Biodiversity:
Species and Biotope Conservation

Ecological evaluation of forest management using leaf-litter ants and stingless bees as indicators

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Foreword

Tropical ecosystems constitute the natural basis for the livelihood of the greater part of the world’s population. Increasing destruction and degradation of the natural resources of the developing countries are jeopardising the efforts towards a sustainable development and an effective fight against poverty.

In the context of development cooperation, the Tropical Ecology Support Programme (TOEB) aims to contribute to a more effective assessment, processing and application of the insights and experience gained in this field.

TOEB is a transregional service project which is run by the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) on behalf of the Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (BMZ).

The programme supports those submitted studies which deal with questions of tropical ecology which are relevant for a particular project. It wants to encourage the development of concepts for the protection and sustainable management of tropical ecosystems which can provide innovative instruments for a more ecologically sound development cooperation.

The application of scientific results in its extension services helps the projects to fulfil international agreements like *Agenda 21* and the *Convention on Biodiversity*, which are afforded special significance by the BMZ.

An important element of the programme’s conception is that German and local scientists work together to solve problems of applied research. TOEB thereby makes an important contribution to the practically relevant further training of partner experts and towards the development of tropical ecological expertise in the partner countries.

With its publication series, the Tropical Ecology Support Programme aims to provide the results and recommendations of the project-based studies in a form which can be easily understood by the organisations and institutions engaged in development cooperation and the general public interested in environmental and development policy questions alike.

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The work would not have been possible without help from a large number of people in both Malaysia and Germany. We wish to thank Herman Anjin, Albert Radin, Lutz Kulenkampff, Dr. Michael Kleine and the entire staff of the Malaysian-German Sustainable Forest Management Project (M-G-SFMP) in Sanadakan for their hospitality and for providing logistical support and valuable information.

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Last but not least, we wish to thank our supervisor Prof. Dr. K. E. Linsenmair for creating the opportunity for conducting this research on tropical insect ecology and for his advice and support during the entire duration of the project.

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Glossary

Community	Assemblage of species populations that occur together in space and time
Diversity	An aspect of natural communities that incorporates both species richness and the relative abundance of species
Diversity index	Mathematical expression of quantitative (abundance) and/or qualitative (species richness, community composition) aspects of diversity
Indicator	A taxon (e.g. species, genus, etc.) whose characteristics (e.g. presence/absence, abundance) reflect the effects of a disturbance regime
Indicator species	see ‘indicator’
Reduced Impact Logging	Logging practices following guidelines aimed at minimizing damage on soils and the residual stand (e.g. those of the Sabah Forestry Department)
Selective Logging	Timber extraction that leaves a residual forest stand (in contrast to clear-cutting)
Species richness	The number of species in a sample

Abbreviations

dbh	diameter at breast height
DFR	Deramakot Forest Reserve
DVCA	Danum Valley Conservation Area
DVFC	Danum Valley Field Centre
EIA	Environmental Impact Assessment
FRC	Forest Research Centre, Sepilok, Sabah
FSC	Forest Stewardship Council
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
KSFR	Kabili-Sepilok Forest Reserve
MDS	Multidimensional Scaling
M-G-SFMP	Malaysian-German Sustainable Forest Management Project
RIC	Rainforest Interpretation Centre
RIL	Reduced Impact Logging
TÖB	Begleitprogramm Tropenökologie der GTZ (Tropical Ecology Support Program of the GTZ)
UMS	Universiti Malaysia Sabah, Kota Kinabalu, Sabah

1 Project Outline and Summary

Title

“Ecological evaluation of forest management using leaf-litter ants and stingless bees as indicators”

Country

Malaysia

Investigators, supervisor and cooperation

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Current situation and problems

Large areas of Malaysian forest have been and are currently being transformed by logging for timber extraction. In the last years growing emphasis has been given to the necessity of sustainable forest management. Sustainable management of production forests is an absolute prerequisite for meeting growing timber demands. It is also regarded as a potential way of preserving large proportions of Malaysian forest biodiversity. In 1989 the State Forestry Department of Sabah, Malaysia, assisted by the German Government through 'Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)' started a project aimed at introducing sustainable management practices into its 2.5 million hectares of commercial forest. In order to establish an appropriate management model, an area of 55,000 ha of logged-over forest (Deramakot Forest Reserve) was set aside for this purpose (Kleine & Heuveldop, 1993). Increasing knowledge on tropical rain forest ecosystems suggest that long-term economic sustainability is unlikely to be achieved without taking into account the various links between timber species and the surrounding forest. The assessment of sustainability and the evaluation of forest management systems should therefore include information on how representative groups of animals respond to logging. In 1997 we started our project on forest insects in Sabah. Ants of the leaf-litter and stingless bees were selected as focal groups of organisms for an impact assessment of logging on lowland dipterocarp forests. The project was funded through "Tropenökologisches Begleitprogramm (TÖB)" of the GTZ and integrated into the Malaysian-German-Sustainable Forest Management Project (M-G-SFMP) based in Sandakan, Sabah.

Aims of the project

∗ To develop and/or test suitable methods for the assessment of diversity, abundance and community composition of leaf-litter ants and stingless bees in Bornean forests.

∗ To assess the impact of forest disturbance of varying intensity on communities of ants and bees and relate potential responses to causal mechanisms

∗ To deduce implications for forestry and make recommendations concerning the development of sustainable forest management systems

Results and Recommendations

∗ Quantitative and standardized assessment methods for both stingless bees (quantitative nest survey) and leaf-litter ants (transect sampling, Winkler method) were developed and applied in a range of primary and logged forest sites in Sabah. Patterns of abundance and species richness were investigated, causative factors evaluated.

∗ Most stingless bee nests were found in commercial trees of harvestable size and below-average timber quality. Nest mortality directly caused by logging operations is expected to be around 1/3 and will vary with logging intensity and harvesting methods. The retention of (i) low-quality (hollow) trees and (ii) very large trees (>120 cm dbh) will promote the retention of stingless bee nests and is recommended for implementation in forest management systems.

∗ Comparisons between different sites did not show a clear response of stingless bees to logging, although a negative trend was apparent in both bee diversity and nest density. However, up to 90% of the variation in stingless bee nest density was explained by factors other than logging disturbance, specifically by the availability of non-forest pollen sources.

* The diversity and species density of leaf-litter ants was significantly lower in all types of logged forests compared to the primary forest control sites, and total species numbers were reduced to an average of 70%. No pronounced differences were found between logged forests varying in the intensity and history of logging.

* Aspects of ant community composition were correlated with environmental factors such as (i) litter and soil temperature, (ii) litter humidity and (iii) forest stand structure. However, only one abundant ant species, the myrmecine *Lophomyrmex bedoti*, was consistently found in conjunction with disturbed habitat conditions. Its use as an indicator, though, is hampered by the high demands of ant inventories concerning working effort and expertise.

Results from both groups of organisms suggest that natural forest management can succeed in retaining relatively large fractions of biodiversity. Data on ant communities indicate that the environmental impact of selective logging is likely to be dwarfed by the impact caused by alternative forms of land use, e.g. oil palm plantations. The main focus must therefore be the long-term preservation of non-plantation forests in general.

Students involved in the project

Mohd. Fairus Jalil completed his MSc studies at Universiti Malaysia Sabah (UMS) and carried out his thesis work on butterfly diversity in close cooperation with the investigators.

Jupailin Naiman endeavoured to study wasp ecology and systematics within the project and is now working for Inoprise Sabah.

Dipl. Biol. Martin Gossner completed his Diploma thesis on ‘Diversity patterns of ants of the lower vegetation’ and received his degree from the University of Würzburg.

Tobias Bickel is currently finishing his Diploma thesis on the genetic diversity of ants in contiguous and fragmented forests.

Activities aimed at transfer of knowledge

*	Final workshop on ‘Insects in changing forests’ in November 2000 in Sepilok. More than 30 scientists (UMS, DVFC, FRC) and forest managers (Sabah Forestry Department) attended the presentation and discussion of the project results.

*	Insect exhibition in the Rainforest Interpretation Centre (RIC) in Sepilok in cooperation with the Environmental Education Section of FRC.

2 Introduction

Large areas of Malaysian forest have been and are currently being transformed by selective logging. The residual stands, though frequently altered in many important characteristics (Whitmore & Sayer, 1992), will play an increasingly important economic and ecological role in future times (Saunders, Hobbs & Margules, 1991; Marsh, 1992; Johns, 1992; Chazdon, 1994; Lugo, 1995). In the last years growing emphasis has been given to the necessity of sustainable forest management (Uebelhör & von der Heyde, 1993; Porritt, 1994). Sustainable management of production forests is an absolute prerequisite for meeting growing timber demands, and first concepts and techniques have been introduced that are aimed at facilitating the transition from pure exploitation to long-term production (Kleine & Heuveldop, 1993; Marsh et al., 1996). However, due to the long reproductive cycles of trees the applicability of these concepts is still unknown. At the moment, sustainability is mostly judged by monitoring the early regeneration of a limited number of valuable timber species (e.g.: Bossel & Krieger, 1994; Cannon et al., 1994; Liu & Ashton, 1995). This approach severely neglects the fact that the long-term preservation of tropical forest ecosystems depends on the persistence of the complex and delicate interactions between all levels of forest biota, including both animals and plants (Miller, 1993). Thus, sustained economic use of natural forest timber necessitates the conservation of large fractions of the non-commercial biodiversity. The importance of these ecological aspects has been recognised and confirmed during the 1992 conference of UNCED in Rio de Janeiro (Chichilnisky, 1996).

As a consequence, faunal parameters have to be incorporated when evaluating the sustainability of different forms of tropical forest management. Fauna indicators can add considerable depth to analyses of ecosystem state and functioning.

Short-lived animals, e.g. the diverse and ubiquitous insects, are likely to react much faster to environmental change than long-lived plants (Noss, 1990; Johns, 1992; Oliver & Beattie, 1993; 1996).

In 1989 the State Forestry Department of Sabah, Malaysia, assisted by the German Government through ‘Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)’ started a project aimed at introducing sustainable management practices into its 2.5 million hectares of commercial forest. The concept embraces the conservation of the native flora and fauna, and the management system specifically requires environmental impact assessment (EIA). In order to establish an appropriate management model, an area of 55,000 ha of logged-over forest (Deramakot Forest Reserve, Fig. 1) was set aside for this purpose (Kleine & Heuveldop, 1993) and served as a test ground for the application of Reduced Impact Logging (RIL) methods and for the implementation of the management concept developed by the Malaysian-German Sustainable Forest Management Project (M-G-SFMP). In 1997 Deramakot was issued a Forest Stewardship Council (FSC) certificate by an independent auditing company acknowledging sustainable forest management.

In 1997 we started our project ‘Ecological evaluation of forest management using leaf-litter ants and stingless bees as indicators‘. The project was funded through TÖB and integrated into M-G-SFMP, based in Sandakan, Sabah. The main research area was the Deramakot Forest Reserve (Fig. 1), which harbours a wide range of disturbed forests with differing logging intensities and histories which therefore provided ample opportunity to assess the ecological impact of timber extraction.

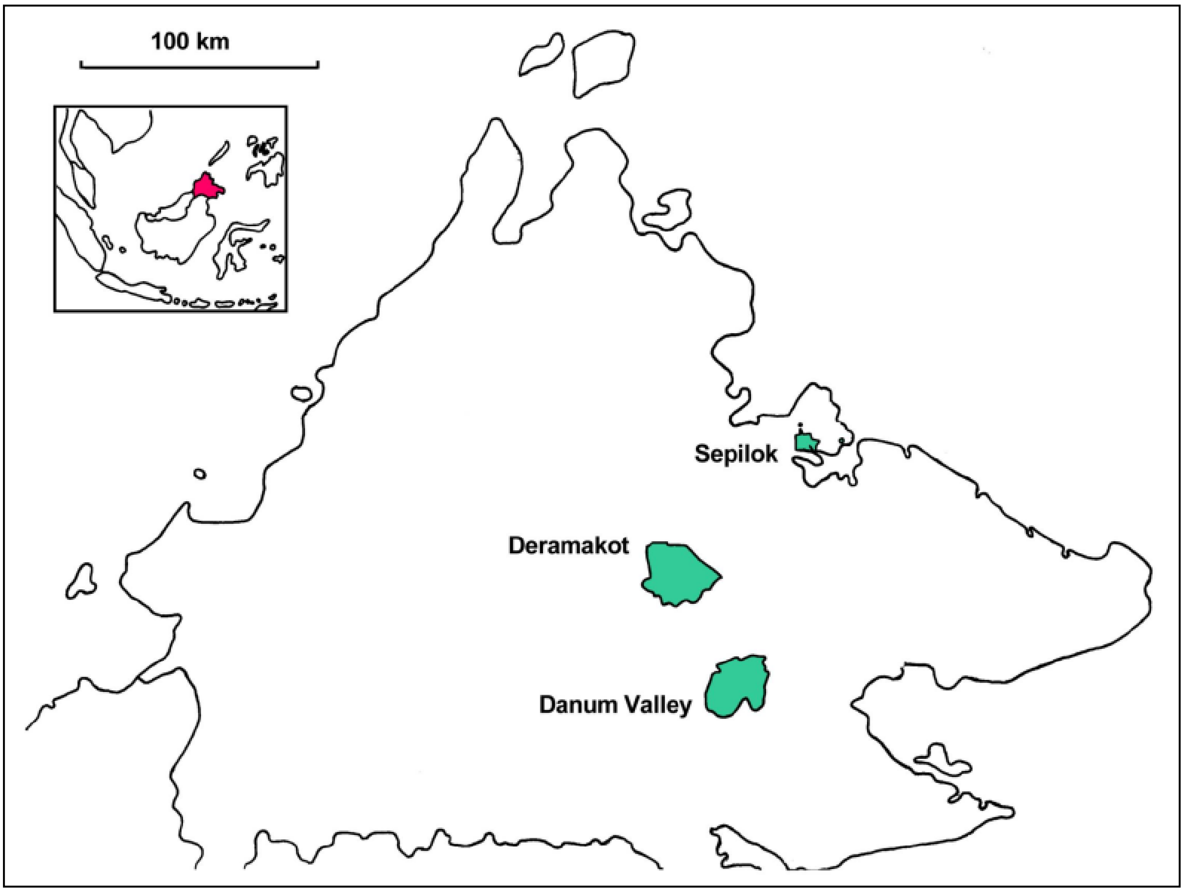


Fig. 1: Map of Sabah, Malaysia. Research areas indicated in grey.

3 Research Approach and Study Sites

Original project plans had considered a direct comparison of the ecological impact on insect communities between the RIL methods applied by the German-Malaysian Sustainable Forest Management Project (G-M-SFMP) in Deramakot and the conventional high-impact methods normally applied by concessionaires. However, fully implemented RIL (stock mapping, skid trail planning, reduced impact harvesting etc.) has only recently been realised in Deramakot in a limited number of locations, and a direct comparison with conventionally harvested sites was impossible due to lack of suitable controls. Alternatively, we decided to use a more general approach that encompassed the existing variation of forests created by more than 40 years of logging history in the Deramakot area. Results obtained from comparing primary forest sites with logged sites varying in the intensity of logging disturbance as well as in the time for regeneration (10 to 30 years) were presumed to allow indirect evaluation of the RIL methods now implemented in Deramakot. To justify this approach, detailed measurements of residual stand structure as well as climatic parameters were obtained for the different sites.

3.1 Sites and site parameters

A total of 14 research sites (five primary, nine logged sites) in three localities (see below, Fig. 1) were selected. In each site we established a 600x600 m transect system (Fig. 2) that served as the basic working grid for data collection. Information on site characteristics was obtained by analysing literature descriptions, stratum maps, logging history maps and aerial photographs, and by ground survey. In addition, we recorded extensive data on stand structure (basal area, tree diameter distributions) by angle-count sampling along the transect grids and (partly in subsets of sites) measured air temperature, leaf-litter and soil temperature, leaf-litter and soil moisture, humidity and precipitation.

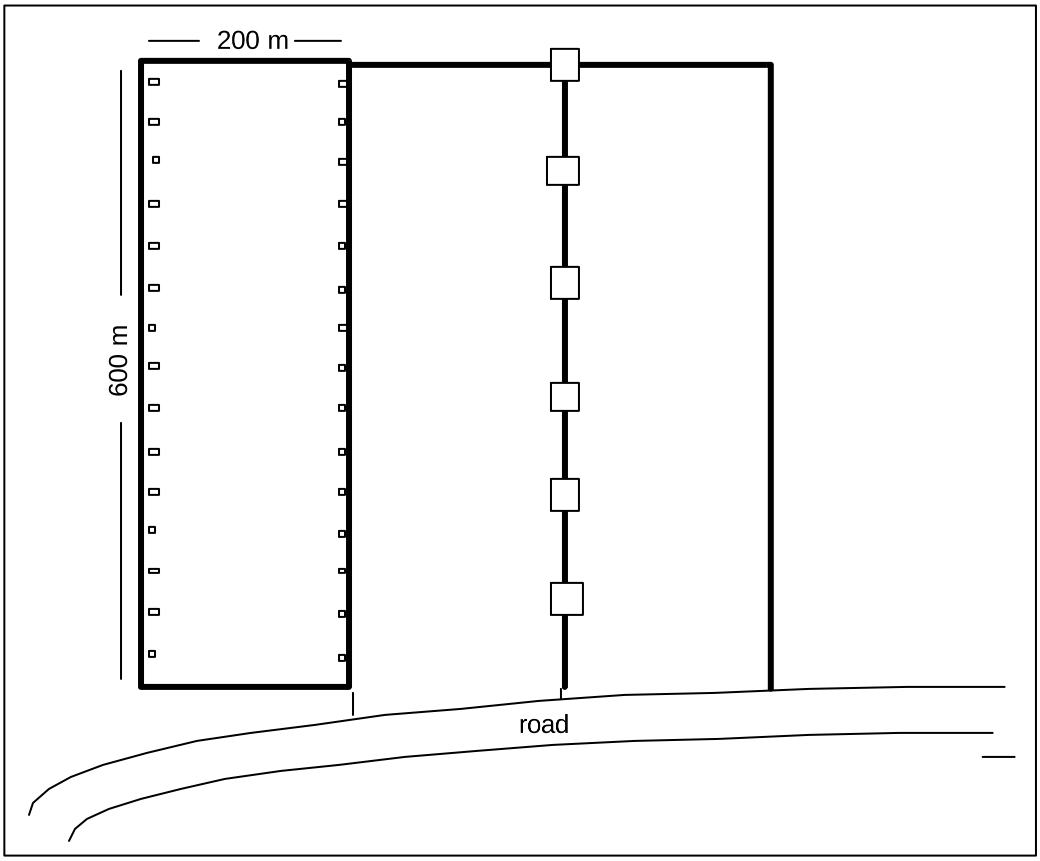


Fig. 2: Schematic view of research plot with transect grid (fat lines). Large squares represent subplots for Winkler samples (see section 5). Small squares are honey-spray stations of one sampling unit (section 4).

3.2 Logged forest sites

All nine logged forest sites (one plot at each site: **A** through **I**) were situated in the Deramakot Forest Reserve, a 55,000 ha commercial forest reserve in the centre of Sabah (see Fig. 1). Deramakot is covered by mixed dipterocarp lowland forest of the *Parashorea tomentella -Eusideroxylon zwageri* type and has been subject to timber extraction since 1956 (Chai & Amin). The selected sites were chosen in order to fit into one of three 'types' of logged forests:

∗ Old logged-over forests, *slightly* disturbed: selectively logged once between 1974 and 1976; largely intact canopy; for simplicity termed **'good'** forest sites (**A**, **B**, **C**); all three sites are situated in the relatively well-stocked area around the Deramakot Base Camp (Compartments 44, 51, 54).

∗ Old logged-over forests, *heavily* disturbed: logged once or twice between 1968 and 1970; partly detrimental silvicultural treatment; very heterogeneous, with canopy partly ragged; still heavily infested with vines and climbers; termed **'regenerated'** forest sites (**D**, **E**, **F**); all sites located in the South of Deramakot, along the road heading towards Kampung Balat (Compartments 58, 69).

∗ Young logged-over forests, *heavily* disturbed: logged up to three times between 1980 and 1989; ragged canopy; forest structurally still far from recovery; heavy infestations with vines and climbers; termed **'bad'** forest sites (G, H, I); situated at the northern border of DFR (Compartments 3, 4).

3.3 Primary forest sites

There were no remaining undisturbed forests in Deramakot. Therefore, we had to select primary forest control sites from two neighbouring areas:

∗ Primary forest in Danum Valley: The Danum Valley Conservation Area (DVCA) is situated about 60 km to the Southeast of Deramakot and includes 43,800 ha of currently uninhabited forest of the *Parashorea malaanonan* Type A (Marsh & Greer, 1992). The area in and around our sites (**L**, **M**) has never been used in any commercial way and can be considered **'primary'** for the purposes of this study.

∗ Primary forest in Sepilok: The Kabili-Sepilok Forest Reserve (KSFR) is a coastal forest fragment of 4,294 ha, with more than 50% of that area consisting of mangrove forest fringing Sandakan Bay (Fig. 9). Lowland forest of the *Parashorea tomentella -Eusideroxylon zwageri* type is found between 20 and 120 m a.s.l. (Fox, 1973). In the East, North and West the Reserve is bordered by plantations. Although Sepilok has been partly logged 50 to 100 years ago, the areas in and around our sites (**K**, **N**, Sepilok **Laut**) are probably '**primary**'. Sites **K** and **N** are situated in the north of the reserve (Plantation side), Sepilok **Laut** (laut = sea, ocean (Malay)) borders the mangroves in the South (see Fig. 9).

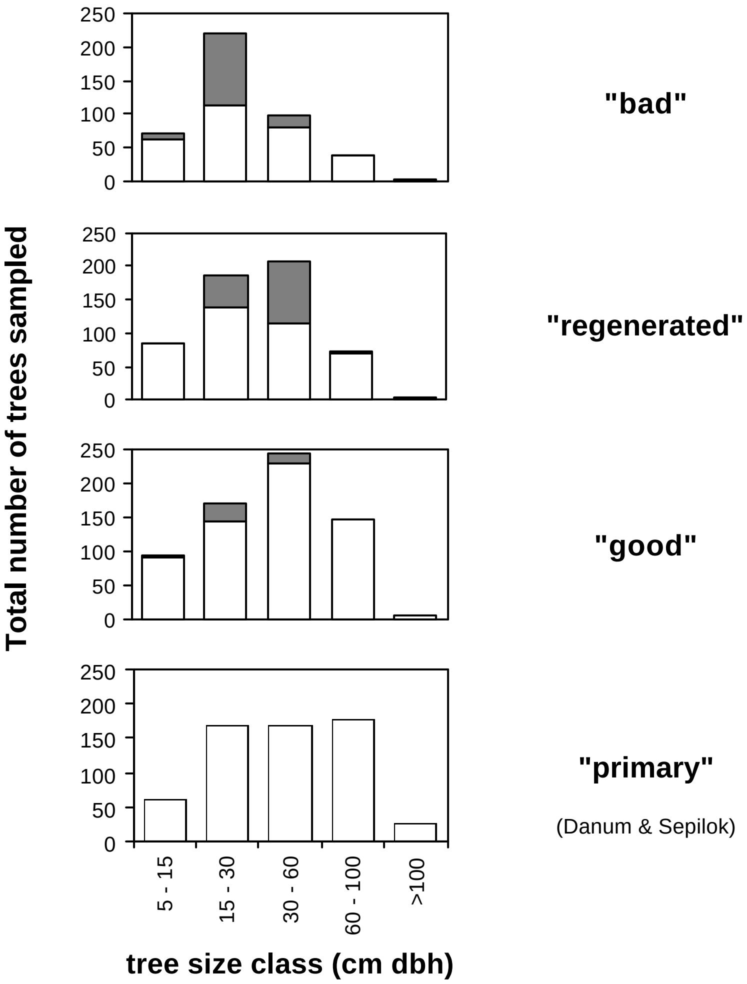


Fig. 3: Size distribution of trees and predominance of pioneer trees (genus *Macaranga*) in the different types of forests. Data from sites belonging to the same disturbance 'type' were pooled.

3.4 Analysis of stand structure

The forest types (primary and three types of logged forests) significantly differed in several parameters of stand structure: basal area, the number of large trees above 60 cm dbh, the skewness of the size distribution, and the predominance of the pioneer tree genus *Macaranga*. Fig. 3 shows a summary of the results. Generally, it is evident that basal area (not shown) and the predominance of larger trees decrease with an increasing degree of disturbance (**‘primary’** > **‘good’** > **‘regenerated’** > **‘bad’**), whereas the presence of *Macaranga* pioneer trees increases in the same direction. Thus, the analysis of structural parameters justifies the selection of sites and the preliminary grouping into forest types.

4 Stingless Bees

Stingless bees (Apidae: Meliponinae) are social bees that live in perennial colonies of a few hundred to several thousand individuals. The colonies of Southeast Asian species normally have a single queen and are usually situated in natural cavities in trees or crevices in rocks (Salmah et al., 1990; Eltz et al., submitted; Eltz, 2001; see 4.1). Stingless bees are generalist foragers that are known to exploit a wide range of floral resources in order to collect pollen (food for developing larvae) and nectar. Diet overlap between species is considered high but some floral specializations have been demonstrated (Nagamitsu et al., 1999; Eltz, 2001; Eltz et al., in press). Founding of new colonies occurs by colony fission and swarming. Stingless bees represent an important group of pollinators in all strata of forests in SE-Asia (Inoue et al., 1990; Momose & Inoue, 1994; Nagamitsu & Inoue, 1994) and are known to pollinate dipterocarp timber trees (Momose et al., 1994).

Stingless bees are promising targets for assessing logging impact due to their intricate relationship with large trees that serve as nesting resources for the colonies.

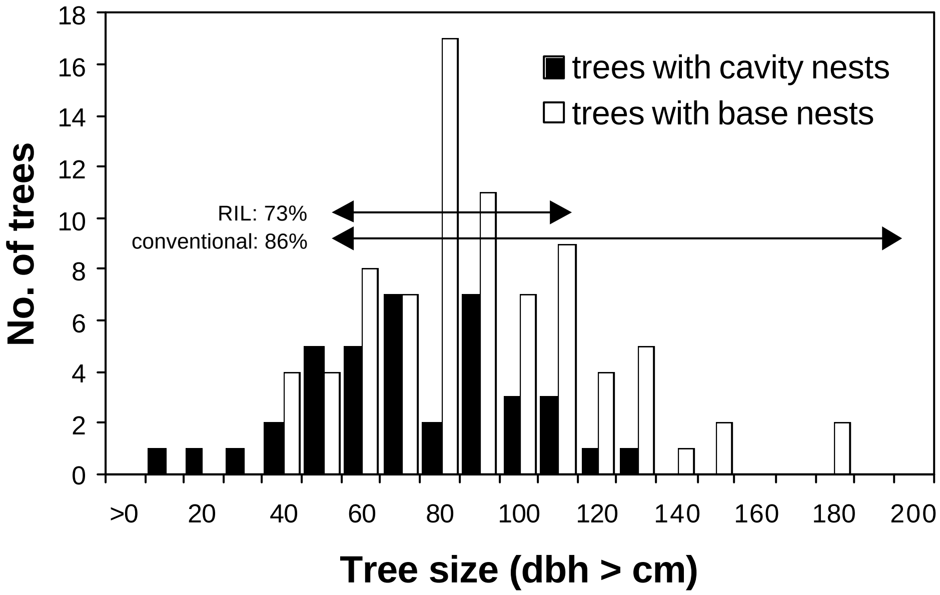


Fig. 4: Diameter distribution of stingless bee nest trees. The arrows indicate the size range targeted by harvesters under RIL and conventional guidelines. Data are shown separately for two types of tree nests.

4.1 Stingless bees and their nest trees

In order to quantify nesting requirements of Meliponinae in Sabah we searched for bee nests in primary and logged forests in Danum Valley, Sepilok and Deramakot. All nests that we found (total 276) were situated in cavities in tree trunks or in cavities in/under the bases of trees. Harvesting of the nest tree would almost certainly have caused the death of those colonies. Of special interest in respect to estimating the potential logging impact was (i) whether the nest tree was alive or dead, (ii) whether the nest tree was a commercial species, (iii) whether it was of commercial size, and (iv) whether log quality of nest trees is sufficient to warrant harvesting.

(i) 92 % of all nest trees were alive

(ii) 95 % of the identified living nest trees belonged to commercial timber species, with 44 % Dipterocarpaceae, a tree family that is *the* major target of logging operations, 26 % Lauraceae, and minor fractions of Leguminosae, Anacardiaceae, Euphorbiaceae, Olacaceae and others. 5 % of the nest trees belonged to species that are protected under RIL guidelines.

(iiI) 86 % of all living nest trees were larger than 60 cm dbh and, thus, of harvestable size under conventional guidelines. RIL guidelines do not allow harvesting of trees larger than 120 cm dbh and would reduce the percentage to 73 % (Fig. 4).

(iv) Judged by timber quality evaluation (done by the experienced Forest Ranger Mr. Hussin Achmad) stingless bee nest trees were of significantly lower timber quality in comparison to control trees (Fig. 5). However, 51 % of the nest trees would still qualify as suitable for harvesting (quality classes ‘good’ and ‘medium’).

These results suggest that stingless bees would suffer considerably from the direct effects imposed by timber extraction. The exact extent of damage to the bee community would depend on a range of factors such as the intensity of logging (number of logs extracted per area) and the guidelines followed during the operation. Crude calculations using our data on (i) through (iv) suggest that a full scale conventional operation that covers the entire area will cut 41.9 % of the nest trees and presumably kill an equal fraction of bee colonies. Due to the more restrictive rules concerning size limitations and protected species, RIL would reduce this damage to 35.5 %.

Additional mortality to bee colonies may result from felling damage imposed on non-timber trees (see 4.4.1) as well as from indirect effects of logging on the habitat, such as reduced floral resource levels following disturbance.

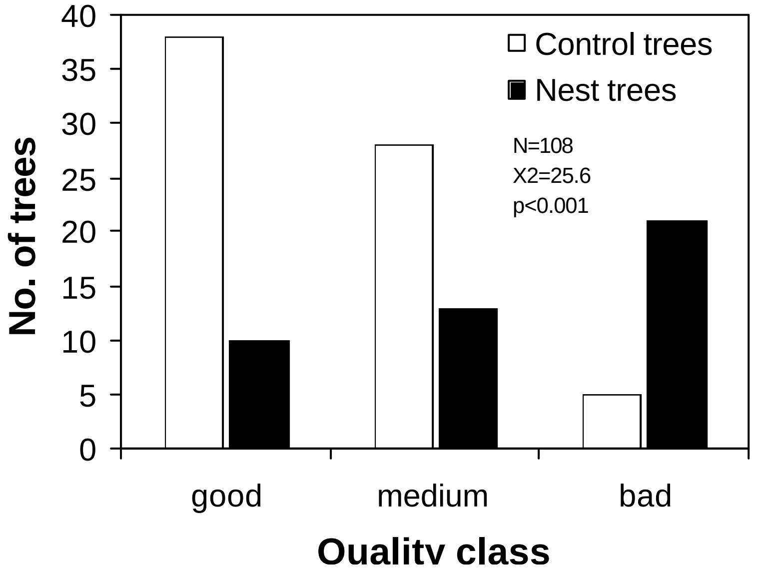


Fig. 5: Timber quality of nest and control trees as judged by evaluation of standing trees by Forest Ranger Mr. Hussin Achmad. Only trees > 60 cm dbh were included.

4.2 Diversity, community composition and nest density

The data shown in 4.1 suggest that logging severely affects bee communities. In order to test this proposition we measured stingless bee diversity and abundance in the different forest types characterised in section 3. Two methods were used for this purpose:

* <u>Spraying of honey water</u> on vegetation along the transect grids. Foraging bees attracted to the spray sites were identified and counted at standardized times after spraying (Eltz et al., 1998). The data from two consecutive years (1998 and 1999) were extremely different and have to be regarded with caution. Total di-

versity (pooled over both years) of social bees (including the species of honeybees of the genus *Apis*) significantly varied between forest sites (Fig. 6) with high numbers of species in **‘primary’** and **‘regenerated’** sites and lower numbers in **‘good’** and **‘bad’** sites. The composition of bee communities in the different types of forests did not exhibit striking differences (see summary in Tab. 1).

Tab. 1: Composition of stingless bee communities in different primary and logged forests. The data summarise the results of two years of honey baiting and includes honeybees of the genus *Apis*.

	primary (all)	primary (Danum)	primary (Sepilok)	good	regenerated	bad
A. andreniformis	x		x	x	x	x
A. koschevnikovi	x	x		x	x	x
A. cerana	x	x	x	x	x	x
T. apicalis	x	x	x	x	x	
T. binghami	x	x	x	x	x	x
T. collina	x	x	x	x	x	x
T. erythrogastra				x		
T. fimbriata	x	x	x	x	x	x
T. fuscobalteata	x	x	x	x	x	x
T. haemathoptera	x		x	x	x	x
T. itama	x	x	x	x	x	x
T. laeviceps	x	x	x	x	x	x
T. melanocephala	x	x	x	x	x	x
T. melina	x	x	x	x	x	x
T. Nr. 16	x	x	x		x	
T. rufibasalis	x	x		x	x	
T. terminata	x	x	x	x	x	x
T. thoracica	x		x	x	x	
T. ventralis	x	x	x	x	x	
No. of species	18	15	16	18	18	13

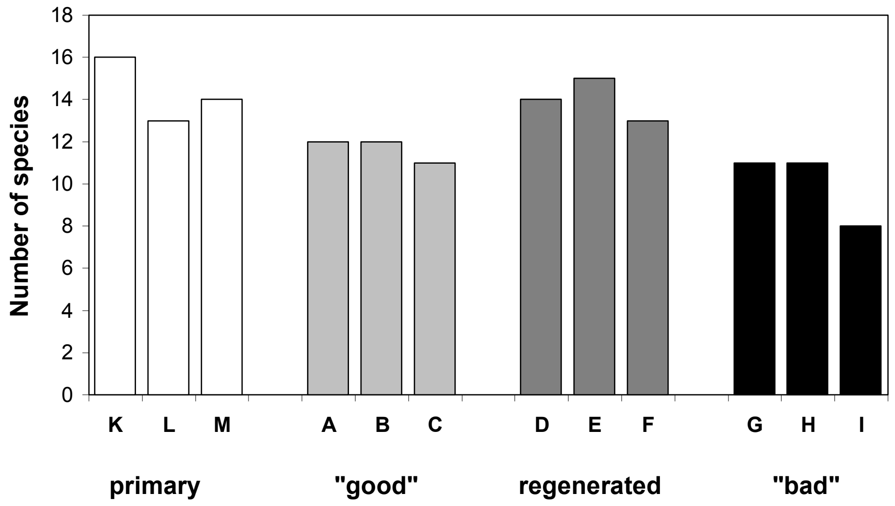


Fig. 6: Total number of species of stingless bees recorded at honey spray sites in different primary and logged forests in 1998 and 1999.

∗ <u>Standardized nest surveys</u> were run along the transect grids. All trees above 30 cm dbh situated within 20-meter corridors along the transects were checked for bee nests. Nest surveys are currently the only reliable method for assessing stingless bee abundance (nest density). Nest density varied over more than one order of magnitude among forest sites (Fig. 7) and was not closely associated with forest type. Instead, it was significantly dependent on locality, with very high nest densities in the Sepilok Forest Reserve. The 16,2 nests/ha in the Sepilok **Laut** plot are outstanding and represent the highest stingless bee nest density ever recorded for any tropical forest (see Roubik, 1989; Roubik, 1996). Within Deramakot densities were generally low, and pair-wise tests between different logged forests were hampered by low numbers of nests as well as lack of sufficient site replicates. However, there was a trend that the lowest nest densities were found in the most heavily disturbed **'bad'** forest sites.

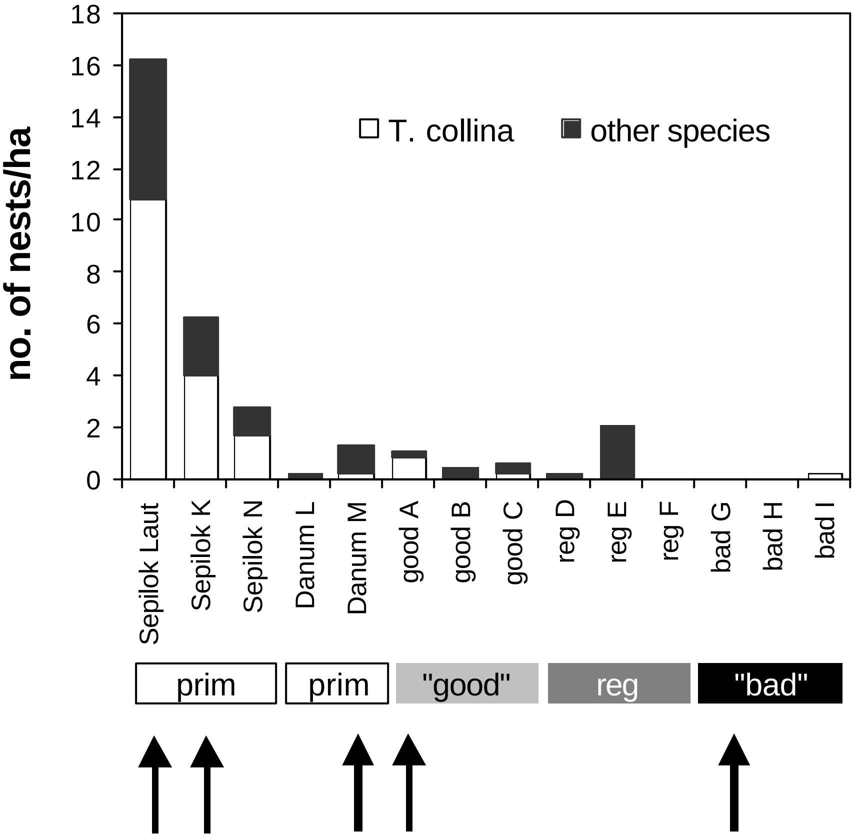


Fig. 7: Nest density of stingless bees as measured by quantitative nest surveys in primary and logged forests. Arrows indicate focal sites for the study of pollen diets.

4.3 Factors associated with stingless bee nest density

What are the causal factors that affect nest densities of stingless bees? Why are there so many nests in Sepilok (and especially in Sepilok **Laut**) in comparison to all other sites?

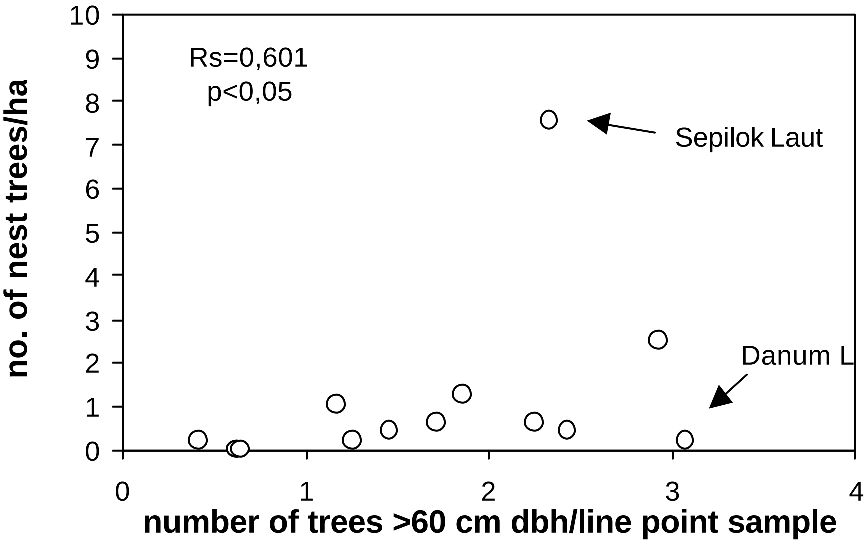


Fig. 8: Correlation between nest density and the availability of potential nesting trees (large trees above 60 cm dbh).

4.3.1 Nesting resources

There was a significant positive correlation between the number of nests and the number of potential nest trees (trees > 60 cm dbh) across the forest sites (Fig. 8). This suggests that some of the variation in nest density may be explained by (i) death of nest trees due to previous logging, and/or (ii) limitation of potential nest trees for colony founding after disturbance. The correlation, however, explains only a minor fraction of the observed variation. E.g., Danum Valley (**L**, **M**) has plenty of large trees but only very few stingless bee nests. Sepilok **Laut**, on the other hand, is by no means outstanding in terms of the number of potential nest trees.

4.3.2 Food resources

In search of alternative explanations we investigated the pollen resources used by selected colonies of one abundant species (*T. collina* Smith) in five different forest sites (Danum Valley **M**, Sepilok **K**, Sepilok **Laut**, Deramakot **'good' A**, Deramakot **'bad' H**). The selected sites covered the entire range of variation in nest density. The importance of different plant taxa as pollen sources was judged by monitoring pollen grains in colony garbage (Eltz et al., 2001) over more than one year. The study produced substantial amounts of information on pollen diets of *T. collina* and only a summary can be presented here (Fig. 10). There were striking differences in the diversity and taxon composition of pollen diets between the different sites. Most notably, the two Sepilok sites with the highest nest densities were also outstanding in respect to their pollen sources. Pollen diets of colonies in Sepilok **Laut**, located in close proximity to the mangroves of Sandakan Bay (Fig. 9), were heavily dominated by pollen of a single species, the mangrove tree *Rhizophora apiculata* (81.5 % of total pollen volume). *R. apiculata*, the dominant mangrove species in Sepilok, is mainly wind-pollinated (Tomlinson et al., 1979) and produces copious quantities of pollen. Additionally, two other pollen types were also derived from mangrove sources (Fig. 10). Pollen diets in Sepilok **K**, located in the northern part of the Reserve, were much more diverse and almost completely different in composition. In addition to a range of true forest taxa, the pollen samples contained a substantial amount of pollen (29,8 % of volume) derived from adjacent plantation areas (e.g. 15.6 % corn (*Zea mays*) and 5,7 % manioc (*Manihot esculenta*), etc.). In order to use plantation flowers the bees had to fly at least 400 to 600 meters to the nearest forest edge, but probably much further. Thus, although the taxonomic composition of pollen sources was very different between Sepilok **Laut** and Sepilok **K**, the two sites had in common that the bees heavily exploited non-forest flowers. This was in sharp contrast to colonies in the other three sites situated within much larger forest tracts. Here, the pollen diets consisted of a wide range of taxa belonging to many different plant families (e.g. Bombacaceae, Convolvulaceae, Anacardiaceae, Rutaceae, Leguminosae, Tiliaceae, Rubiaceae, Euphorbiaceae). Only very few of the pollen types could be related to non-forest sources introduced by humans. These notable exceptions were manioc pollen and pollen from the ornamental *Turnera ulmifolia* found in pollen diets of colonies in Deramakot **A**. Both plants are grown in the nearby clearing of the M-G-SFMP base camp. Generally, our pollen data suggest that food availability plays a major role in determining stingless bee population density. The presence of external (non-forest) pollen sources in diets of *T. collina* is positively correlated with *T. collina* nest density (Fig. 11). The optional (or principal, as in Sepilok **Laut**) exploitation of flowers in habitats other than the nesting habitat may substantially supplement bee diets. This will be especially beneficial in times when flowering is low within the forest, a situation that frequently arises in dipterocarp rain forests in Southeast Asia. Many mangrove trees, including *Rhizophora apiculata*, flower over substantial periods of the year (Christensen et al., 1977; Tomlinson et al., 1979; Wium-Andersen, 1981). A tree as abundant as *R. apiculata* may therefore represent a pollen source which is exceptionally reliable in space and time and which can sustain the high levels of bee population densities observed in nearby forest areas. To a lesser extent, this may also be true for the crop plants that supplemented the diets of *T. collina* nests in Sepilok **K**. The dominance of *R. apiculata* as the pollen source in Sepilok Laut was also confirmed in all other species of stingless bees investigated (*T. terminata* (76.2 %), *T. binghami* (91.3 %), *T. melanocephala* (55.9 %) and *T. melina* (53.0 %)).

Fig. 9: Map of the Kabili-Sepilok Forest Reserve with fringing mangroves. Green areas are completely forested; white surroundings are various plantations, e.g. orchards, oil palm and other cash crops.

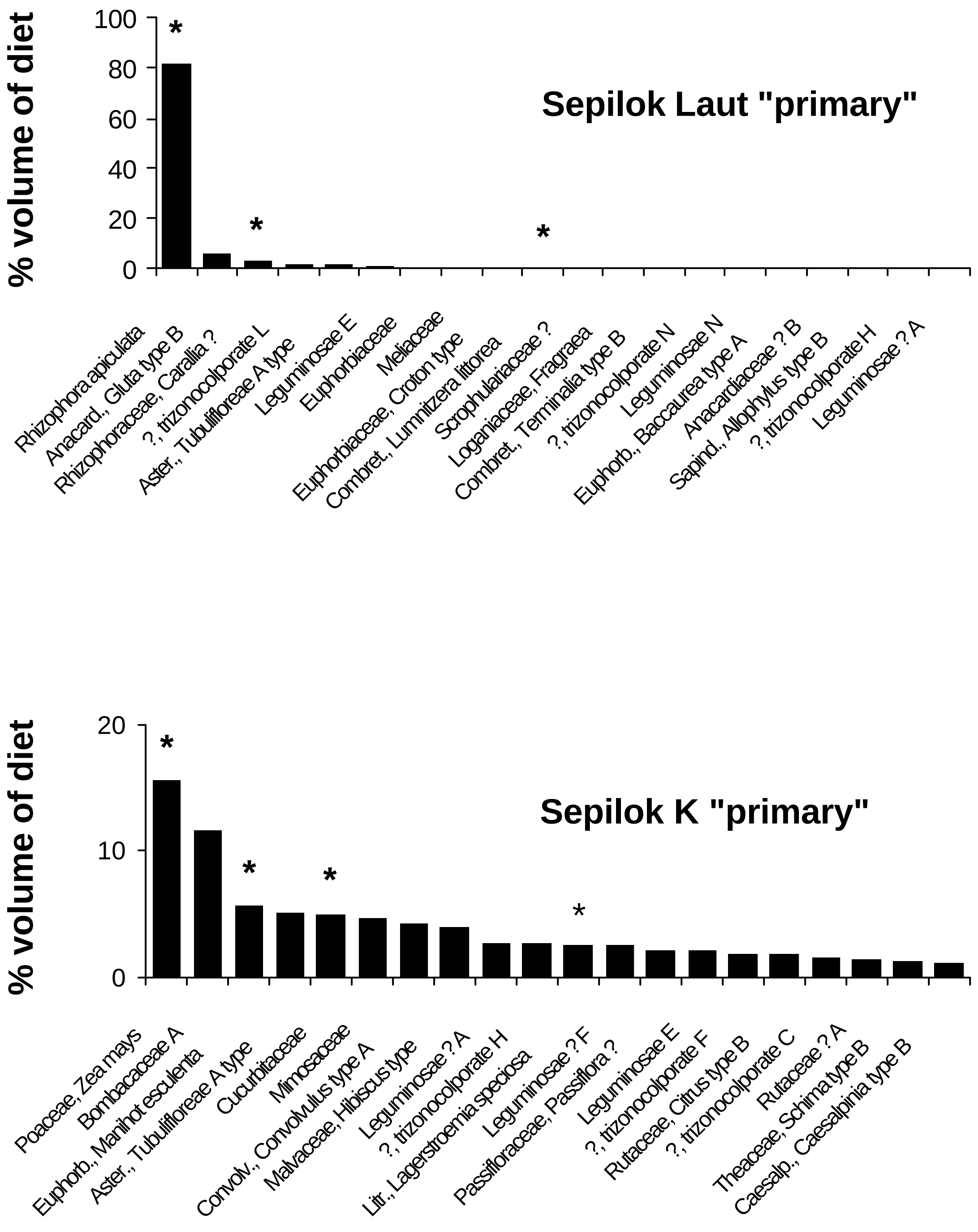
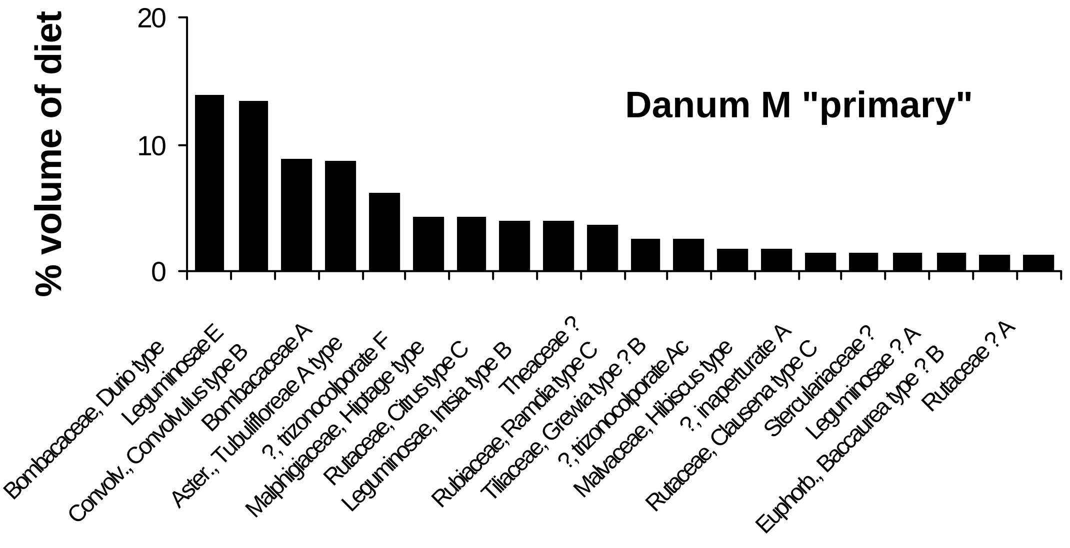
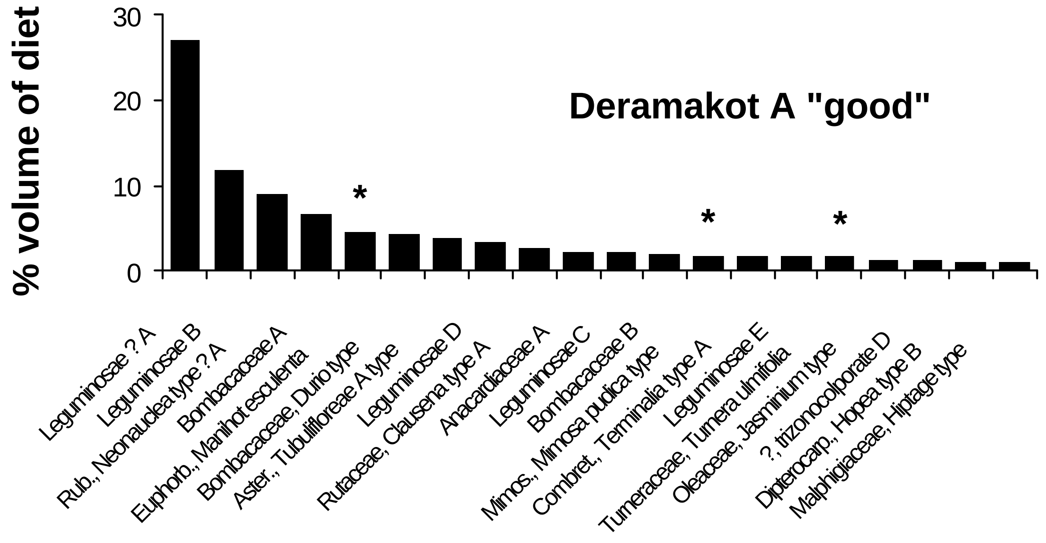
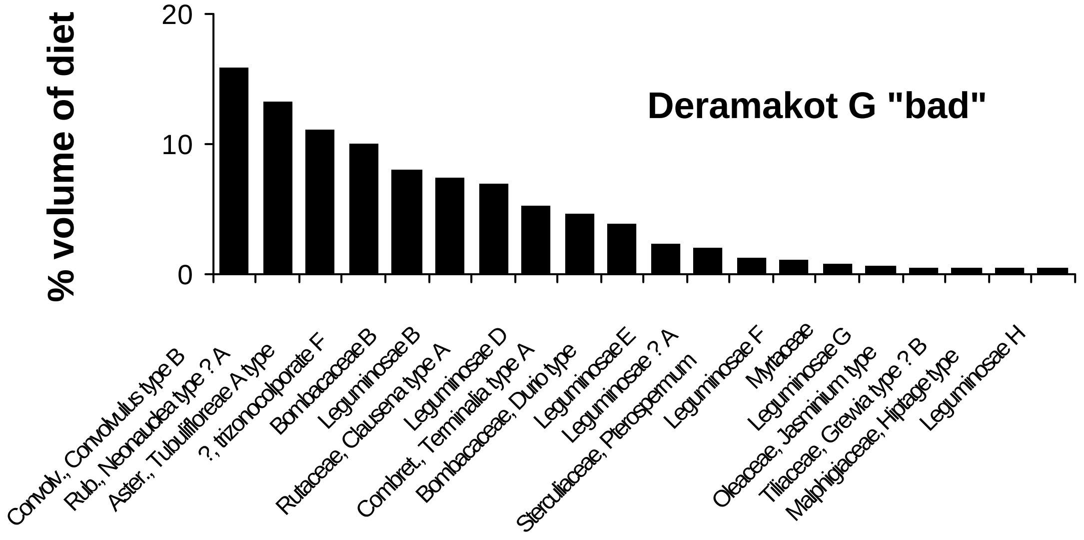


Fig. 10: Composition of pollen diets of *Trigona collina* colonies in five forest sites. Note different scales on y-axes. Only the 20 most dominant pollen sources are shown. Types with an asterisk are considered non-forest sources. Continued on the next page.


% volume of diet
20
10
0
Danum M "primary"
Bombacaceae, Durio type
Leguminosae E
Convolv., Convolvulus type B
Bombacaceae A
Aster., Tubuliflorae A type
?, trizonocolporate F
Malphigiaceae, Hiptage type
Rutaceae, Citrus type C
Leguminosae, Intsia type B
Theaceae ?
Rubiaceae, Randia type C
Tiliaceae, Grewia type ? B
?, trizonocolporate Ac
Malvaceae, Hibiscus type
?, inaperturate A
Rutaceae, Clausena type C
Sterculariaceae ?
Leguminosae ? A
Euphorb., Baccaurea type ? B
Rutaceae ? A


% volume of diet
30
20
10
0
Deramakot A "good"
*
*
*
Leguminosae ? A
Leguminosae B
Rub., Neonauclea type ? A
Bombacaceae A
Euphorb., Manihot esculenta
Bombacaceae, Durio type
Aster., Tubuliflorae A type
Leguminosae D
Rutaceae, Clausena type A
Anacardiaceae A
Leguminosae C
Bombacaceae B
Mimos., Mimosa pudica type
Combret., Terminalia type A
Leguminosae E
Turneraceae, Turnera ulmifolia
Oleaceae, Jasminium type
?, trizonocolporate D
Dipterocarp., Hopea type B
Malphigiaceae, Hiptage type


% volume of diet
20
10
0
Deramakot G "bad"
Convolv., Convolvulus type B
Rub., Neonauclea type ? A
Aster., Tubuliflorae A type
?, trizonocolporate F
Bombacaceae B
Leguminosae B
Rutaceae, Clausena type A
Leguminosae D
Combret., Terminalia type A
Bombacaceae, Durio type
Leguminosae E
Leguminosae ? A
Sterculiaceae, Pterospermum
Leguminosae F
Myrtaceae
Leguminosae G
Oleaceae, Jasminium type
Tiliaceae, Grewia type ? B
Malphigiaceae, Hiptage type
Leguminosae H

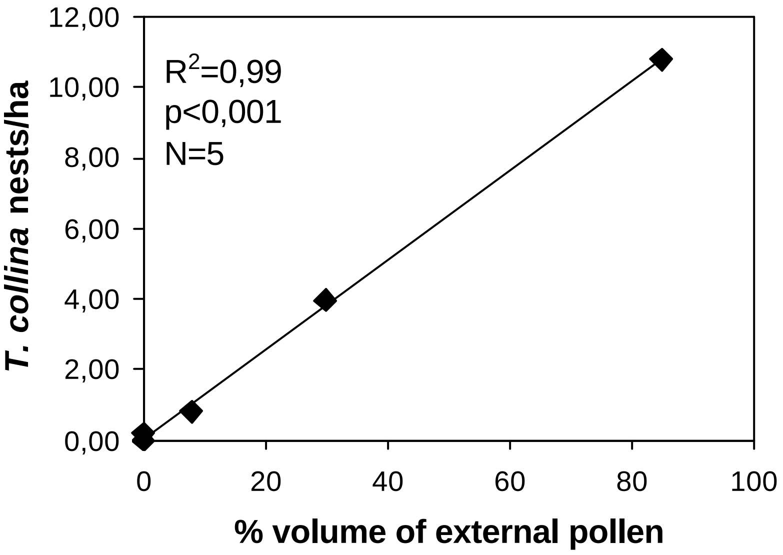


Fig. 11: Relationship between the amount of external (non-forest) pollen used by populations of *T. collina* and the nest density in the respective area.

4.4.1 Implications for forest management

According to the results presented in section 4.1, stingless bee populations are prone to be *directly* affected by logging operations. The exact amount of damage imposed will depend on the management system. Reduced Impact Logging (RIL) methods, as those applied by the G-M-SFMP are very likely to reduce stingless bee mortality in comparison to conventional systems. This is due to the following reasons:

Firstly, RIL minimises the damage on the residual stand by requiring detailed stock mapping, by reducing the length of skid trails and by reducing damage caused by felling and log transport. This is in sharp contrast to conventional methods that directly damage or kill large fractions of non-timber trees (40-70%, Marsh et al, 1996). As we have shown, stingless bees often nest in potentially fragile hollow (low quality) trees that will be particularly susceptible to the impact of heavy machinery or felling of neighbouring trees. In this context it should be noted that felling damage can be further reduced by advance vine cutting (Fox, 1968), but the positive effects on the residual tree stands (and bee populations) may be offset by negative effects on vine-associated fauna and flora (see Marsh et al., 1996).

Secondly, the RIL guidelines used in Deramakot restrict the diameter range of harvest trees to 60 to 120 cm dbh. This regulation results in the protection of bee nests situated in very large trees and will consequently reduce the impact on the bee community (as outlined in 4.1). As very large trees are also likely to serve as seed sources for the regeneration of commercial tree species, we strongly recommend the continued application of RIL size regulations.

Thirdly, RIL restricts tractor harvesting to slopes of less than 25% in order to reduce soil erosion. In Deramakot, Skyline Yarding by cable crane is partly applied in steeper areas, but normally the RIL slope restrictions will leave part of the harvested compartment untouched (see also Marsh et al., 1996). Obviously, this will benefit bee communities along with the rest of the forest biome.

Generally, concerning the direct ecological damage imposed by logging, it is feasible to state that the conservation of bees (including their important pollination services) can be incorporated into forest management systems. RIL already implements a range of features that will favour bee populations. However, in the future, conflicts between conservation and forest management will arise from economic pressures eroding those very features. The current steep decline of commercially manageable forests in Sabah has a tendency to lead to intensified timber exploitation in the remaining fragments (Putz et al., 2000). In order to meet the planned forest productivity in Sabah, Trockenbrodt et al. (in press) suggest increasing the use of timber in intact fractions of hollow trunks as well as large branches within the Annual Allowable Cut (AAC). Although this approach may be recommendable because it maximises the amount of wood extracted from hollow trees accidentally harvested, it has the dangerous implication of leading to a general intensification of forest management. Low-quality timber trees, home to stingless bees and many other endangered forest animals (Gibbons & Lindenmayer, 1996; Lindenmayer et al., 1997), may increasingly be targeted by the forest industry, thus reducing the beneficial effects of RIL practices described above. We concede that commercial and political pressures have to be considered in order to assure broad acceptance of management systems by stakeholders and decision-makers. The increased use of low-quality trees, however, is not likely to lead to the desired increase of wood production, but may substantially add to the damage imposed on biodiversity.

4.4.2 Stingless bees as indicators of forest disturbance

The results of this study suggest that stingless bees are of limited use for assessing the effects of man-made disturbances in Southeast Asian forests. Although logging certainly causes mortality to stingless bee nests (see 4.1 and 4.4.2), we were unable to demonstrate the respective changes of bee communities in differentially disturbed forests. This is mainly due to the following reasons:

1. Lack of reliable low-effort methods for measuring bee diversity and abundance. Quantitative nest surveys can provide reasonable estimates of bee nest densities, but will require increased efforts in order to produce sufficient nest numbers for statistical comparisons in areas with generally low bee density (4.2). Honey-baiting cannot be regarded as a true alternative because the results are extremely variable over time (data not shown), probably due to fluctuating levels of natural flower resources that compete with the exposed honey-baits.

2. Large variation of bee abundance based on factors that are not related to logging-induced nest mortality, e.g. the availability of floral resources. Differential availability of pollen resources may have explained up to 90% of the observed variation of bee abundance in this study. Thus, effects of disturbance were probably smudged.

Due to these complications the comparative measurement of effects of forest disturbance on stingless bee communities would demand very high efforts that are not practicable within the scope of applied EIA projects. Salmah et al. (1990) have monitored apid bees (honey bees, bumble bees and stingless bees) over seven years in a range of primary and disturbed habitats in Sumatra, including plantations and various logged-over forests. Their findings do suggest that some differences exist in bee diversity and community composition, with highest species richness and bee abundance occurring in primary forests. However, in order to use a group of organisms as indicators for habitat change in forestry, one would wish for a relatively straightforward relationship between forest structural integrity and the relative abundance of the indicator. So far, the accumulating data suggest that such a clear-cut relationship does not exist for stingless bees.

5 Leaf-litter Ants

Ants are the most important group of insects in tropical rain forests with regard to biomass, number of individuals and ecological impact (Hölldobler & Wilson 1990, Stork 1988). Usually, about 45-50% of all leaf litter macro-invertebrate individuals belong to the ants (Lavelle & Kohlmann, 1984; Adis et al., 1989; Burghouts et al., 1992; Brühl, 1996; Brühl et al., 1998). Soil and litter inhabiting ants are of great importance to nutrient cycling because of their soil turning activity (Gunadi & Verhoef 1993) and are therefore termed ecosystem engineers. As important invertebrate predators ants are remarkable for their possible structuring role in the arthropod community in tropical systems (Caroll & Janzen 1973, Hölldobler & Wilson 1990).

As most of the leaf-litter ant species nest at ground level it is conceivable that they are directly affected by logging and soil compaction caused by heavy machinery. Indirect effects may arise from changes in forest structure and microclimate. Leaf litter ants fulfil all criteria of a potential indicator group (Kremen, 1992; Hammond, 1994; Pearson, 1994): they are speciose (Brühl, 1996; Brühl et al., 1998; Brühl, 2001), they are reliably sampled in a quantitative way using the established Winkler litter sifting method (Besuchet et al., 1987; Belshaw & Bolton, 1993), and the general taxonomy is stable with available keys on the genus level (Bolton, 1994). Unlike most other invertebrates, genera are relatively easy to identify and specimens can be adequately sorted to morphospecies level with comparatively little training (Andersen, 1999).

5.1 Diversity and community composition

For sampling of the leaf litter ant community we used one transect in each of the established research sites in the different forests in Danum Valley and Deramakot (see section 3). Ten single square meters of leaf litter were sampled every 100 m, yielding 60 sqm of leaf litter per plot (see Fig. 2). The ants were then extracted from the samples using the Winkler litter sifter method (for a detailed description see Brühl, 1996; Brühl, 2001). Collecting was undertaken in 1998 in all sites and in 1999 in one site of each forest type to account for seasonal changes. 1,140 sqm of leaf litter were sampled in total during the course of the study.

5.1.1 Species diversity

184 species of litter dwelling ants in 51 genera and five subfamilies were present in the comparison of primary (Danum Valley) and logged forests (three types of logged-over forests in the Deramakot Forest Reserve). Species accumulation curves were similar in all sites and indicated a high sampling efficiency (70 to 85% of the estimated species). This is a prerequisite for a valid comparison of communities in different forests.

Species numbers in all sites and a selection of diversity indices are displayed in Tab. 2. The ant communities in **'primary'** Danum Valley were the most speciose and diverse compared to the assemblages collected in the sites in the different Deramakot forest types. Within Deramakot the sites were similar in alpha diversity and species richness.

Tab. 2: Measures of species diversity (Species number, Fishers α, Shannon-Wiener index H', Simpson index D) for the ant communities of the sites of the four different forest types.

Forests	Plots	Number of species	α	H'	D
Danum Valley	L98	105	34.99	4.22	57.44
	L99	97	33.17	4.07	45.23
	M98	100	34.07	4.02	41.57
Deramakot good	A98	88	31.30	3.96	38.34
	A99	69	26.35	3.79	35.74
	B98	70	30.51	3.85	38.19
	C98	74	28.15	3.87	38.14
Deramakot regenerated	D98	63	30.21	3.72	34.11
	E98	68	29.34	3.76	33.89
	E99	72	36.53	3.85	37.37
	F98	75	26.98	3.74	29.11
Deramakot bad	G98	66	26.89	3.71	33.62
	H98	71	27.92	3.86	42.10
	H99	69	-	3.66	30.68
	I98	79	31.31	3.91	41.32

When we compared species numbers collected at the sampling sites along the transects (6 sites per plot; 12 sampling sites in Danum Valley and 18 in every forest type of Deramakot) there was a significant difference between Danum Valley and the different forests of Deramakot, but not among the forests types in Deramakot (Fig. 12). 47 ant species were found on average in 10 sqm of leaf litter in Danum Valley, 31, 22 and 27 in the three forest types in Deramakot, with a higher variation than in the primary forest.

Another measure for the diversity of an ecosystem – although rarely analysed – is the species density distribution. We obtained distributions of ant species per square meter (Fig. 13) in the different forests by adding up one-sqm-samples with the same number of species (numbers of Danum Valley corrected by $^3/_2$ because of lower sample size).

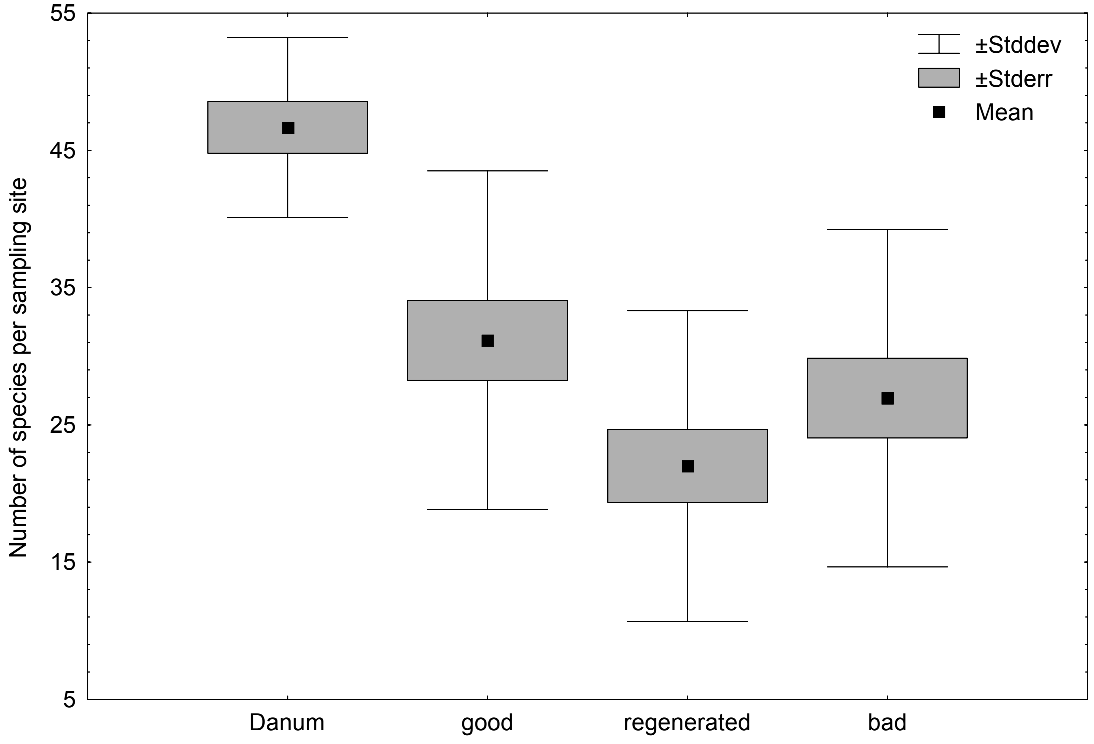


Fig. 12: Species number of leaf-litter ants per site in the four different forests (Danum Valley: 'primary', Deramakot: 'good', 'regenerated', 'bad').

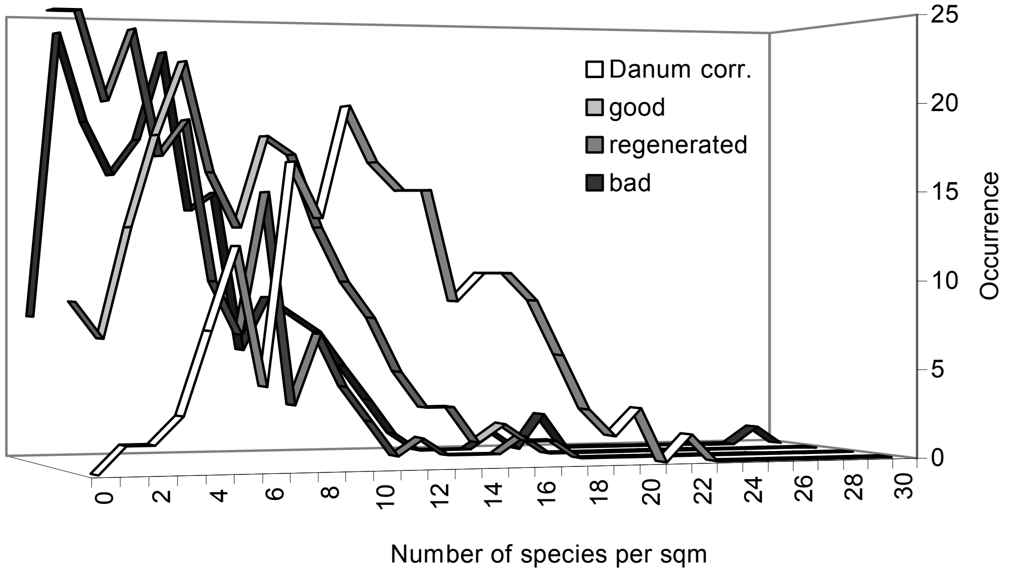


Fig. 13: Ant species per square meter (=density) distributions in the four different forests.

The shapes of the distribution curves of the four forest types were different: Whereas the curve of Danum Valley was bell shaped, we found a skewed density distribution for the Deramakot forests. In Danum eight to 15 species were present in a typical square meter. This value decreased to three to eight in the Deramakot forests, with lower values in the more disturbed forests. Another important feature of the distribution is the starting point of the curve: in the **'primary'** forest of Danum Valley there was no sample without ants. The Deramakot **'good'** and **'bad'** forests had nine and eight samples lacking ants, and in the **'regenerated'** forest there were even 25 out of 180 sqm without any ants.

5.1.2 Community composition

For an analysis of the community composition in the forests a multi-dimensional scaling analysis (MDS) was performed. In two-dimensional graphs, research sites with a similar species composition are situated close to each other. As can be seen in Fig. 14, the sites of the four different forest types formed distinct groups in the MDS plot: The Danum Valley sites are positioned on the left whereas all sites of different Deramakot forests can be found on the right along dimension 1. The species composition of the bad forest type sites was most similar to each other.

5.2 Factors associated with ant community composition

In order to evaluate whether our findings on the composition of ant communities were associated with certain changes of environmental parameters in the different forests we used two different approaches: (i) correlation of MDS results with measurements of environmental variables in the natural habitat (5.3.1), and (ii) manipulation of environmental variables in a long-term field experiment (5.3.2).

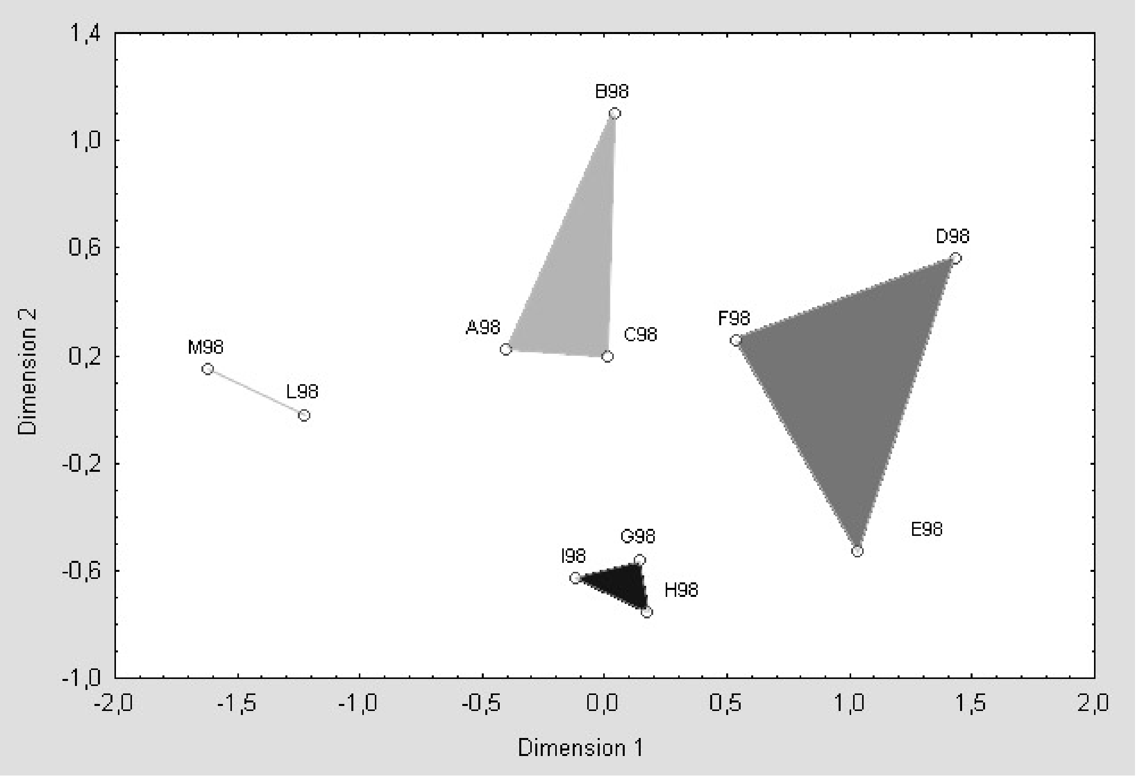


Fig. 14: MDS ordination of the ant community composition of the different forest types (two dimensions, stress: 0.064). The primary and logged forests are separated along dimension 1 (ANOVA, $p << 0.001$).

5.2.1 Correlations with temperature, humidity and stand structure

We measured air, soil and leaf-litter temperature as well as humidity in one site of each forest type. The **'bad'** forest of Deramakot was significantly drier and hotter than the other sites and had a higher mean (+ 1.5 ^{O}C in soil temperature) as well as more pronounced extremes. Our measurements were taken in a wet and cloudy period in 1999 and microclimatic differences are expected to be even more extreme in other times (e. g. ENSO of 1998).

A multiple regression analysis yielded three variables with the most explanatory power that were highly correlated with species number at the sampling sites (r mult= 0.84, $p << 0.001$): leaf litter humidity, volume and temperature.

Species numbers were higher with higher humidity and volume, and lower in cooler sites.

We cannot distinguish between direct or indirect effects of these parameters on the ant community composition. They might have a direct influence as maxima and minima in temperature and humidity can have destructive effects on the brood in ant colonies (Southerland, 1988). Changes in microclimate and forest structure could also alter food and nesting resources and affect the ants therefore indirectly (Bernstein, 1975; Covarriubas et al., 1982; Southerland, 1988; Stradling, 1978).

5.2.2 Experimental manipulation of shade and leaf-litter

We tested the effect of manipulating the light and leaf litter environment on the leaf litter ant community. The field experiment was carried out in five gaps in the primary forest of Danum Valley and consisted of four different treatments (two-way crossed design, similar to Perfecto & Vandermeer, 1996): (1) shade and leaf litter, (2) shade and no leaf litter, (3) light and leaf litter, (4) light and no leaf litter. A nursery shading (50%) which allows precipitation to reach the ground was installed tent-like over the shade treatments. Leaf litter collected from the two shading roofs was distributed evenly on the two litter treatments during the experiment. The experiment continued for two years (1998–2000) and treatments were controlled monthly.

Ground temperatures were recorded in the treatments in two gaps: Treatment (1) and (2) showed about 0.5 ^{O}C lower mean temperatures and also slightly lower minimum temperatures. The maxima recorded in treatments (3) and (4) are about 8 ^{O}C higher than recorded in the shaded treatments (1) and (2).

From January to April each year we sampled the ant community monthly using tuna baits. In total 67 species of leaf litter ants were recorded in the eight sampling events. After pooling the temporal samples of each treatment in every gap and excluding rare species and generalists we analysed the resulting communities with MDS (29 ant species included).

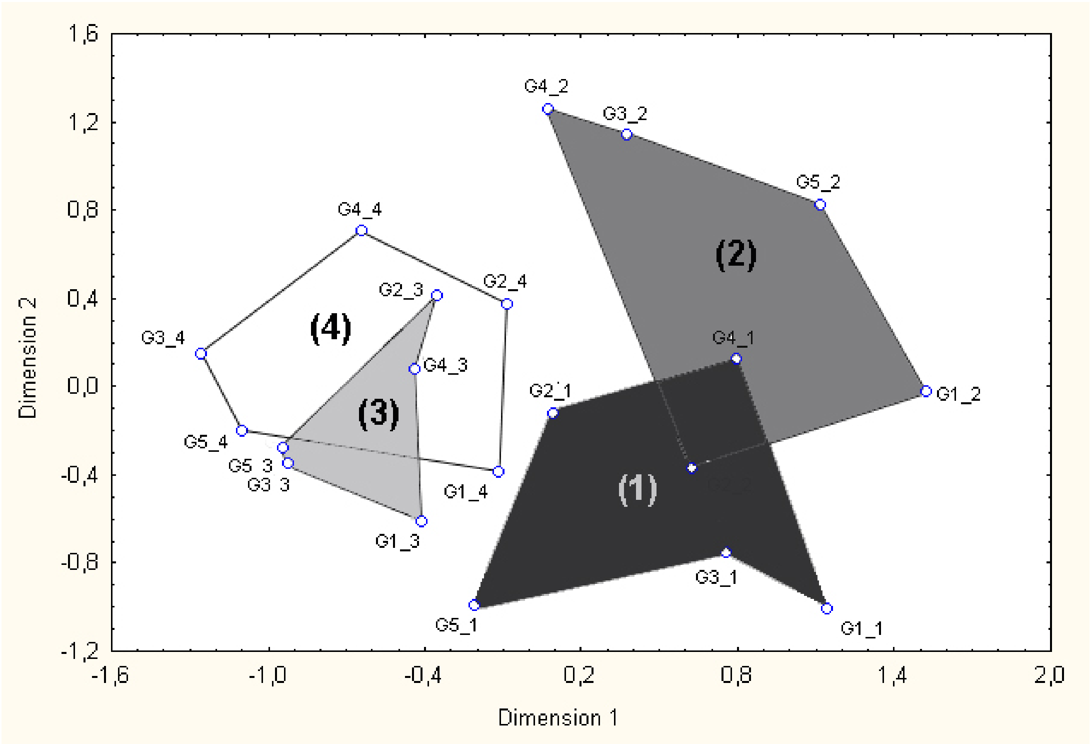


Fig. 15: MDS ordination of the ant community composition of the different treatments (two dimensions, stress=0.222). Light and shade treatments are separated along dimension 1 (ANOVA $p < 0.001$).

We observed a distinction between the light and shade treatment communities along dimension 1 (see Fig. 15). The values of dimension 1 were correlated with the mean temperature recorded in the different treatments in two gaps. The litter treatment seemed to have a smaller effect than light and separated the communities along dimension 2. This trend was more pronounced among the shade treatments.

5.3 Indicator species

For an assessment of potential indicator species of the different forest types we analysed the abundance data of all species in all forest sites of 1998.

* Typical species: Species were classified as ‘typical’ for a given type of forest when they were among the ten most abundant species in at least two of the sites of the respective type. Tab. 3 shows the presence/absence of the most abundant species in the different forest types. Five species are present in both the primary forests of Danum Valley and the various logged forests of Deramakot. These species seem to be typical for the forest leaf litter ant community in general because they occur in high abundances everywhere. If we now consider the species presented below those generalists we follow a gradient of possible habitat preferences from primary to more and more disturbed forests. On the lower end, *Lophomyrmex bedoti* is a species collected in greater abundances only in heavily disturbed forests. This ant is of intermediate abundance in primary forests. Note that all species in this table are present in all four forest types. It is only the difference in abundance that leads to the tabulated classification.

Tab. 3: Classification of ant species found among the ten most abundant species in each forest type.

Species	**Danum Valley**	**Deramakot good**	**Deramakot regenerated**	**Deramakot bad**	**Type**
Paratrechina h	x	x	x	x	Generalists
Tetramorium a	x	x	x	x	
Hypoponera e	x	x	x		
Strumigenys juliea	x	x		x	
Pachycondyla b	x		x	x	
Ponera e	**x**				Primary
Hypoponera f	**x**				
*Pheidole c**	x	x			
Pseudolasius a		x	x		⇩
Lophomyrmex bedoti		**x**	**x**	**x**	
Crematogaster a		x		x	
*Pheidole e**				**x**	
Oligomyrmex c				**x**	
Lophomyrmex longicornis				**x**	disturbed

In order to add more strength to this classification we also characterised species in the litter shade experiment (5.3.2) and compared the results with Tab. 3. Congruencies were only found in one case: *Lophomyrmex bedoti* is associated with high-temperature treatments (3) and (4) and was also collected in higher abundances in the warm and dry **'bad'** forests (see Tab. 3). The lack of a closer agreement between experiment and inventory is likely to be due to a strong influence of local species pool at Danum Valley. Many logged forest species of Tab. 3 were probably too rare in Danum in order to play a role in the experiment.

* Rare species: Another aspect of the communities are species that are only present in one forest type and completely absent in others. All these species occur in low abundances and their restricted presence in only one type could be due to chance. It is notable, however, that the number of those rare species is related to the disturbance gradient: 22 species are restricted to **'primary'** Danum Valley, 11 to the Deramakot **'good'** forest type, six to Deramakot **'regenerated'** and only three to Deramakot **'bad'**.

5.4 Impact of the Skyline Yarding System

In areas with slopes exceeding 25% the Deramakot Management System specifically requires the use of cable cranes for log extraction and transport. The 'Skyline Yarding System' necessitates the clearing of long corridors for setting up the skyline (Uebelhör & Nydegger, 1996). The method is considered to be of low impact on soils and evidently allows rapid regeneration of vegetation in the corridors. We have now studied litter ant communities in skyline corridors of various ages (1993, 1997, 2000) in order to assess the influence microhabitat change following canopy opening. Adjacent forest (**C**; close to skyline 00) as well as a nearby former log landing were included for comparison. Sampling was undertaken using tuna baits along 200 m transects. Species number was lowest in the log landing and highest in forest **C** (Tab. 4). Diversity ordering revealed the highest diversity in forest **C** followed by skyline 97, 00 and 93 and finally the log landing. Although sampling efficiency was not very high it is obvious that the ant communities in the skyline corridors had almost recovered after the logging impact and showed similar diversity values as the surrounding logged forest.

This recovery followed the recovery of woody vegetation in the corridors that, three years after logging, had already reached up to 6 m in height. Considerable amounts of leaf litter had accumulated. In contrast, the high soil compaction and/or greater openness of the log landing did not permit recolonisation by either seedlings or ants.

Tab. 4: Species number, alpha diversities and sampling efficiency of the communities along the different transects.

	Number of species	a	H´	D	Sampling efficiency
Skyline 93	9	5.97	2.03	9.55	66.1%
Skyline 97	18	20.26	2.69	19.33	44.7%
Skyline C 00	15	12.50	2.49	14.50	55.9%
Forest C	19	19.68	2.76	21.57	54.8%
Loglanding 94	4	1.79	1.02	2.50	82.6%

5.5 Oil palm plantations: worse than any form of forest management

So far we have shown that ant diversity is reduced following disturbance from timber extraction (see 5.1), but an evaluation of the ecological impact of forest management would be incomplete without considering the impact of alternative forms of land use. During the last decade, monocultures of oil palm (*Elaeis guineensis*) have replaced production forests in much of lowland Sabah (see below) and the conversion is still continuing. We therefore surveyed ant communities in a range of oil palm plantations adjacent to our research areas. Sampling of ants in oil palm plantations took place at four sites of different age (5 to 20 years) and stand structure (open ground to old undergrowth up to 3 m) along 9 transects (150 m to 1000 m) using tuna baits (Tab. 5)

Ant diversity was generally low in all oil palm plantations with less than ten species at most transects. A total of 23 species and 14 genera were found at a total of 300 tuna baits. For a comparison: the total forest leaf litter ant community included 184 species in 51 genera. 13 of the 23 species from oil palm plantations were also collected on the forest floor. Most of these species are generalists or high temperature specialists such as *Lophomyrmex bedoti* and *Monomorium floricola*. The remaining ten plantation species are open-area species and can also be found in parking lots in cities or along roads.

As the sampling effort was quite high and collecting took place at different locations the likelihood to encounter additional species in oil palm plantations is low and estimations reached on average 34 species. This suggests that only 18% of the ground ant forest community is present in oil palm plantations that are now covering over 1 Mio. ha (ca. 15%) of Sabah's land area (Forest Research Center, Sabah, pers. comm.).

Tab. 5: Number of ant species at tuna baits in the different plantation transects.

Plantation transects	Number of bait sites	Transect length (m)	Distance between bait sites (m)	Number of species
Sepilok 1	5	250	25	4
Sepilok 2	13	150	10	4
Sepilok 3	13	150	10	6
Tawi 1	13	500	50	12
Tawi 2	13	150	10	5
Tawi 3	10	1000	100	11
Deramakot 1	13	150	10	1
Deramakot 2	10	1000	100	8
Mayvin 1	10	200	20	9

5.6 Message from litter ants

Leaf litter ants do respond to disturbances from logging. The Deramakot forests comprise only 70% of the species of the primary forest in Danum Valley that are situated in the same regional species pool. Species diversity followed this trend and revealed the similarity of the three different forest types in Deramakot: forests logged 30 years ago (**‘regenerated’**) showed similar diversity values to forests that were heavily exploited until recently (**‘bad’**) or forests that were harvested with relatively little impact (**‘good’**).

These results are strengthened by findings on the ant communities of the lower vegetation (M. Gossner, Diploma thesis): the highest diversity value was found in the primary forest Danum Valley (135 species) and differences in diversity were not apparent among the three forest types of Deramakot (104-116 species). A loss of ground living ant species and a decrease in diversity along a disturbance gradient was also found in other studies, supporting the results of this study (Greenslade & Greenslade, 1977; Roth & Perfecto, 1994).

Although Deramakot Forest Reserve covers a large area with small patches of untouched forest inside which presumably operate as sources for the establishment of species in depleted areas, litter ant species number does not reach a similar value as in Danum Valley - even after 30 years recovery time. The forests of Deramakot and Danum Valley are distinguishable in their species density distribution patterns as well as in community composition. Composition is correlated with environmental parameters of the disturbance gradient (forest structure) and microclimatic parameters. The latter are also correlated with community composition in a field experiment manipulating the litter and light environment. In both cases we were unable to differentiate between direct or indirect effects on the litter ant community.

Distribution patterns of abundant species and evidence from the field experiment produced one indicator species that is collected in higher abundances in warm and dry disturbed forest conditions: *Lophomyrmex bedoti*. Other species also showed distinct distribution patterns, which is the basis for the different communities observed in the area, but are not collected in high abundances which is desirable for an indicator: 42 of the 184 species were considered rare and were collected in only one forest type. The presence of rare species is very informative for the state of the forest ecosystem but it is impossible to collect them in a rapid, cost-effective way.

Two other species might also be used as indicators: *Odontomachus rixosus* and *Pheidole aristotelis*. They are collectable at tuna baits (field study of T. Bickel), show a preference for primary forests and are found in the experiment only in shade treatments (1) and (2).

Careful forest management can at least keep the species pool of a large area of logged forest, as can be concluded form the study in the skyline corridors.

Whether these methods would have a similarly low impact in primary forests is impossible to say, as all areas in Deramakot were already logged once before skyline harvesting started.

The biggest threat for the forest ecosystem and the leaf litter ant community in Sabah at the moment is the conversion of large tracts of land into oil palm plantations. These areas lose probably more than 85% of their native leaf litter ant fauna. Conclusions drawn from other plantation studies (e. g. Belshaw & Bolton, 1994) are invalid for oil palm plantations, because of the high impact during conversion, the lack of undergrowth vegetation and the large scale of these monocultures: oil palm plantations keep presumably as much of the ant biodiversity as parking lots or scattered roadside vegetation.

The mentioned changes in logged forest and plantation litter ant communities – most conceivably the decrease in species density - will also influence other invertebrates due to the structuring role of ants: Wood boring insects for example, that are common as pests on freshly logged rainforest trees might have a heavy impact on harvested timber in areas with a disturbed ant community. Other important ecosystem functions of the group under study, such as soil perturbation and nutrient cycling might be delayed or interrupted in regions with a depleted ant fauna and generate tremendous effects on the entire ecosystem.

6 General conclusions

Although changes of diversity and/or community composition following logging were evident (ants) or at least apparent (bees) in our study, we could not demonstrate a clear relationship between the severity of the forest disturbance and the magnitude of the effect on insect communities. This lack of a clear gradient is contrary to previous expectations and does not comply with the general idea of using leaf-litter ants and stingless bees as indicators for logging-induced habitat change and/or general patterns of forest biodiversity. Furthermore, the presence or abundance of ant species in differentially logged forests was largely unpredictable, with the exception of one species that was consistently associated with heavily disturbed habitat conditions. Clear-cut relationships between certain fauna indicators and general taxon diversity or ecosystem processes seem to be generally rare (Lawton et al., 1998; Lindenmayer, 2000; van der Hoeven, 2000), probably because of the fact that different organisms are influenced in different ways by interacting sets of ecological factors. In addition to problems arising from ecological complexity, the use of ants and bees as indicators in forest management is difficult because of the substantial requirements concerning sampling effort and taxonomic expertise.

At present, we cannot make clear statements on the topic of judging the sustainability of forest management practices. The logged forests in Deramakot did retain substantial fractions of ant and bee diversity, but it is impossible to predict the effects of long-term habitat change. RIL methods as those implemented in the Deramakot management system are expected to cause less direct damage to bee populations in comparison to conventional practices and should therefore (and because of many other economic and ecological incentives) be promoted. We recommend putting particular emphasis on the retention of potential bee nesting trees as specified in section 5.

The greatest danger to biodiversity in Sabah is currently the conversion of production forests into oil palm plantations. In contrast to even heavily logged forests vast oil palm monocultures cannot provide living space and resources for the majority of forest organisms (e.g. ants, see 5.5). Instead their rapid expansion has already led to a threatening degree of isolation of the remaining forest fragments that is likely to cause additional losses in diversity. We wish to emphasise that above all considerations concerning management methods the main focus for biodiversity conservation must be the retention of large areas of non-plantation forest, notwithstanding their degree of disturbance.

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