# Impacts of conventional logging and portable sawmill logging operations on tree diversity in East New Britain, Papua New Guinea

FRIDA LINDEMALM[1] *and* HOWARD M. ROGERS[2]

School of Resource Science and Management, Southern Cross University, PO Box 157 Lismore,
New South Wales 2480, Australia.

[1] Essinge Kyrkväg 15, SE-112 65 Stockholm, Sweden
Email: frida.lindemalm@scc.se
[2] Department of Natural Resources P.O. Box 147, Barcaldine, Queensland 4725, Australia
Email: howardrogers@hotmail.com

## Summary

Portable sawmill logging in Papua New Guinea is widely advocated by ecoforestry organisations as an ecologically improved method of rainforest exploitation because of its reduced impact on biodiversity. Here the impacts of conventional high impact/intensity conventional logging, and low impact/intensity portable sawmill logging on tree diversity six years after harvest are compared based on current operational practices. Tree diversity was significantly lower after high impact/intensity logging in comparison to low impact/intensity logging and unlogged forest. Low impact logging resulted in a reduction in tree diversity of 5 % and 25 % for the Shannon Wiener index (*H*') and Simpson's index (*D*) of diversity, respectively, in comparison to unlogged forest. Conventional logging resulted in a reduction in diversity of 25 % (*H*') and 48 % (*D*) in comparison to unlogged forest. Based on comparisons with other studies high reductions in tree diversity after conventional high impact logging are attributed to initial losses from high harvesting intensities, high post harvest mortality, and low diversity of new recruitment. The implications of these results for sustainable forest management and forest conservation in Papua New Guinea are discussed.

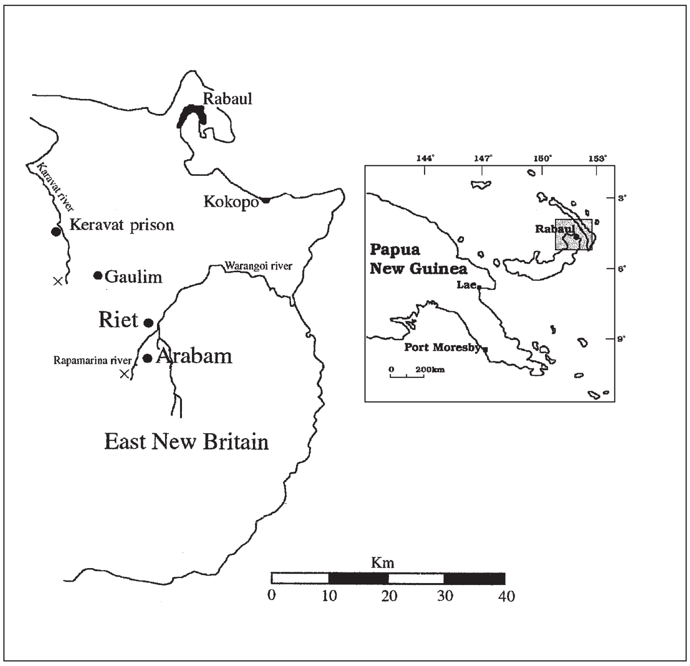
## Introduction

One of the many concerns over conventional logging of tropical rainforests is the potential loss of biodiversity from the world's most diverse ecosystems. Every year around 15 million hectares of productive closed tropical forest is logged (FAO 1997), which presents a serious threat to the future existence and functioning of tropical forests. A decline in species richness can be expected to influence major ecosystem processes such as energy flow and nutrient cycling (Orians *et al*. 1996). In particular, a decline in species richness of an ecosystem's physiognomic dominants, such as trees in forests is considered a more serious threat to ecosystem functioning than a decline in plant diversity per se (Grime 1998). Forestry would therefore present one of the greatest threats to the functioning of tropical forests. Despite this, the effects of logging on tree diversity in tropical forests are largely unknown (Cannon and Peart 1998).

Papua New Guinea has about 28 million hectares of native forests (Filer and Sekhran 1998), of which only 1.7 million hectares (6 %) is protection forest, gazetted as having high conservation and biodiversity status. Protection forest is mainly located in inaccessible areas, in steep mountainous regions (PNGFA 1996), where commercial forestry could not operate. The remainder has been logged, will be logged or is proposed to be logged once technology is available for logging on steep slopes and inundated areas (PNGFA 1996). Most logging operations in Papua New Guinea have suffered from poor performance and high level corruption (APAG 1990, Filer and Sekhran 1998), which resulted in a shift in forest policy to the principles of sustainable forestry embodied in Papua New Guinea's 1991 Forest Policy Act. However, logging of native forests in Papua New Guinea is still criticised for a host of unsustainable practices. The social and economic impacts of rainforest logging in Papua New Guinea are well documented (McCallum and Sekhran 1997, Filer and Sekhran 1998), and many have commented on the severe environmental impacts of unplanned logging (e.g. McCallum & Sekhran 1997, Lamb 1990), but there are no published studies that have quantified the impacts on tree diversity.

The New Guinea region provides habitat to some 20000 species of ferns and flowering plants, about 190 species of mammals, more than 750 species of birds, 300 reptile species and 197 species of amphibians (Miller *et al*. 1994), most of which are forest dependent. With such megadiversity and the paucity of protected areas (< 0.03 % of the land area is set aside from all extractive commercial and traditional activities in national parks, (Kula 1994), forestry potentially presents one of the most imposing threats to the maintenance of forest biodiversity. Thus it is important to understand the impacts of logging so that practices which have a reduced impact may be determined. Most studies on the impacts of logging on plant diversity present results of contrived felling regimes (e.g. Panfil and Gullison 1998). Our study has a different focus in that we consider it is critical to quantify the situation that relates to every day forestry practice that will undoubtedly occur for many years to come without major intervention. Consequently the objectives of this paper are to investigate the impacts of different types of currently operational logging regimes on tree diversity that are likely to be used for the forseeable future. Specifically the objectives of this study are (1) to quantify the impacts of logging on tree diversity under high impact/high intensity harvesting in comparison to low impact/low intensity harvesting, and (2) to consider the implications for forest conservation and sustainable forest management in Papua New Guinea.

**Figure 1.** . Map of the study sites on the Gazelle Peninsula, East New Briatin Province, Papua New Guinea. The high impact logging forest is located by the Kerevat River, near Guam, the low impact logging forest and the unlogged forest are located along the west bank of Rapamarina River between the villages Riet and Arabam. ¥ marks the location of the study sites.



## Materials and Methods

### Study area

The study was located in mixed species lowland tropical forest on the Gazelle Peninsula of East New Britain, around 40 km south from Rabaul (Figure 1). Landforms of the area consist of volcanic cones, foothills, alluvial fans and associated plains. Away from the larger rivers the soils are derived from volcanic ash, which are generally fertile, but can be deficient in phosphorus (Bleeker 1983). Annual rainfall is approximately 3000 mm with relatively little seasonality. Temperature regimes are equable with maximum temperatures around 30-32$^{o}$C, and minima around 23$^{o}$C (McAlpine *et al.* 1983). Adjacent to rivers the forest is dominated by uniform stands of *Eucalyptus deglupta* Bl. on alluvial material. Further from the rivers the forest is more diverse with abundant *Pometia pinnata* Forst.f. and *Syzygium* spp. which is typical of forest encountered in low lying foothills (Paijmans 1976).

Three study sites were chosen to represent low impact logging (LIL), high impact logging (HIL), and unlogged forest (UL). Ideally these three treatments would have been present at each site in identical forest types so that pseudoreplication in sampling design could be avoided. Unfortunately the spatially variable nature of logging in PNG precludes this situation. Landowners who have allowed conventional high impact logging to occur do not also practice low impact logging, thus it is inevitable that different types of logging are separated. To compensate for this problem, every effort was made to ensure that the sites had comparable landforms, soils and forest type based on the following procedure. The study sites were located on the most common and accessible landform which was gently sloping plains (c. 150-200 m above sea level). The plains had been derived from the fluvial distribution of volcanic material (Löffler 1974). Consistency of forest type was determined by ensuring the landforms fell within the same forest type boundary based on the forest vegetation map (Saunders 1993). Aerial photographs of the forest before logging were then checked to avoid any vegetation discontinuities. A field assessment was then made of stand composition to ensure that canopy trees present in the unlogged site were also present in the logged sites. In addition, logging records were reviewed to determine if the species removed from the harvested sites were present in the canopy of the unlogged forest. Saunders (1993) classifies the forest as medium crowned with a canopy 25-30 m in height, which is generally slightly uneven and has 60-80 % crown closure.

The LIL forest had been logged by local villagers involved in a community forestry project using three portable Lewis sawmills in 1992. Approximately 4.2 $m^2ha^{-1}$ of basal area were harvested. Portable sawmill operations involve felling selected high value trees followed by sawmill processing at or near the stump. The size of stems felled in the study area was around 80 cm dbh (diameter at breast height, 1.3 m above point of establishment). Villagers only felled suitable trees if there was another of the same species within sight of the tree chosen to harvest. Portable mills are manually transported to each log where they are reassembled. Heavy vehicles are not used as the sawn timber is manually carried out of the forest to the nearest road. The HIL forest had been logged using conventional high impact techniques in 1990/91, removing around 20 $m^2ha^{-1}$. Conventional logging of rainforests in Papua New Guinea is practiced using a selection system, where stems ≥ 50 cm dbh are harvested on a 35 yr. felling cycle. Heavy bulldozers are used for extraction with little or no planning to limit the damage to the residuals. This situation may have improved since the introduction of the PNG logging code of practice in 1996.

### Sampling procedure

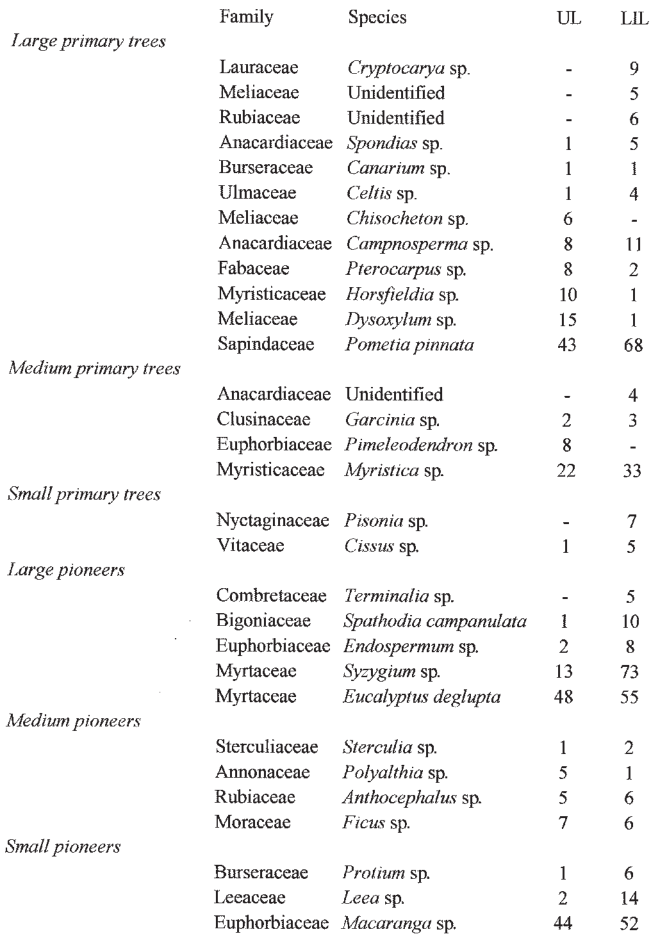
At each of the three sites six 0.2 ha transects (200 m ¥ 10 m) were located at 150 m intervals perpendicular to the major river. For each transect each tree ≥ 10 cm dbh was measured and identified to genus level. Care was taken to ensure correct identification by using a combination of techniques. If the scientific name was not known names were recorded by the traditional landowners in either Tok Pisin or their traditional language (Uramat), and later cross-checked against translation lists prepared by Pacific Heritage Foundation forestry staff. Specimens were taken of any unidentified trees for later identification by staff at the National Herbarium in Lae. Unidentified specimens were assigned a number and kept for comparison to ensure they were not recorded twice within any one transect.

### Data analysis

Shannon-Wiener (*H'*) and Simpson (*D*) indices were used as measures of diversity. These indices were chosen because they provide measures of the different components of diversity. The Shannon-Wiener index reflects the manner in which abundance is distributed amongst the different species constituting the population. The index is based on the relative frequencies of species in the population (Giramet-Carpentier *et al.* 1998), thus taking into account both species richness and evenness. The value of the index is most strongly related to species richness (Magurran 1988). Simpson's index (Simpson 1949) is a dominance measure since it is weighted towards the abundance of the most common species in a sample rather than providing a measure of species richness. It reflects the probability of any two individuals drawn at random from an infinitely large population belonging to different species. The index is less sensitive to species richness (Magurran 1988).

One-way Anova multi-variate analysis of variance was used to test for significant difference amongst the treatments. To identify which pairs of treatments were significantly different the Tukey HSD (honestly significant difference) test was used. Tukey HSD is recommended for unplanned comparisons when all possible comparisons of means between two treatments are required (Sheskin 1997).

**Table 1.** . Number of individuals for the most common species (> 4 individuals) in the three study sites.



| | Family | Species | UL | LIL |
|---|---|---|---|---|
| *Large primary trees* | | | | |
| | Lauraceae | *Cryptocarya* sp. | - | 9 |
| | Meliaceae | Unidentified | - | 5 |
| | Rubiaceae | Unidentified | - | 6 |
| | Anacardiaceae | *Spondias* sp. | 1 | 5 |
| | Burseraceae | *Canarium* sp. | 1 | 1 |
| | Ulmaceae | *Celtis* sp. | 1 | 4 |
| | Meliaceae | *Chisocheton* sp. | 6 | - |
| | Anacardiaceae | *Campnosperma* sp. | 8 | 11 |
| | Fabaceae | *Pterocarpus* sp. | 8 | 2 |
| | Myristicaceae | *Horsfieldia* sp. | 10 | 1 |
| | Meliaceae | *Dysoxylum* sp. | 15 | 1 |
| | Sapindaceae | *Pometia pinnata* | 43 | 68 |
| *Medium primary trees* | | | | |
| | Anacardiaceae | Unidentified | - | 4 |
| | Clusinaceae | *Garcinia* sp. | 2 | 3 |
| | Euphorbiaceae | *Pimeleodendron* sp. | 8 | - |
| | Myristicaceae | *Myristica* sp. | 22 | 33 |
| *Small primary trees* | | | | |
| | Nyctaginaceae | *Pisonia* sp. | - | 7 |
| | Vitaceae | *Cissus* sp. | 1 | 5 |
| *Large pioneers* | | | | |
| | Combretaceae | *Terminalia* sp. | - | 5 |
| | Bigoniaceae | *Spathodia campanulata* | 1 | 10 |
| | Euphorbiaceae | *Endospermum* sp. | 2 | 8 |
| | Myrtaceae | *Syzygium* sp. | 13 | 73 |
| | Myrtaceae | *Eucalyptus deglupta* | 48 | 55 |
| *Medium pioneers* | | | | |
| | Sterculiaceae | *Sterculia* sp. | 1 | 2 |
| | Annonaceae | *Polyalthia* sp. | 5 | 1 |
| | Rubiaceae | *Anthocephalus* sp. | 5 | 6 |
| | Moraceae | *Ficus* sp. | 7 | 6 |
| *Small pioneers* | | | | |
| | Burseraceae | *Protium* sp. | 1 | 6 |
| | Leeaceae | *Leea* sp. | 2 | 14 |
| | Euphorbiaceae | *Macaranga* sp. | 44 | 52 |

## Results

### Transect characteristics

The study sites were characterised by the large primary species *Pometia pinnata*, the medium pioneer *Myristica*, the large pioneers *Eucalyptus deglupta* and *Spathodia campanulata* Beauv., and the small pioneers *Macaranga and Syzygium* (Table 1). Pioneers were most common in HIL forest. For the HIL forest 78 % of stems were pioneers and 22 % of stems were primary species, the LIL forest had 43 % pioneers and 53 % primary stems, and the UL site had 52 % pioneers and 48 % primary stems. Mean residual basal area of the HIL transects was lowest (19.9 $m^2ha^{-1}$) compared with the LIL forest (29.6 $m^2ha^{-1}$), and the UL forest (31.5 $m^2ha^{-1}$), and showed least variation (Table 2). The LIL transects had the greatest range in basal areas (19.8-44.9 $m^2ha^{-1}$), reflecting the patchy nature of harvesting often associated with portable sawmill operations.

**Table 2.** . Number of taxa, number of individuals per taxon and basal area ($m^2ha^{-1}$) for each transect for the unlogged forest, low impact logged forest, and the high impact logged forest.

| Unlogged | Transect | No. of genera | No of individuals | Ind./genera | Basal area |
|---|---|---|---|---|---|
| | 1 | 15 | 59 | 4 | 24.2 |
| | 2 | 19 | 49 | 3 | 32.0 |
| | 3 | 22 | 41 | 2 | 23.1 |
| | 4 | 20 | 44 | 2 | 37.3 |
| | 5 | 25 | 54 | 2 | 40.7 |
| | 6 | 20 | 61 | 3 | 31.8 |
| Mean | | 20± 3 | 51± 8 | 3 | 31.5 ± 7 |
| Total | | 62 | 308 | | |
| Low impact logging | | | | | |
| | 1 | 18 | 68 | 4 | 19.8 |
| | 2 | 30 | 78 | 3 | 22.9 |
| | 3 | 29 | 75 | 3 | 24.5 |
| | 4 | 25 | 82 | 3 | 44.9 |
| | 5 | 19 | 83 | 4 | 39.2 |
| | 6 | 17 | 78 | 5 | 26.6 |
| Mean | | 23± 5 | 77± 15 | 3.5 | 29.6 ± 10 |
| Total | | 72 | 461 | | |
| High impact logging | | | | | |
| | 1 | 19 | 106 | 6 | 19.0 |
| | 2 | 11 | 72 | 6.5 | 27.9 |
| | 3 | 14 | 119 | 6.5 | 23.7 |
| | 4 | 20 | 85 | 4 | 21.8 |
| | 5 | 15 | 89 | 6 | 17.3 |
| | 6 | 15 | 82 | 5 | 9.7 |
| Mean | | 16± 5 | 92± 20 | 6 | 19.9 ± 5 |
| Total | | 41 | 553 | | |

### Genus richness and diversity

The LIL forest was the most rich with 72 taxa from 461 individuals. Sixty two taxa occurred in the unlogged forest from 308 individuals. The HIL forest had the lowest richness with 40 taxa from 553 individuals (Table 2). Although the LIL forest was the most rich it was not the most diverse. The unlogged forest had the highest mean Simpson's index of diversity and the highest mean Shannon-Wiener index of diversity. The LIL forest had the second highest mean indices and the HIL forest had the lowest (Table 3). Analysis of variance indicated significant differences ($p < 0.001$) in tree diversity for both indices amongst the sites, however Tukey HSD test indicated significant differences only between the UL forest and the HIL forest, and the LIL forest and the HIL forest. These significant differences represent 25 % and 48 % lower levels of diversity for the Shannon Wiener index and Simpson's index, respectively, for the HIL forest in compared with the UL forest, based on mean values. The LIL forest had 5 % and 25 % lower levels of diversity for $H'$ and $D$ respectively in comparison to the UL forest.

## Discussion

Analysis of tree diversity can be confounded by variation in factors such as soil, topography, and natural disturbance history, however our study sites were chosen to minimise such variation. Although it is difficult to attribute differences in diversity unequivocally to differences in logging impact in the absence of pre-logging measurement of diversity, loss of tree richness in our study was greatest under high impact logging. This finding is in contrast to Panfil and Gullison (1998) who found the rate

**Table 3.** . Index values and means for Shannon Wiener (H') index and Simpson's index (D). Different letters in parenthesis indicate Tukey-Kramer significant differences between treatments for each index. Simpsons index is expressed as the reciprocal, as is convention (Magurran 1983).

| Transect | Unlogged | | Low impact logging | | High impact logging | |
|---|---|---|---|---|---|---|
| | H' | D | H' | D | H' | D |
| 1 | 0.983 | 7.061 | 1.019 | 6.612 | 0.851 | 3.679 |
| 2 | 1.050 | 7.125 | 1.227 | 9.627 | 0.814 | 4.454 |
| 3 | 1.232 | 13.263 | 1.228 | 10.246 | 0.824 | 4.681 |
| 4 | 1.204 | 13.260 | 1.135 | 8.598 | 1.104 | 9.777 |
| 5 | 1.203 | 10.414 | 0.906 | 4.875 | 0.867 | 5.270 |
| 6 | 1.147 | 10.662 | 0.963 | 6.351 | 0.786 | 4.022 |
| Mean | 1.137 ± 0.10 **(a)** | 10.293 ± 2.76 **(a)** | 1.080 ± 0.14 **a)** | 7.718 ± 2.10 **(a)** | 0.851 ± 0.06 **(b)** | 5.314 ± 2.25 **(b)** |

of reduction in tree diversity (*H*') decreased with increased harvest intensity in tropical forest, where a maximum of six trees per hectare were harvested. However, harvest intensity in the HIL forest is estimated to be more than twice this, resulting in high levels of residual mortality, and a greater reduction in diversity when compared with lower harvesting intensities.

Other factors are also considered to contribute to the lower levels of tree diversity in the HIL forest. Although our interpretation is limited to factors having an influence over a relatively short time (5–6 yr. since logging), we suggest losses are due to selective cutting of preferred commercial species, also resulting in a depleted source of propagules for less common species, localised loss of uncommon species from damage to residuals, and a greater uniformity in environment associated with loss of canopy, favouring recruitment and dominance by pioneers, e.g. *Macaranga spp*. Conventional logging practices in Papua New Guinea often have a devastating impact on stand structure. Losses of up to 80 % of the canopy followed by the death of 30 – 70 % of the residuals in the post harvest period are not uncommon (Cameron and Vigus 1993). Studies from other tropical countries suggest most damage to residuals is caused by skidding and felling (Sist *et al.* 1998), with skidding being the primary cause of initial mortality, particularly of small trees (10-20 cm dbh) (Bertault and Sist 1996). In this study felling damage is likely to vary markedly between the HIL and LIL forest as felling damage is primarily related to the intensity of felling in tropical forests (Sist *et al.* 1998). Damage from skidding will also be much greater in the HIL forest because of mechanical skidding. Greater species loss from higher post harvest mortality of damaged stems is also likely in the HIL forest. In Papua New Guinea's lowland forests growth model data predicts an annual mortality rate of 6.3 % for damaged stems compared to 2.5 % for sound stems (Alder 1998). The same growth model predicts negative growth for at least five years after conventional logging, reflecting high stem mortality. Stem mortality after portable sawmill logging is unknown.

Differences in diversity between the HIL and the LIL forests can partly be explained by different regeneration responses to the different types of logging. More diverse recruitment may occur in the LIL site because of greater environmental heterogeneity created by smaller sized logging gaps. Although our measurements were taken only six years after logging, diameter growth rates of many Papua New Guinea tree species in excess of 20 mmyr$^{-1}$ (Alder 1998) were sufficient for new individuals to be recruited into the 10 cm dbh size class since logging. Portable sawmill operations are thought to create canopy gaps comparable to those created by small-scale windthrow and tree senescence, although there have been no studies to quantify this in Papua New Guinea. Portable sawmill logging may better reflect the frequent, spatially unpredictable small-scale disturbances that occur in many tropical forests, maintaining high species richness in this way (Phillips *et al.* 1994). However, such disturbances will only influence tree diversity between the periodic catastrophic disturbances that affect many of the lowland forests across Papua New Guinea (Johns, 1986). In the HIL forest the larger gaps created by bulldozers and skidders provide a more uniformly open environment with a limited variety of seedling establishment microsites, resulting in less diverse recruitment.

This interpretation is based on the assumption that diversity at the genus level is related to species diversity when comparing forests that are of similar original floristic composition. Thus a reduction in diversity amongst treatments reflects losses of congeneric series of species that are presumed to have similar ecological characteristics, such as the response to changes in the primary habitat variables of soil and light (Ashton 1996).

It is difficult to make comparisons of our index values, or levels of richness with other studies because of the lack of related work, and because our study is confined to diversity at the genus level. Confining our study to genus level only is reflected by low values of the Shannon-Wiener index, which is sensitive to species richness. Where taxa have been identified to species level Shannon-Wiener index values of 4 and 5 occur in other Papua New Guinea forests (Wright *et al.* 1997) in comparison to values around 1 in this study. In a 0.2 ha transect our maximum number of taxa were 30, while Wright *et al.* 1997 identified about 90 taxa to species level in 0.2 ha in a montane forest in Papua New Guinea. Similarly Simpson's index values were dissimilar to other studies. In Morobe Province Hitofumi et al. 1999 calculated values of c. 19 (1/D value) for Simpson's index in two 1 ha plots with 69 and 94 species present respectively. Our highest Simpson's index was 13 for an unlogged 0.2 ha transect with 22 taxa. Simpson's index is sensitive to dominance with higher values reflecting higher diversity and low dominance (fewer individuals per taxa), for the reciprocal index (Magurran 1983) used here.

Not surprisingly our study has shown that in the short term at least, portable sawmill logging operations maintain higher levels of tree diversity compared to conventional logging practices. Portable sawmill operations may therefore be an improved way of exploiting Papua New Guinea's rainforests for timber production when maintenance of tree diversity is an objective. Comparisons with other studies suggest this reflects the lower harvesting intensity, resulting in lower felling and skidding damage, lower post harvest stem mortality and more diverse recruitment. However, this conclusion will only be valid for operations that follow a management plan and have regular monitoring. Sustainable management of native forests for conservation objectives is not per se connected with portable sawmill logging.

Moreover a species rich forest is not necessarily a productive forest for commercial timber yield. Although a diverse forest may have conservation benefits by providing a diverse habitat for forest dependant biota, if this diversity is largely composed of non-commercial short lived pioneers its value for future timber production may be substantially reduced. The diversity (richness and abundance) of the residual commercial canopy trees, saplings, and seedlings may be the critical issue for long term economic sustainability, since these will largely determine the economic potential of future harvests

Although our results partly confirm the conservation benefits of portable sawmill forestry, their long term viability as a real alternative to conventional logging must be based on a wider discussion of sustainable forest management in Papua New Guinea. The question of sustainable forestry must be viewed at local and national levels. Portable sawmills provide community benefits in terms of employment, the production timber for local village housing, and some revenue from commercial sales where infrastructure (e.g. roads) and access to local markets exists. Portable sawmill operations are intrinsically small scale with low rates of harvest, producing modest economic returns. They do not provide the large economic returns required by the Papua New Guinea Government for national economic development, nor do they meet the economic aspirations of remote communities that have little or no infrastructure development. Exports from conventional logging provide about 10 % of PNG's export earnings (Filer and Sekhran 1998) that can not be replaced by a total shift to portable sawmill logging. Conventional logging provides vastly higher initial revenue for village communities, where previously there had been little or no substantial economic activity. However, despite this, the conventional logging industry in its present form is marred by poor performance, massive corruption, unsustainability, and often results in catastrophic social change to village life (Filer 1997, McCallum and Sekhran 1997, Filer and Sekhran 1998). This lack of good forestry practice has resulted in a temporary moratorium on new logging concessions in 2000. Although there are considerable international efforts through AusAID (Australian Aid Agency) to implement the new logging code of practice (PNGFA 1996), which will improve the likelihood of achieving good forestry practice, high level corruption and failure to comply with the new code remain an important concern. Until these problems are resolved and the Papua New Guinea Forest Authority is funded sufficiently to ensure effective monitoring, there is little long term benefit from conventional logging in its current form. Consequently portable sawmill forestry is one of the few alternatives that many communities have to derive an income from their forest resources, while facilitating community and economic development at a sustainable rate.

Unfortunately the social, ecological and long term economic benefits of portable sawmill logging are generally confined to those operations that are monitored and managed by professional foresters working for Non Governmental Organisations, which are often funded by international donors. Without this input of grant aided technical expertise portable sawmill logging will not yet provide the panacea to conventional logging that is hoped.

Although conventional logging of tropical forests is often perceived as having catastrophic impacts (Bruenig 1999), it is noteworthy that the conventionally logged forest possessed two thirds of the number of taxa present in the other sites, and is thus still an important conservation resource despite being allocated to conventional production forestry. However there is still cause for concern. Studies from lowland tropical forests in Panama have found that many tropical tree species are extraordinarily rare with restricted distributions (Hubbell & Foster 1992). If lowland tropical forests in Papua New Guinea possess the same characteristics, the extensive logging of huge concessions that have, and are still to occur presents an alarming threat to the future existence of any less common tree species with restricted distributions. If the reduction in species richness found in the conventionally logged forest is a long-term trend, Papua New Guinea's lowland forest may suffer extinction of less common tree species.

Although portable sawmill logging may provide the opportunity to minimise such species extinction, the maintenance of biodiversity is a difficult and time consuming objective to monitor for those promoting the conservation benefits of this type of forestry compared with conventional logging. In addition it may be unrealistic to aim for the greatest biodiversity in all managed forests. The practical application of the conservation of biodiversity for managed forests must be viewed on a forest landscape level rather than on the scale of individual logging operations. Village communities often own several thousand to hundreds of thousands of hectares of forest, which can include a range of quite different forest types. A land use planning approach that gazzetted community forest to different uses, and ensured that a proportion of any one forest type was reserved for minimal extractive activities only, across any one forest landscape, may be preferable to imposing difficult biodiversity objectives on small scale low intensity portable sawmill logging operations. Ultimately, if portable sawmill logging is to be a success it must focus on the long term economic benefits, which will require the promotion of adequate growth and regeneration of the commercial canopy species through good silviculture. This must be a priority irrespective of the other impacts on the forest. Without long term economic returns there is little incentive for landowners to choose portable sawmill logging over selling their logging rights to the operators of large scale high impact conventional logging operations.

## Acknowledgements

The authors wish to thank the following for their generous support and invaluable advice that enabled us to complete this study: The staff of the Pacific Heritage Foundation, the people from Riet and Arabam villages, Vudal Timbers, Göran Nilson Axberg, Sven Bråkenhielm, Neville Howcroft, Emerick Davige, Wesley Watt, Susanna Nandre, Jim Coupland, Shirley and Nowen, World Wide Fund for Nature in Sweden, and the International Unit of the Swedish University of Agricultural Sciences. Doland Nichols and Jerry Vanclay provided useful comments on an early draft of the manuscript.

## References

Alder, D 1998. Pinform: A growth model for lowland tropical forests in Papua New Guinea. ITTO Project Report PD 162/91-Papua New Guinea.

APAG 1990. The Barnett report. A summary of the commission of inquiry into aspects of the timber industry in Papua New Guinea. The Asian Pacific Action Group, Hobart.

Ashton, P. S. 1996. Niche specificity among tropical trees: A question of scales. In *Dynamics of Tropical Communities* (D. M. Newbery, H. H. T. Prins and N. D. Brown, eds). pp 491-514. Blackwell Science, Oxford.

Bertault, J. G. and Sist, P. 1996. An experimental comparison of different harvesting intensities with reduced-impact and conventional logging in East Kalimantan, Indonesia. *Forest Ecology and Management* **94**: 209-218.

Bleeker, P. 1983. Soils of Papua New Guinea. Australian National University Press, Canberra.

Bruenig, E. F. 1999 Sustainable social forestry and society: comments on tropical rain forests. *International Forestry Review* **1**: 40-42.

Cameron, A. L. and Vigus, T. R. 1993. *Regeneration and growth of the moist tropical forest in Papua New Guinea and the implications for future harvest - volume and growth study*. A series of reports prepared for the World Bank. CSIRO Division of Wildlife and Ecology, Canberra, Australia, .

Cannon, R. H., and Peart, D. H. 1998. Tree species diversity in commercially logged Bornean rainforest. *Science* **281**: 1366-138.

FAO 1997. *State of the world forests* 1997. FAO, Rome.

Filer, C. 1997. *NRI Monograph 32, The political economy of forest management in Papua New Guinea*. International Institute for Environment and Development, London.

Filer, C., and Sekhran, N. 1998. *Loggers, donors and resource owners. Policy that works for forests and people series no. 2: Papua New Guinea*. International Institute for Environment and Development, London.

Giramet-Carpentier, C., Pelissier, R., Pascal, J. P. and Francois, H. 1998. Sampling strategies for the assessment of tree species diversity. *Journal of Vegetation Science* **9**: 161-172.

Grime, J. P. 1998. Benefits of plant diversity to ecosystems: immediate, filter and founder effects. *Journal of Ecology* **86**: 902-910.

Hitofumi, A., Damas, K., Niangu, M., Nalish, S. and Kiyono, Y. 1999. Enumeration and species diversity study at Mongi-Busiga forest research plots, Fincshafen, Papua New Guinea. PNG Forest Research Institute, Lae.

Hubbell, S.P. and Foster, R.B. 1992 Short-term dynamics of a neotropical forest: why ecological research matters to tropical conservation and management. Oikos **63**: 48-61.

Johns, R. J. 1986. The instability of the tropical ecosystems in New Guinea. *Blumea* **31**: 341-371.

Kula, G.R. 1994. Managing the forests for conservation and protection. In *Proceedings of the Huon Seminar* 1994 (B. Louman ed.). pp 183-196. Papua New Guinea University of Technology, Lae.

Lamb, D. 1990. *Exploiting the tropical rainforest: an account of pulpwood logging in Papua New Guinea*. The Parthenon Publishing Group. 259 p.

Löffler, E. 1974. *Explanatory notes to the geomorphological map of Papua New Guinea*. Land Research Series No. 33, CSIRO, Melbourne.

Louman, B. 1994. Von Mantel and sustainability in PNG, a commentary. *Klinkii* **5**: 13-18.

Magurran, A. E. 1988. *Ecological diversity and its measurement*. Croom Helm, London.

McCallun, R., and Sekhran, N. 1997. *Race for the rainforest, evaluating lessons from an integrated conservation and development "experiment" in New Ireland, Papua New Guinea*. PNG Biodiversity Conservation and resource management programme. UNOPS-PNG/93/G31. Waigani, Papua New Guinea.

Mcalpine, J. R., Keig, G. and Falls, R. 1983. *Climatic tables for Papua New Guinea. Canberra.*

Mccallum, R. and Sekhran, N. 1997. *Race for the rainforest, evaluating lessons from an integrated conservation and development "experiment" in New Ireland, Papua New Guinea*. PNG Biodiversity Conservation and Resource Management Programme PO Box 165, Waigani, Papua New Guinea, Waigani.

Miller, S., Hyslop, E., Kula, G. and Burrows, I. 1994. Status of biodiversity in Papua New Guinea. In *Papua New Guinea study on biological diversity. A report to the United Nations Environment Programme* (N. Sekran and S. Miller, eds.). Department of Environment and Conservation-Conservation Resource Centre, Port Moresby.

Orians, G. H., Dirzo, R., and Cushman, J. H. 1996. Synthesis. In *Biodiversity and ecosystem processes in tropical forests* (G. H. Orians, R. Dirzo and H. Cushams, eds). pp 195-220. Springer-Verlag, Berlin.

Paijmans, K. 1976. *New Guinea Vegetation*. Australian National University Press, Canberra.

Panfil, S. N. and Gullison, R. E. 1998. Short term impacts of experimental timber harvest intensity on forest structure and composition in the Chiamanes Forest, Bolivia. *Forest Ecology and Management* **102**: 235-243.

Phillips, O. L., P., H., Gentry, A. H., Sawyer, S. A. and Vasquez, R. 1994. Dynamics and species richness of tropical rain forests. *Proceedings National Academy of Science. USA* **91**: 2805-2809.

PNGFA 1996. National forest plan for Papua New Guinea. Papua New Guinea Forest Authority, Port Moresby.

Saunders, J.C. 1993. Forest resources of Papua New Guinea: [map with explanatory notes]. Scale 1:1 000 000. PNGRIS Publication No. 2. AIDAB, Canberra.

Sheskin, D. 1997. Handbook of parametric and nonparametric statistical procedures. Boca Raton.

Sist, P.T.N., Bertault, J. G. and Dykstra, D. 1998. Harvesting intensity versus sustainability in Indonesia. Forest Ecology and Management 108: 251-260.

Simpson, E.H. 1949. Measurement of diversity. Nature 163: 688.

Upton, C. and Bass, S. 1995. The forest certification handbook. Earthscan Publications, Guildford.

Wright, D. D., Jessen, J. H., Burke, P. and de Silva Garza, H. G. 1997. Tree and Liana enumeration and diversity on a one-hectare plot in Papua New Guinea. Biotropica 29: 250-260.