistical analysis were considered essential. Many statistically significant differences were found between sites, with earthworms and all macroarthropods being better discriminators at intermediate levels of disturbance. Termites were significantly different between the richest and poorest sites. Abundance and biomass of ants did not differ significantly across the site gradient as a whole; however, it may still be concluded that ant activity and biodiversity are high in sites that are botanically diverse.

### 7.9.4 Surface concentrationl:

Ants, termites and earthworms were concentrated in the top 10 cm of the soil profile, more or less in all sites, to such an extent that sampling of litter and of the soil profile below 10 cm is probably unnecessary. The top 10 cm may, consequently, be a crucial zone for ecosystem processes mediated by the soil fauna, and the effects of disturbance on this layer probably determine the responses of the soil macrofauna as a whole.

### 7.9.5 Future studies:

These should employ 6-10 monoliths per transect; however the logistical and manpower requirements of such intensive sampling are very demanding.

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