



Impacts of Portable Sawmill
Logging on Stand Structure and
Regeneration in the Lowland
Forests of West New Britain, Papua
New Guinea

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Summary

Small-scale portable sawmill logging, which is a form of reduced impact logging is promoted across Papua New Guinea as a sustainable development mechanism for village based communities. It provides a technically feasible approach for landholders to manage their commercial forest resources rather than selling logging rights to international companies. However, despite over 10 years of operational practice little research has been conducted on portable sawmilling impacts or its silvicultural effectiveness.

This study investigated the impacts of well planned and controlled portable sawmill logging on stand structure and regeneration in lowland hill forest at Kilu in West New Britain. Logging impacts were compared to natural changes in unlogged forest. Gap size, diameter increment, tree health, stem mortality and regeneration were assessed over 61 months. Portable sawmill logging caused 1 – 6 % of the ground area to be heavily disturbed based on harvesting 1 – 2 trees ha⁻¹. The logging gaps promoted abundant regeneration of primary and secondary species. Early regeneration was dominated by secondary species (61 %) but after 61 months the secondary species accounted for only 9 % of the juvenile population with primary species dominating. Impacts were low compared to conventional industrial logging in PNG, but were less marked when compared to conventional logging at similar harvest intensities elsewhere. A shift towards a slightly higher harvest intensity warrants consideration to reduce the impacts per stem harvested.

Keywords: portable sawmill; reduced impact logging; regeneration; Papua New Guinea

1 Introduction

Papua New Guinea (PNG) has been subjected to large scale high impact exploitative logging practices since the early 1970's (APAG 1990; Filer 1997) reflecting poor performance, weak governance, lack of compliance with legislation, and unsustainable practices in the forestry sector, all of which continue to occur (ITTO 2007a). Poor performance in tropical forest management is not unique to PNG but is widespread amongst International Tropical Timber Organisation producer member countries, with only 3.5% of the permanent forest estates managed sustainably (ITTO 2007b). As an alternative to conventional high impact logging, village run portable sawmill logging are advocated by various Non Government Organisation's (NGOs) as a form of eco-forestry, providing a mechanism for landholder managed sustainable development based on ecologically sustainable principles. Portable sawmills are one of the few viable forms of long term economic development that village communities will consider as an alternative to selling the logging rights of their forests to international companies, and or allowing conversion of forest to oil palm plantations, which is an increasing threat where terrain permits.

Across PNG portable sawmill forestry has been promoted by various NGO's such as the Foundation for People for Community Development (FPCD) and the Village Development Trust (VDT), and international donors such as the European Union (EU), all of whom have provided technical assistance. The EU sponsored one of the foundation initiatives to establish eco-forestry in PNG under the Islands Regional Environment and Community Development Programme which later became the Eco-forestry Programme (EFP). The programme aimed for formalised sustainability under the internationally recognised Forest Stewardship Council Certification Scheme, and was initiated in West New Britain from Walindi, near Kimbe.

As part of the wider EFP a National Eco-Forestry Policy (MOF 2004) was developed to ensure Eco-Forestry is clearly defined. The June 2004 National Eco-Forestry Policy sets out the following principles:

- Sustainable yield reflecting natural variation in specific forest ecosystems;
- Preserving natural stand structures and species composition;
- Promoting natural regeneration;
- Protecting wildlife and associated habitats;
- Protecting non timber forest products (e.g. food and medicinal plants);
- Using low-impact harvesting systems; and
- Local value-added processing and manufacturing

The policy focuses on collaborative management of forests, where communities define and guarantee amongst themselves a fair sharing of the managerial functions, entitlements and responsibilities for sustainable forest management.

From an international perspective portable sawmill logging can be viewed as a form of reduced impact logging (RIL) which in PNG is typically low intensity (low volume) logging. RIL is defined as *intensively planned and carefully controlled timber harvesting conducted by trained workers in ways that minimise the deleterious impacts of logging* (Putz *et al.* 2008). RIL techniques are thought to protect forest biodiversity and critical forest functions, while maintaining a sustainable and financially viable flow of timber (Fredericksen 1998). In PNG portable sawmills are typically manually carried into the forest, or transported by small farm tractors, and assembled near to the tree to be felled. Felled trees are processed at stump, and the processed timber is then carried to the nearest vehicle access track where the timber is transported to point of sale by either tractor or occasionally water buffalo.

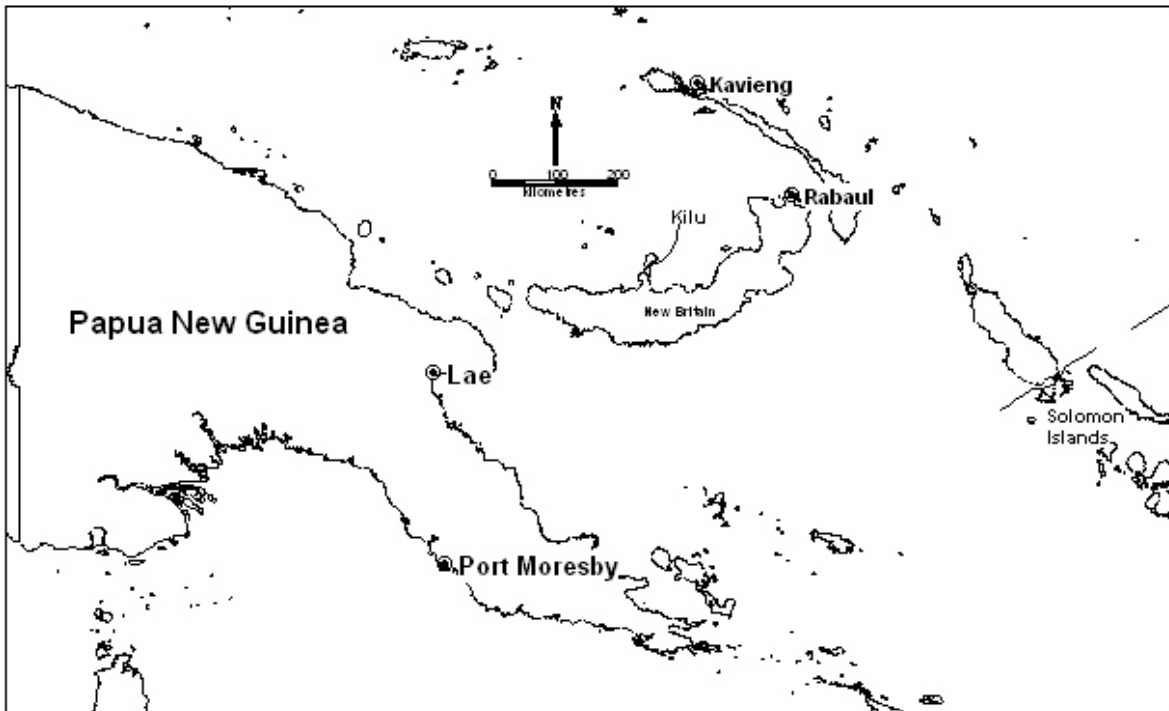
However, the use of portable sawmills *per se* does not guarantee sustainable forestry. At present there are no published studies to assess the impacts of portable sawmill operations on forests in Papua New Guinea. Studies of the impacts of portable mills are required to ensure sustainability. For example the level of damage to the residuals (non-harvested stems) from harvesting has not been quantified. High levels of damage to the residuals in conventional logging can result in residual stem mortality for up to 10 years after logging (Alder 1998). Also it is not known whether commercial species will regenerate in the post logging environment, which is an increasing concern (Park *et al.* 2005). To partly address this lack of information on sustainability, this study aims to quantify the impacts of typical portable sawmill operations practices on forest structure and regeneration.

2 Materials and methods

2.1 Site Details

The Study was located in lowland hill forest at Kilu, near Walindi, in the Talasea District of West New Britain Province (Figure 1). This site was chosen because it was a trial project initiated by the EU under the European Union Islands Region Environmental and Community Development Programme in collaboration with the customary landholders of Kilu. The site was located within a community forest management area, operating under a Timber Authority Licence issued by the PNG Forest Authority.

Figure 1 Study site location at Kilu, West New Britain



The forest is broadly classified as low altitude medium crowned forest on uplands (i.e. lowland hill forest) (Saunders, 1993). Dominant commercial timber species include *Castanospermum australe*, *Pometia pinnata* and *Calophyllum* sp. (Table 1). Landforms are classified as volcanic foot slope and volcano-alluvial fans, partly dissected or undissected, with intermediate to acid igneous rock (Loffler, 1974). The climate is typical of lowland tropical forests in PNG. The average daytime temperature ranges from 28 to 32°C, with mean night-time temperatures ranging from 25 to 27°C. Annual precipitation is about 3,810 mm, and rainfall is lowest from May to August. Humidity is variable, but usually high, averaging between 75-95% (MND 2008).

Table 1 Species dominance in the study area based on standing timber volume

| Species | % volume |
|--------------------------------|----------|
| <i>Castanospermum australe</i> | 26.3 |
| <i>Pometia pinnata</i> | 12.3 |
| <i>Calophyllum</i> sp. | 11.9 |
| <i>Endospermum</i> sp. | 7.4 |
| <i>Burckella</i> sp. | 7.2 |
| <i>Neonauclea</i> sp. | 7.0 |
| <i>Homalium</i> sp. | 4.5 |
| <i>Terminalia.complanata</i> | 3.7 |
| <i>Terminalia</i> sp. | 3.4 |
| <i>Dysoxylum</i> sp. | 3.0 |
| <i>Canarium indicum</i> | 2.4 |
| <i>Amoora</i> sp. | 2.4 |
| <i>Syzygium</i> sp. | 1.8 |
| <i>Ganophyllum</i> sp. | 1.6 |

| Species | % volume |
|----------------------------|-----------------|
| <i>Heritiera</i> sp. | 1.4 |
| <i>Chisocheton</i> sp. | 1.3 |
| <i>Dracontomelon dao</i> | 0.8 |
| <i>Mastixiodendron</i> sp. | 0.6 |
| <i>Palaquium</i> sp. | 0.4 |
| <i>Toona</i> sp. | 0.3 |
| <i>Planchonella</i> sp. | 0.3 |
| <i>Garcinia</i> sp. | 0.2 |

(EU unpublished forest inventory data)

2.2 Permanent Sample Plots

Two one hectare (100 m × 100 m) permanent sample plots were established in the study area in October 2001 to assess one logged area and one unlogged area. Each plot was located in forest that was characteristic of the area, based on a reconnaissance survey and forest inventory data supplied by the European Union. Each plot was established following an adaptation of guidelines outlined in the manual Permanent Sample Plot Standards and Procedures (FRI 1994). For each plot all trees ≥ 10 cm dbh were identified and their diameters measured. Genera were classified as primary, secondary or intermediate species with the terms primary and secondary being equivalent to the climax and pioneer species of Swaine and Whitmore (1988).

For each tree measured tree condition was also recorded. Tree condition codes were used to record visible characteristics which might affect a tree's growth (Table 2). Different codes apply to the crown, stem and base of a tree and range from broken top to butt damage. The range of codes adequately describe conditions attributable to natural phenomena and logging impacts. These codes were recorded at plot establishment and after 27 months.

Table 2 Tree condition codes

| Tree Section | Descriptor |
|-----------------------|--------------------------|
| | |
| Crown of tree: | |
| | BT = Broken top |
| | CD = Crown damage |
| | CI = Climber infestation |
| | DF = Defoliation |
| Stem of tree: | |
| | BS = Broken stem |
| | SD = Stem damage |
| | SR = Stem rot |
| | CG = Callus growth |
| | SE = Stem exudates |

| Tree Section | Descriptor |
|----------------------|---------------------------------|
| Base of tree: | |
| | BD = Butt damage |
| | BR = Butt rot |
| | FD = Fire damage |
| | DL = Double or multiple leaders |
| | LT = Leaning tree |
| | ST = Strangled tree |

2.3 Regeneration

Regeneration was monitored in logging gaps and in the unlogged 1 ha stand from October 2001 to December 2006 at 0, 17, 27 and 61 months. Three recent logging gaps were used to monitor regeneration across harvested forest for which the area of each gap was determined. For each gap the longest axis and the widest point perpendicular to this axis were measured. The intersection of the axis located the centre of the gap. The shape of the gap was determined from the distance to the edge of the gap in eight compass directions from the centre point. The area of the gap was subsequently calculated using AutoCAD. Other studies (van Gardingen *et al.* 1998) recommend using 16 compass directions which provides a more accurate measure of the gap area, however the additional site trampling that this involves would have caused excessive damage to the existing seedlings.

Within each gap seedlings and saplings were recorded within 2 m × 2 m quadrats. A seedling is defined as a plant below 1.3 m and > 0.1 m height. A sapling is defined as a plant > 1.3 m height and < 5 cm dbh. Quadrats were positioned at 5 m intervals along the main axis of each gap. For the unlogged stand quadrats were positioned at 5 m intervals along randomly located transects. For each quadrat all seedling and saplings were identified, tagged, and their height recorded. Seedling and sapling height, and new seedling recruitment were recorded at 0, 18, 27 and 61 months.

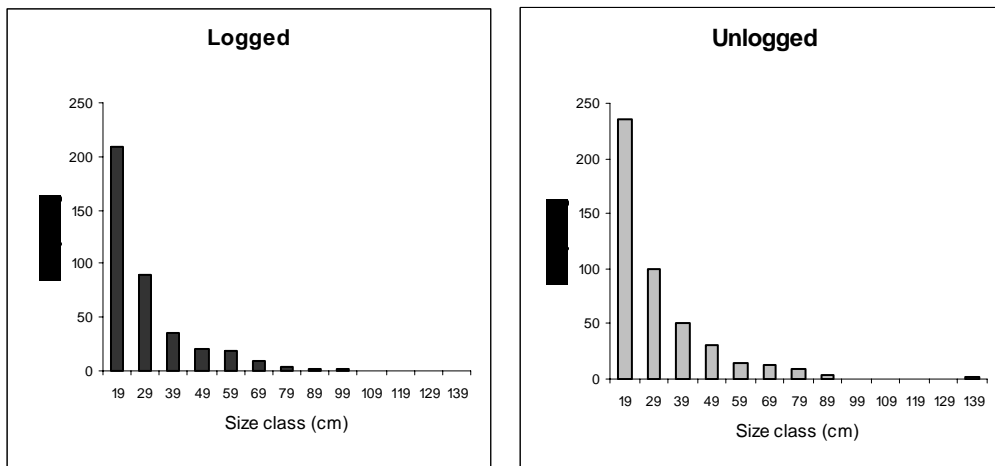
3 Results

3.1 Stand structure and floristics

From the two permanent sample plots a total of 65 genera were identified for trees ≥10 cm dbh, with a further five identified to family level only (Appendix A). Of these taxa 70% were common to both stands. The unlogged plot was dominated by *Dysoxylum* (14%), *Pometia pinnata* (13%), *Myristica* (9%), *Neonauclea* (4%), and *Octomeles sumatrana* (4%). The logged plot was dominated by *Endospermum* (11%), *Myristica* (8%), *Kleinhovia* (7%), *Castanospermum* (6%), and *Aglaia* (6%). These species are common throughout the Papua New Guinea mainland and islands, with the exception of *Castanospermum australe*.

Both plots displayed similar reverse “J” shaped size-class frequency distributions, with stems to 130 cm dbh in the unlogged plot (Figure 2). Size class frequency distributions remained relatively stable over the sample period. The logged stand had a 0.6% increase in basal area over the 27 month sample period from 25.3 to 26.8 m²ha⁻¹ while the unlogged stand’s basal area remained stable at 30.5 m²ha⁻¹.

Figure 2 Size class frequency distributions for the two stands. Size class intervals are 10 cm: 10-19, 20-29 etc



3.2 Gaps, area disturbed and tree damage

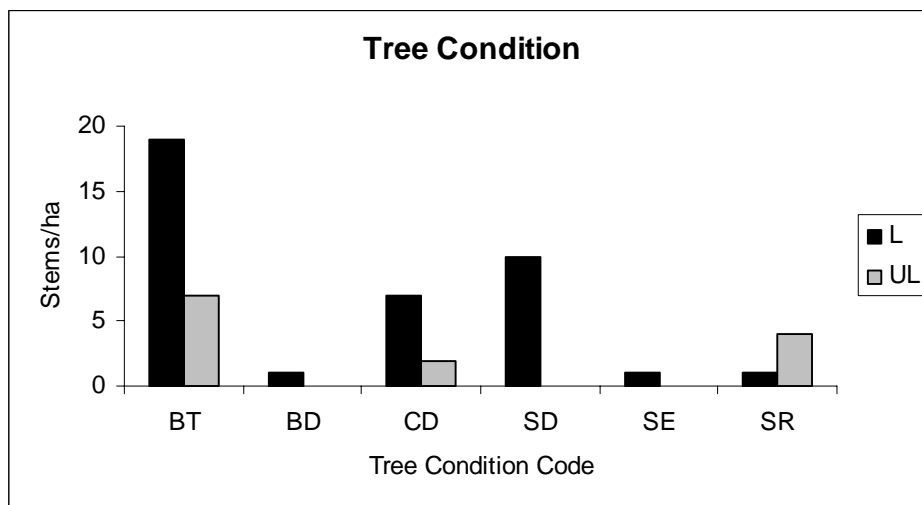
Four recent logging gaps were measured to determine their size. Each gap was created by both the felling of individual trees and by the processing of logs within the felling gap using a Lucas Mill. Setting up a Lucas Mill requires vegetation to be cleared to provide clear and safe access to operate the mill, and space to stack the timber. This results in high intensity disturbance over a small area (Figure 3). Gap sizes were: Gap 1, 631 m², Gap 2, 122 m², Gap 3, 147 m², and Gap 4, 335 m². Gap 1 was formed from the felling and processing of two stems while the others were formed from the felling and processing of a single stem. Standard EU practices harvest 1-2 trees ha⁻¹ which for these gap sizes resulted in 1-6 % of the ground area being severely damaged by felling and processing. Based on the 454 of stems \geq 10 cm dbh in the unlogged plot, a clearing of 6% would result in the loss of only 27 stems (\geq 10 cm dbh). Additional damage also occurs from the establishment of temporary access tracks for a small farm tractor to transport the sawn timber. Tracks within the logged area were estimated to cause an additional 3% clearing.

Figure 3 High intensity disturbance in a typical logging gap



Both stands had a low incidence of damaged stems (≥ 10 cm dbh) as assessed by tree condition codes, with 39 stems in the logged stand and 13 stems in the unlogged stand displaying obvious signs of damage. Broken tops, crown damage and stem damage were more abundant in the logged stand (Figure 4), and mainly occurred adjacent to the logging gap. Stem mortality was also low, with only seven stems having died in the logged stand over 27 months since logging, and two in the unlogged stand for the same period.

Figure 4 Tree condition codes for the logged (L) and unlogged stand UL after 27 months



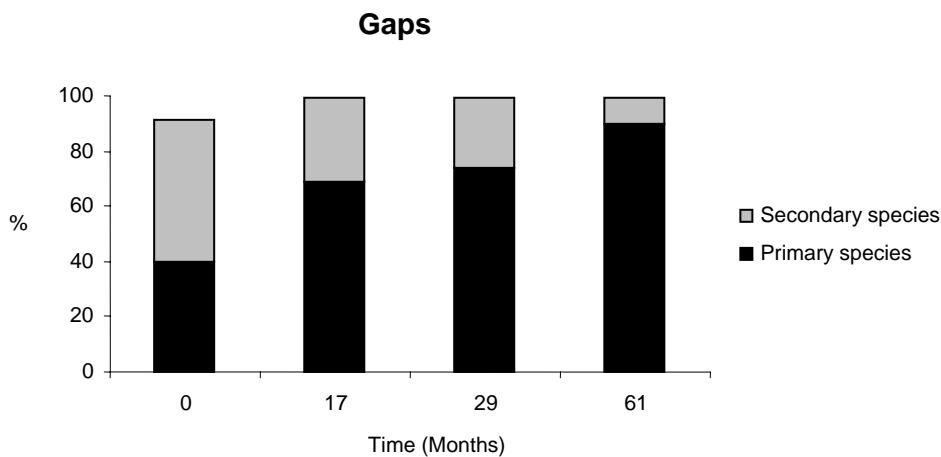
* Condition codes: BT = Broken Top, BD = Butt Damage, CD = Crown Damage, SD = Stem Damage, SE = Stem Exudate, SR = Stem Rot.

3.3 Regeneration

Regeneration was monitored in three recent logging gaps and in the closed canopy unlogged stand. The gaps differed in age by up to two months with Gap 3 being the most recent with no pre-existing regeneration at the first measurement. Regeneration contrasted between gaps and unlogged forest. For the unlogged forest juvenile populations (seedlings and saplings) were relatively stable in both the number of individuals and composition over the 61 month sample period, suggesting low levels of recruitment and mortality, and therefore a relatively stable seedling bank. Seedling/sapling composition in the unlogged stand was dominated by primary/intermediate genera, which accounted for 93 – 95 % of juveniles over the four sample periods (Figure 5). The dominant genus was *Syzygium*, with *Cinnamomum*, *Chisocheton*, *Pouteria*, *Dysoxylum* and *Microcos* also common (Table 3).

Regeneration in the gaps showed considerable fluctuations in population and composition over time. Early regeneration was characterised by a relatively rapid colonisation by both secondary and primary species. However, by 61 months the overall population of secondary species had dropped from 61% to 9%. Juvenile composition also varied amongst the gaps, with only 6 genera common to all of the three gaps at 27 months and 13 genera common to all after 61 months. The pioneer *Macaranga* was common to all. Gaps 2 and 3 were dominated by seedlings of the primary species *Canarium* and *Spondiuous* respectively, reflecting the presence of adjacent parent trees that had fruited heavily during the sample period. Regeneration levels were at their maximum at the 17 month sample. After 29 months populations of some of the most abundant species had substantially declined (e.g. *Macaranga*, *Canarium* and *Spondiuous*), but with several primary species that had established in relatively low numbers remaining stable.

Figure 5 Regeneration in the gaps (pooled data) and unlogged stand



Unlogged Stand

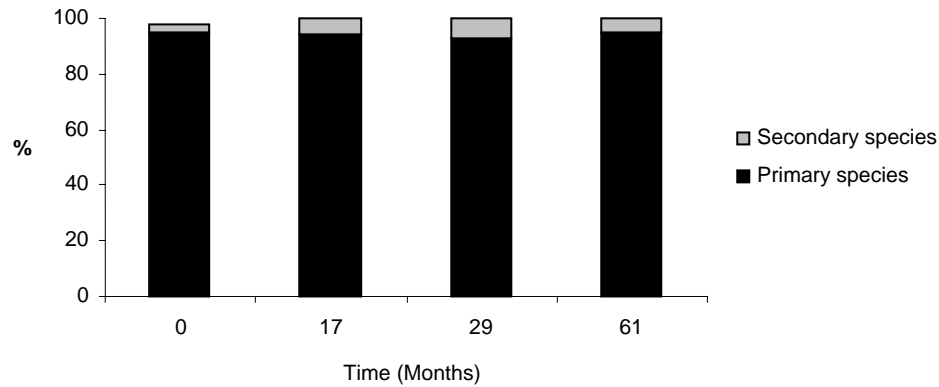


Table 3 Seedling/sapling abundance at 0, 17, 29 and 61 months

| Species | Eco | Gap 1 | | | | Gap 2 | | | | Gap 3 | | | | Unlogged | | | |
|-----------------------------|-----|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|----------|-------|-------|-------|
| | | 0 mo | 17 mo | 29 mo | 61 mo | 0 mo | 17 mo | 29 mo | 61 mo | 0 mo | 17 mo | 27 mo | 61 mo | 0 mo | 17 mo | 29 mo | 61 mo |
| <i>Achmena</i> sp. | P | 2 | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Aglaiia</i> sp. | P | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Archidendron</i> sp. | P | 1 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Barringtonia</i> sp. | I | 0 | 0 | 0 | 1 | 0 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 5 | 4 | 4 | 5 |
| <i>Buchanania</i> sp. | I | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| <i>Calophyllum</i> sp. | P | 3 | 7 | 7 | 6 | 0 | 4 | 4 | 5 | 0 | 0 | 0 | 1 | 4 | 5 | 5 | 7 |
| <i>Canarium</i> sp. | P | 1 | 4 | 3 | 5 | 1 | 20 | 8 | 9 | 0 | 1 | 1 | 1 | 2 | 1 | 2 | 1 |
| <i>Celtis</i> sp. | P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 2 | 3 |
| <i>Ceodes</i> sp. | I | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 4 |
| <i>Chisocheton</i> sp. | P | 6 | 10 | 8 | 18 | 0 | 2 | 2 | 4 | 0 | 5 | 5 | 6 | 9 | 10 | 9 | 8 |
| <i>Cinnamomum</i> sp. | P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 3 | 2 |
| <i>Cryptocarya</i> sp. | I | 0 | 2 | 1 | 7 | 0 | 1 | 0 | 4 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 2 |
| <i>Dendrocnide</i> sp. | S | 3 | 13 | 9 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Diospyros</i> sp. | P | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 3 | 4 | 6 |
| <i>Dysoxylum</i> sp. | P | 3 | 4 | 5 | 22 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 3 | 5 | 6 | 6 | 7 |
| <i>Elaeocarpus</i> sp. | I | 1 | 1 | 1 | 2 | 2 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 |
| <i>Endiandra</i> sp. | P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Endospermum</i> sp. | S | 3 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 2 | 0 | 0 | 0 | 0 |
| <i>Fagraea</i> sp. | I | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Ficus</i> sp. | S | 1 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 3 | 0 |
| <i>Garcinia</i> sp. | P | 1 | 1 | 1 | 4 | 0 | 1 | 1 | 2 | 0 | 2 | 2 | 14 | 2 | 2 | 2 | 5 |
| <i>Gmelina arborea</i> | P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| <i>Goniothallamus</i> | P | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Guoia</i> sp. | P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| <i>Harpullia</i> sp. | I | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 4 |
| <i>Homalium</i> sp. | I | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Leea</i> sp. | S | 1 | 2 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 0 | 0 | 0 | 0 |
| <i>Litsea</i> sp. | I | 0 | 1 | 0 | 2 | 1 | 4 | 1 | 5 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| <i>Macaranga</i> sp. | S | 23 | 27 | 14 | 7 | 17 | 17 | 4 | 1 | 0 | 7 | 6 | 4 | 0 | 0 | 0 | 0 |
| <i>Mangifera minor</i> | I | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| <i>Maniltoa</i> sp. | P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 2 |
| <i>Microcos grandifolia</i> | P | 0 | 2 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 2 | 2 | 0 | 6 | 7 | 7 | 4 |
| <i>Myristica</i> sp. | I | 3 | 4 | 4 | 12 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 5 | 3 | 4 | 4 | 4 |
| <i>Neolitsea</i> sp. | P | 0 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| <i>Pangium edule</i> | P | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 4 | 4 |

| Species | Eco | Gap 1 | | | | Gap 2 | | | | Gap 3 | | | | Unlogged | | | |
|---------------------------|----------|----------|----------|----------|-----------|----------|----------|----------|----------|----------|-----------|-----------|----------|-----------|-----------|-----------|-----------|
| <i>Pimeleodendron</i> | <i>P</i> | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| <i>Pisonia</i> sp. | <i>I</i> | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 5 | 6 | 6 | 6 | 5 |
| <i>Pometia pinnata</i> | <i>P</i> | 1 | 4 | 4 | 4 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 |
| <i>Pouteria</i> sp. | <i>P</i> | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 1 | 4 | 6 | 6 | 6 |
| <i>Prunus</i> sp. | <i>S</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 4 | 4 | 4 |
| <i>Semecarpus</i> sp. | <i>I</i> | 1 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 2 | 2 | 2 |
| <i>Sericolia</i> sp. | <i>I</i> | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Sloania</i> sp. | <i>P</i> | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| <i>Spondious</i> sp. | <i>P</i> | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 44 | 25 | 5 | 0 | 0 | 0 | 0 |
| <i>Sterculia</i> sp. | <i>I</i> | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| <i>Syzygium</i> sp. | <i>P</i> | 3 | 4 | 4 | 6 | 1 | 1 | 1 | 7 | 0 | 3 | 2 | 5 | 17 | 17 | 16 | 14 |
| <i>Terminalia</i> sp. | <i>P</i> | 1 | 1 | 1 | 6 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 6 | 6 | 6 | 7 |
| <i>Timonious</i> sp. | <i>S</i> | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| <i>Trema</i> sp. | <i>S</i> | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| <i>Zizyphus</i> sp. | <i>P</i> | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Unidentified | | 4 | 3 | 3 | 0 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 0 |
| Total | | 66 | 108 | 80 | 145 | 31 | 64 | 29 | 58 | 0 | 75 | 54 | 68 | 96 | 108 | 107 | 115 |
| No plots (2m × 2m) | | 10 | 10 | 10 | 10 | 3 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 10 | 10 | 10 | 10 |

Taxa with at least 5 seedlings in one sample period are marked in bold. Eco = ecological group, *P* = primary, *I* = intermediate and *S* = secondary (pioneer)

3.4 Seedling height increment

For the closed canopy unlogged forest mean annual seedling height increment was mainly $< 10 \text{ cm yr}^{-1}$ with low variability over time. In contrast, for the gaps seedlings displayed a wide variation in height growth amongst species in the elevated light environment (Table 4). The secondary species *Macaranga*, had the highest increment, reaching 11 m after 29 months. Primary species also had increased height increments in the gaps, e.g. *Calophyllum*, *Canarium*, *Pometia* and *Syzygium*. Seedlings of the common timber tree *Pometia pinnata* grew up to 66 cm yr^{-1} in gaps compared to 8 cm yr^{-1} in the unlogged forest. Height increment appeared to decline over time for many of the species in the gaps which appeared to be associated with a reduction in space and light from the new growth.

Table 4 Seedling/sapling height increment rate (cm yr^{-1}) after 12, 17, 32 and 61 months

| Genera/Time | E | Gaps | | | | | | Unlogged | | | | | |
|-------------------------|----------|------|-------|------|-------|------|-------|----------|-------|------|-------|------|-------|
| | | 17 | | 29 | | 61 | | 17 | | 29 | | 61 | |
| <i>Acmena</i> sp. | <i>p</i> | 0.05 | ± 0.1 | 0.02 | ± 0.0 | 0.12 | ± 0.0 | - | - | - | - | 0.12 | - |
| <i>Aglaiia</i> sp. | <i>P</i> | 0.25 | - | 0.00 | - | - | - | - | - | - | - | - | - |
| <i>Archidendron</i> sp. | <i>P</i> | 0.16 | - | 0.25 | - | 0.24 | - | - | - | - | - | 0.24 | - |
| <i>Barringtonia</i> sp. | <i>I</i> | - | - | 0.16 | ± 0.0 | 0.00 | - | 0.00 | ± 0.0 | 0.01 | 0.0 | 0.01 | ± 0.0 |
| <i>Buchanania</i> sp. | <i>I</i> | - | - | - | - | - | - | 0.00 | - | 0.01 | - | 0.01 | - |
| <i>Calophyllum</i> sp. | <i>P</i> | 0.12 | ± 0.1 | 0.06 | ± 0.1 | 0.09 | ± 0.1 | 0.03 | ± 0.0 | 0.05 | 0.1 | 0.06 | ± 0.0 |
| <i>Canarium</i> sp. | <i>P</i> | 0.65 | ± 0.8 | 0.06 | ± 0.1 | 0.03 | ± 0.0 | 0.00 | ± 0.0 | 0.02 | 0.0 | 0.03 | - |
| <i>Celtis</i> sp. | <i>P</i> | - | - | - | - | - | - | - | - | 0.03 | 0.0 | 0.03 | - |
| <i>Ceodes</i> sp. | <i>I</i> | - | - | 0.14 | ± 0.1 | 0.20 | ± 0.0 | - | - | - | - | 0.20 | - |
| <i>Chisocheton</i> sp. | <i>P</i> | 0.45 | ± 0.5 | 0.27 | ± 0.3 | 0.19 | ± 0.1 | 0.01 | ± 0.0 | 0.04 | 0.1 | 0.12 | ± 0.0 |
| <i>Cinnamomum</i> sp. | <i>P</i> | - | - | - | - | - | - | 0.04 | ± 0.0 | 0.08 | ± 0.1 | 0.05 | ± 0.0 |
| <i>Cryptocarya</i> sp. | <i>I</i> | - | - | 0.03 | - | - | - | 0.05 | - | 0.16 | - | 0.02 | - |
| <i>Dendrocnide</i> sp. | <i>S</i> | 1.07 | ± 0.4 | 0.33 | ± 0.3 | 0.38 | ± 0.2 | - | - | - | - | 0.38 | - |

| | | Gaps | | | | | | Unlogged | | | | | |
|---------------------------|----------|------|------|------|------|------|------|----------|------|------|------|------|------|
| | | | | | | | | | ± | | ± | | ± |
| <i>Diospyros</i> sp. | <i>P</i> | - | - | - | - | - | - | 0.02 | ±0.0 | 0.06 | ±0.0 | 0.01 | ±0.0 |
| <i>Dysoxylum</i> sp. | <i>P</i> | 0.20 | ±0.1 | 0.21 | ±0.3 | 0.05 | ±0.0 | 0.01 | ±0.0 | 0.04 | ±0.0 | 0.04 | ±0.0 |
| <i>Elaeocarpus</i> sp. | <i>I</i> | 0.40 | ±0.6 | 0.08 | ±0.1 | 0.41 | - | - | - | 0.00 | ±0.0 | 0.41 | - |
| <i>Endospermum</i> sp. | <i>S</i> | 0.10 | ±0.1 | 0.16 | ±0.1 | 0.12 | ±0.1 | - | - | - | - | 0.12 | - |
| <i>Ficus</i> sp. | <i>S</i> | 0.28 | - | 0.05 | ±0.0 | 0.06 | - | 0.00 | - | 0.02 | ±0.0 | 0.06 | - |
| <i>Garcinia</i> sp. | <i>P</i> | 0.00 | - | 0.26 | ±0.1 | 0.21 | ±0.1 | 0.00 | ±0.0 | 0.03 | ±0.0 | 0.13 | ±0.0 |
| <i>Goniothallamus</i> sp. | <i>P</i> | 0.04 | - | - | - | - | - | - | - | - | - | - | - |
| <i>Harpullia</i> sp. | <i>I</i> | 0.00 | - | 0.32 | - | 0.00 | - | 0.01 | ±0.0 | 0.01 | ±0.0 | 0.01 | - |
| <i>Leea</i> sp. | <i>S</i> | 0.00 | - | 0.41 | ±0.4 | 0.53 | ±0.1 | - | - | - | - | 0.53 | - |
| <i>Litsea</i> sp. | <i>I</i> | 0.11 | - | 0.29 | ±0.2 | 0.14 | - | 0.00 | - | 0.02 | - | 0.08 | - |
| <i>Macaranga</i> sp. | <i>S</i> | 2.04 | ±1.1 | 2.19 | ±1.4 | 0.63 | ±0.5 | - | - | - | - | 0.63 | - |
| <i>Maniltoa</i> sp. | <i>P</i> | - | - | - | - | - | - | 0.00 | ±0.0 | 0.01 | ±0.0 | 0.03 | ±0.0 |
| <i>Microcos</i> sp. | <i>P</i> | - | - | 0.14 | ±0.2 | - | - | 0.01 | ±0.0 | 0.17 | ±0.3 | 0.30 | ±0.4 |
| <i>Myristica</i> sp. | <i>I</i> | 0.18 | ±0.1 | 0.06 | ±0.1 | 0.05 | ±0.0 | 0.06 | ±0.1 | 0.01 | ±0.0 | 0.04 | ±0.0 |
| <i>Neolitsea</i> sp. | <i>P</i> | - | - | 0.06 | - | - | - | - | - | 0.03 | - | - | - |
| <i>Pangium</i> sp. | <i>P</i> | - | - | - | - | - | - | 0.02 | ±0.0 | 0.02 | ±0.0 | 0.05 | ±0.1 |
| <i>Pimelodendron</i> sp. | <i>P</i> | 0.26 | - | 0.00 | - | 0.11 | - | 0.00 | - | 0.07 | - | 0.11 | - |
| <i>Pisonia</i> sp. | <i>I</i> | - | - | - | - | - | - | 0.02 | ±0.0 | 0.06 | ±0.1 | 0.02 | ±0.0 |
| <i>Pometia</i> sp. | <i>P</i> | 0.36 | ±0.4 | 0.66 | ±0.9 | 0.09 | ±0.1 | 0.21 | - | 0.03 | - | 0.08 | - |
| <i>Pouteria</i> sp. | <i>P</i> | - | - | - | - | - | - | 0.06 | ±0.1 | 0.08 | ±0.1 | 0.06 | ±0.1 |
| <i>Prunus</i> sp. | <i>S</i> | - | - | - | - | - | - | 0.10 | ±0.1 | 0.09 | ±0.1 | 0.02 | ±0.0 |
| <i>Semecarpus</i> sp. | <i>I</i> | 1.50 | - | 0.69 | ±0.3 | 0.24 | ±0.0 | 0.05 | - | 0.14 | ±0.2 | 0.14 | ±0.0 |
| <i>Sericolia</i> sp. | <i>I</i> | 0.28 | - | - | - | - | - | - | - | - | - | - | - |
| <i>Spondious</i> sp. | <i>P</i> | - | - | 0.26 | ±0.4 | 0.11 | ±0.0 | - | - | - | - | 0.11 | - |
| <i>Syzygium</i> sp. | <i>P</i> | 0.29 | ±0.4 | 0.07 | ±0.1 | 0.03 | ±0.0 | 0.01 | ±0.0 | 0.05 | ±0.1 | 0.03 | ±0.0 |
| <i>Terminalia</i> sp. | <i>P</i> | 0.04 | - | 0.22 | - | 0.01 | - | 0.03 | ±0.0 | 0.04 | ±0.0 | 0.15 | ±0.4 |

E = Ecological group: *I* = intermediate, *P* = Primary and *S* = Secondary

3.5 Diameter increment

Growth increment from the two stands was combined to provide overall growth rates (Table 5). Diameter increment ranged from 0.1 cm yr⁻¹ for slow growing primary species to 1.8 cm yr⁻¹ for the pioneer *Macaranga*. Common primary timber species grew at rates from 0.3 - 0.8 cm yr⁻¹ which implies commercial species take between 125 and 333 years to reach the minimum harvestable size¹ of 100 cm dbh.

¹ Under EU ecoforestry principles the minimum harvestable diameter is set at 100 cm. The legal harvestable size for commercial operations in PNG is 50 cm dbh.

Table 5 Mean annual diameter increment (cm) for pooled growth data

| Genus | Commercial timber group* | Mean | Standard deviation | Sample size |
|------------------------|--------------------------|------|--------------------|-------------|
| <i>Macaranga</i> | 4 | 1.8 | 1.9 | 8 |
| <i>Sterculia</i> | 4 | 1.6 | 2.6 | 5 |
| <i>Homalium</i> | 1 | 1.3 | 2.0 | 4 |
| <i>Endospermum</i> | 2 | 1.0 | 1.5 | 13 |
| <i>Neonauclea</i> | 4 | 0.9 | 1.6 | 7 |
| <i>Castanospermum</i> | 1 | 0.8 | 0.8 | 8 |
| <i>Cryptocarya</i> | 3 | 0.6 | 0.7 | 18 |
| <i>Ficus</i> | 4 | 0.6 | 1.5 | 9 |
| <i>Goniothalamus</i> | 4 | 0.6 | 0.5 | 18 |
| <i>Chisocheton</i> | 4 | 0.5 | 0.5 | 40 |
| <i>Calophyllum</i> | 1 | 0.5 | 0.5 | 11 |
| <i>Aglaiia</i> | 2 | 0.5 | 0.3 | 16 |
| <i>Pometia pinnata</i> | 1 | 0.5 | 0.5 | 26 |
| <i>Dracontomelon</i> | 1 | 0.5 | 0.4 | 6 |
| <i>Vitex</i> | 2 | 0.4 | 0.4 | 4 |
| <i>Dysoxylum</i> | 3 | 0.4 | 0.3 | 102 |
| <i>Microcos</i> | 4 | 0.4 | 0.4 | 29 |
| <i>Myristica</i> | 4 | 0.4 | 0.6 | 172 |
| <i>Kleinhovia</i> | 4 | 0.4 | 0.6 | 9 |
| <i>Terminalia</i> | 1 | 0.4 | 0.2 | 7 |
| <i>Harpullia</i> | 4 | 0.4 | 0.2 | 6 |
| <i>Pimeleodendron</i> | 4 | 0.4 | 0.3 | 20 |
| <i>Pouteria</i> | 4 | 0.3 | 0.3 | 7 |
| <i>Celtis</i> | 3 | 0.3 | 0.5 | 20 |
| <i>Ceodes</i> | 4 | 0.3 | 0.5 | 15 |
| <i>Canarium</i> | 1 | 0.3 | 0.3 | 8 |
| <i>Syzygium</i> | 3 | 0.3 | 0.3 | 31 |
| <i>Litsea</i> | 3 | 0.2 | 0.3 | 12 |
| <i>Mangifera</i> | 4 | 0.2 | 0.2 | 8 |
| <i>Maniltoa</i> | 4 | 0.2 | 0.2 | 13 |
| <i>Diospyros</i> | Banned from export | 0.2 | 0.2 | 7 |
| <i>Garcinia</i> | 4 | 0.2 | 0.1 | 8 |
| <i>Leea</i> | 4 | 0.2 | 0.1 | 6 |
| <i>Sericolea</i> | 4 | 0.2 | 0.1 | 4 |
| <i>Dendrocnide</i> | - | 0.1 | 0.1 | 10 |
| <i>Barringtonia</i> | 4 | 0.1 | 0.1 | 6 |

* Commercial timber groups: Group 1, premium species to Group 4, least valuable species (PNGFA, 1996)

4 Discussion

Reduced impact logging as implemented using portable sawmills in this study had a low impact on stand structure as indicated by low levels of damage to the residuals, low stem mortality and the small percentage of forest area disturbed by gaps and tracks. The logging gap disturbance had a positive impact on regeneration resulting in abundant regeneration of both secondary and primary species. Based on comparisons with other studies the low impacts and rapid recovery appeared to

reflect the low harvest intensity as much as the reduced impact logging practices. These findings are discussed in the following sections.

4.1 Impacts on stand structure

The low intensity of the logging appeared to be the major factor resulting in low impacts. Only 1-2 trees ha⁻¹ were normally harvested with a mean log volume of 4.3 m³ ± 2.5. This caused stand damage to 4 - 9 % of the forest area, which is attributed to disturbance from felling, within gap processing of logs and clearing for access tracks. This level of impact is very low when compared to conventional logging in Papua New Guinea where 14 – 30 m³ha⁻¹ (3 – 7 stems) may be harvested, resulting in mortality of 30 -70% of the residual stems in the post-harvest period (Cameron and Vigus 1993). Modelling of mortality of damaged stems in PNG suggests that stand decline can occur for up to ten years after logging (Alder 1998). For logged over forest in PNG average annual mortality rates are about 2.5% for sound trees and 6.3% for damaged trees (Alder 1998). In this study overall annual mortality for portable sawmill logging was less than 2% for trees ≥ 10 cm dbh, which is attributed to the low level of damage.

However, when portable sawmill logging is compared to conventional logging of similar intensities differences are less marked. Comparable conventional logging harvest intensities occur in West and Central Africa where 1- 3 trees ha⁻¹ are harvested. In these forests 4 -15% of the original population of stems is damaged (Sist 2000), compared to an estimated < 5 % of stems for portable sawmill logging in this study where 4-9 % of the forest area is disturbed. The reduction in the maximum level of stem damage may be attributed to several factors, including good planning, directional felling, and reduced access tracks. However other studies suggest that the primary reason RIL practices reduce stem damage compared to conventional logging is because of a reduction in skidding damage by up to 40%, reducing the number of trees destroyed (Jackson 2002; Sist *et al.* 2003). Directional felling and other possible interventions such as climber cutting are considered to be of low significance in reducing damage (Sist *et al.* 1998). However, with portable sawmill logging skidding does not occur since logs are processed at stump, but tracks are required to transport the sawmill and sawn timber. For this study damage from tracks is estimated to be about 3 % which is relatively high for the small number of stems harvested. For example In Malaysia at conventional logging intensities of 9 trees ha⁻¹ in similarly hilly terrain, the area disturbed by skid trails and roads under RIL causes 7 – 9 % damage, i.e. a maximum of 1% damage for each tree harvested (Pinard *et al.* 2000). Similarly RIL in the Eastern Amazon with a mean logging intensity of 6 trees ha⁻¹ (21 m³ of logs ha⁻¹) results in 7% damage from skid trails (Sist and Ferreira 2007). Logically higher extraction rates utilising the same roads would reduce damage per tree harvested compared to the low volumes involved with portable sawmill logging.

4.2 Gaps

In natural tropical forests gap openings tend to occur at low frequencies of about 1% of the forest area per year, with openings that rarely exceed 200 m² (Brandani *et al.* 1988). Here the logging gaps ranged from 147 m² to 631 m² where two trees were harvested. One method of assessing how ecologically appropriate these gaps are is to compare them to the natural disturbance regime. Anecdotal evidence across the study area suggests canopy gaps are most commonly formed by single tree falls associated with gust fronts from convection storms, hence the felling of individual trees partly mimics such events. Single tree-falls are typically more frequent and smaller scale than other natural forest disturbances. In PNG disturbances from volcanic eruptions, landslides, flooding, lightning strike (Johns 1986) frost and drought (Allen 1997) and associated fire in severe El Nino years, and large scale windthrow from rare cyclone events can occur (Rogers 2000). It is conceivable that the current canopy species composition at Kilu reflects a historical large scale landscape level disturbances event. Although there is no expectation or desire for portable sawmill logging to mimic infrequent large scale disturbance events, the fact that they are a part of the natural forest dynamics suggest that different primary species will have adaptations to successfully regenerate in a range of naturally occurring gap sizes, including the larger gap sizes (c. 600 m²) that portable sawmill logging creates.

Larger gaps can have problems associated with rapid colonisation by climbers, however there was no evidence of climber infestation in this study. It is not clear whether this reflects the typical dynamics of this forest type or competitive exclusion by the fast growing secondary species that initially colonised the gap. In the large gap juvenile populations of commercial species were similar or higher than in the smaller gaps, with comparable height increment suggesting the larger gap had no adverse effects on the regeneration of commercial species.

4.3 Regeneration

Recovery post logging was rapid with adequate establishment of seedlings of a range of primary species comparable to the seedling bank in the unlogged forest. Regeneration in gaps was physically dominated by the secondary species *Macaranga*, however primary species, including commercial species accounted for over 90% of the seeding population after 61 months compared to about 40% at first measurement. The secondary species were rapidly recruited into the gaps contributing to an increased canopy cover by 17 months (Figure 6). Secondary species such as *Macaranga* are a component of the soil seed bank that typically colonise gaps and disturbed forest (Rogers and Hartemink, 2000; Saulei and Swaine 1988). By 61 months all the gaps had developed a low canopy 8-9 m height with abundant primary seedlings comparable to the population in the unlogged forest, but with increased height growth rates. This highlights the effectiveness of the logging gaps in facilitating regeneration. In contrast for the unlogged forest the established seedling bank showed low growth rates, and in some instances showed almost no height growth over the 61 months. Within

gap seedling population dynamics was also influenced by adjacent large seed trees. The profuse regeneration of *Canarium* in Gap 2 and *Spondios* in Gap 3 was associated with mast seeding of nearby parent trees.

Figure 6 **Regeneration in Gap 1 after 17 months**



Where there is an existing seedling bank, the height of seedlings at the time of canopy opening can partly determine which species eventually dominates the gap, which can mean shade tolerant primary species (potentially commercial) dominate rather than faster growing light demanding species (Brown and Press 1992). While this is potentially an important process in the unlogged forest it was not a relevant factor in logging gaps since they are typically free of all pre-existing vegetation due to the intense nature of the disturbance caused by the processing. The presence of fast growing secondary species in the soil seed bank appeared to partly determine which species initially dominated the gap. The most abundant regeneration occurred in the largest gap where two trees had been felled and processed. In this gap (Gap1) the secondary (pioneer) species *Macaranga* quickly dominated forming

a dense thicket, reaching a maximum height of 8 - 9 m by 27 months. By 61 months the population had thinned considerably with several primary species having increased in abundance.

Without knowledge of the long term seedling dynamics in gaps it is unclear whether the regeneration is silviculturally adequate. However the abundance of primary commercial species and the increasing proportion of primary species in relation to secondary species over time suggest the seedling populations in logging gaps will progress towards a primary species dominated mix. For Gap 1 where the sample size was identical to the logged forest seedling population exceeded that of the unlogged forest. Therefore, the abundance and survival of seedlings in logging gaps over the 61 months of the study appears adequate, however the monitoring period is too short to determine which species will eventually dominate the gap to form the next crop.

The healthy seedling population in logging gaps in this study contrasts with conventional logging where poor growth and low seedling survival can occur, because of the impact of high levels of soil disturbance. Soil disturbance from conventional logging can cause erosion, compaction, reduced infiltration and impact on beneficial mycorrhizal diversity (van Gardingen *et al.* 1998). Although these factors were not assessed in this study, there was no evidence of adverse impacts on soils within the gaps.

5 Conclusion

The lack of replication in this study makes firm conclusions inappropriate. However, the likelihood of a significant investment in a full trial of this type of research appears unlikely. There have been no published studies on portable sawmill logging impacts in PNG despite over 10 years of operational practice, and the small scale nature of the logging appears to detract from research interest. Consequently decisions on how to advance portable sawmill may need to be based on minimum data.

Despite the limitations of the project, the study suggests that well planned and executed portable sawmill logging operations are low impact because of the small number of logs harvested in addition to the RIL techniques used. However, a slightly higher harvest intensity may result in lower damage per m³ harvested based on comparisons with other studies. A shift towards slightly higher intensity RIL is also likely to reduce harvest costs making portable sawmill forestry more economically attractive.

Despite the relatively low impacts and successful regeneration in gaps it is unclear which species will eventually dominate the gaps and form the new crop. Further research on the long term gap dynamics would be beneficial. Consequently silvicultural treatment may be required to ensure that preferred commercial species eventually dominate the gaps to form the next crop.

The current approach to eco-forestry in Papua New Guinea appears overly focused on very low impact forestry, however, it is not the abundance of the trees saved, but rather the freedom of the best to grow that dictates further productivity (Wadsworth and Zweede 2006). Consequently more silviculturally astute eco-forestry that maintains low impacts may confer greater economic returns and help increase the uptake of portable sawmill forestry country wide.

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Appendix A

Species composition and basal area (m²ha⁻¹) of the logged (L) and unlogged 1 ha stands in October 2001 and in April 2004

| Family | Genus | Eco Group | L 2001 | L 2004 | UL 2001 | UL 2004 |
|------------------|-----------------------------------|-----------|--------|--------|---------|---------|
| Anacardiaceae | <i>Camposperma brevipetiolata</i> | P | - | - | 0.10 | 0.10 |
| Anacardiaceae | <i>Dracontomelon dao</i> | P | 0.38 | 0.44 | 0.74 | 0.79 |
| Anacardiaceae | <i>Mangifera minor</i> | I | 0.01 | 0.01 | 0.37 | 0.38 |
| Anacardiaceae | <i>Semecarpus</i> sp. | I | 0.06 | 0.06 | - | - |
| Anacardiaceae | <i>Spondias</i> sp. | I | - | - | 0.72 | 0.74 |
| Annonaceae | <i>Goniothalamus</i> sp. | P | 0.11 | 0.14 | 0.69 | 0.54 |
| Annonaceae | Unidentified | - | - | - | 0.01 | 0.01 |
| Apocynaceae | <i>Alstonia</i> sp. | I | - | - | 0.61 | 0.66 |
| Apocynaceae | <i>Cerbera</i> sp. | P | - | - | 0.05 | 0.05 |
| Araliaceae | Unidentified | - | - | 0.01 | - | - |
| Barringtoniaceae | <i>Barringtonia</i> sp. | I | - | - | 0.28 | 0.28 |
| Bombaceae | <i>Bombax</i> sp. | I | - | - | 0.29 | 0.31 |
| Burseraceae | <i>Canarium indicum</i> | P | 0.13 | 0.14 | 0.40 | 0.45 |
| Burseraceae | <i>Garuga</i> sp. | I | - | - | 0.01 | 0.01 |
| Caesalpiniaceae | <i>Maniltoa</i> sp. | P | 0.16 | 0.17 | 0.28 | 0.29 |
| Clusiaceae | <i>Calophyllum</i> sp. | P | 0.31 | 0.18 | 0.57 | 0.62 |
| Clusiaceae | <i>Garcinia</i> sp. | P | 0.02 | 0.02 | 0.17 | 0.18 |
| Combretaceae | <i>Terminalia</i> sp. | P | 0.18 | 0.20 | 0.55 | 0.56 |
| Datisceae | <i>Octomeles sumatrana</i> | I | 0.58 | 0.58 | 1.33 | 1.37 |
| Ebenaceae | <i>Diospyros</i> sp. | P | 0.13 | 0.10 | 0.03 | 0.03 |
| Elaeocarpaceae | <i>Elaeocarpus</i> sp. | I | 0.03 | 0.02 | - | - |
| Elaeocarpaceae | <i>Sericolea</i> sp. | I | 0.01 | 0.01 | 0.04 | 0.04 |
| Elaeocarpaceae | <i>Sloania</i> sp. | P | - | - | 0.12 | 0.13 |
| Elaeocarpaceae | Unidentified | - | 0.07 | 0.07 | - | - |
| Euphorbiaceae | <i>Endospermum</i> sp. | S | 2.73 | 2.73 | 0.92 | 0.67 |
| Euphorbiaceae | <i>Glorchidion</i> sp. | I | 0.03 | 0.03 | - | - |
| Euphorbiaceae | <i>Macaranga</i> sp. | S | 0.08 | 0.09 | 0.20 | 0.31 |
| Euphorbiaceae | <i>Pimileodendron amboinicum</i> | P | - | - | 0.32 | 0.34 |
| Fabaceae | <i>Castanospermum</i> sp. | P | 1.54 | 1.66 | - | - |
| Fabaceae | <i>Pterocarpus indicus</i> | I | 0.19 | 0.20 | - | - |
| Flacourtiaceae | <i>Homalium foetidissima</i> | I | - | 0.36 | 0.07 | 0.08 |
| Gnetaceae | <i>Gnetum</i> sp. | P | - | - | 0.01 | 0.01 |
| Himantandraceae | <i>Galbulilimima</i> sp. | P | - | - | 0.24 | 0.26 |
| Lauraceae | <i>Cinnamomum</i> sp. | P | 0.04 | 0.05 | 0.03 | 0.03 |
| Lauraceae | <i>Cryptocarya</i> sp. | I | 0.98 | 0.93 | 0.38 | 0.29 |
| Lauraceae | <i>Litsea</i> sp. | I | 0.09 | 0.11 | 0.27 | 0.24 |
| Lauraceae | <i>Neolitsea</i> sp. | P | 0.25 | 0.25 | - | - |
| Leeaceae | <i>Leea</i> sp. | S | 0.20 | 0.21 | - | - |
| Meliaceae | <i>Aglaia</i> sp. | P | 1.51 | 1.49 | 1.19 | 1.23 |
| Meliaceae | <i>Chisocheton</i> sp. | P | 1.48 | 1.70 | 0.14 | 0.16 |
| Meliaceae | <i>Dysoxylum</i> sp. | P | 1.16 | 1.24 | 4.33 | 4.60 |
| Meliaceae | Unidentified | - | 0.01 | 0.02 | - | - |
| Mimosaceae | <i>Archidendron</i> sp. | P | 0.02 | 0.02 | 0.01 | 0.01 |
| Moraceae | <i>Artocarpus</i> sp. | S | 0.09 | 0.10 | - | - |
| Moraceae | <i>Ficus</i> sp. | S | 0.16 | 0.22 | 0.92 | 0.88 |
| Moraceae | Unidentified | - | 0.02 | 0.03 | - | - |
| Myristicaceae | <i>Myristica</i> sp. | I | 2.15 | 2.46 | 2.63 | 2.82 |

| Family | Genus | Eco Group | L 2001 | L 2004 | UL 2001 | UL 2004 |
|------------------|------------------------|------------------|---------------|---------------|----------------|----------------|
| Myrtaceae | <i>Syzygium</i> sp. | <i>P</i> | 0.85 | 0.90 | 0.61 | 0.55 |
| Nyctaginaceae | <i>Ceodes</i> sp. | <i>I</i> | 0.29 | 0.31 | 0.09 | 0.09 |
| Nyctaginaceae | <i>Pisonia</i> sp. | <i>I</i> | - | 0.01 | - | - |
| Rosaceae | <i>Prunus</i> sp. | <i>S</i> | 0.06 | 0.06 | - | - |
| Rubiaceae | <i>Gardenia</i> sp. | <i>I</i> | 0.05 | 0.06 | 0.02 | - |
| Rubiaceae | <i>Nauclea</i> sp. | <i>S</i> | - | - | 0.64 | 0.15 |
| Rutaceae | <i>Euodia</i> sp. | <i>I</i> | 0.74 | 0.83 | 0.05 | 0.05 |
| Rutaceae | <i>Flindersia</i> sp. | <i>P</i> | 0.47 | 0.53 | - | - |
| Sapindaceae | <i>Harpullia</i> sp. | <i>I</i> | 0.66 | 0.69 | - | - |
| Sapindaceae | <i>Pometia pinnata</i> | <i>P</i> | 0.63 | 0.68 | 3.51 | 3.88 |
| Sapotaceae | <i>Pouteria</i> sp. | <i>P</i> | 0.29 | 0.29 | 0.49 | 0.53 |
| Sterculiaceae | <i>Kleinhovia</i> sp. | <i>S</i> | 1.74 | 1.70 | 1.24 | 1.01 |
| Sterculiaceae | <i>Sterculia</i> sp. | <i>P</i> | 0.09 | 0.18 | 0.54 | 0.57 |
| Tiliaceae | <i>Microcos</i> | <i>P</i> | 0.58 | 0.59 | 0.75 | 0.44 |
| Tiliaceae | <i>Neonauclea</i> sp. | <i>S</i> | - | - | 1.36 | 1.50 |
| Ulmaceae | <i>Celtis</i> sp. | <i>P</i> | 1.08 | 1.14 | 0.80 | 0.83 |
| Urticaceae | <i>Dendrocnide</i> sp. | <i>S</i> | 0.87 | 0.92 | 0.12 | 0.10 |
| Urticaceae | <i>Pipturus</i> sp. | <i>S</i> | - | 0.06 | - | - |
| Verbenaceae | <i>Gmelina</i> sp. | <i>P</i> | - | - | 0.37 | 0.38 |
| Verbenaceae | <i>Premna</i> sp. | <i>S</i> | - | - | 0.05 | 0.06 |
| Verbenaceae | <i>Vitex cofassus</i> | <i>P</i> | 0.25 | 0.27 | 0.47 | 0.48 |
| Xanthophyllaceae | <i>Xanthophyllum</i> | <i>P</i> | - | - | 0.25 | 0.25 |
| Unidentified | Unidentified | | 0.72 | 0.75 | 0.13 | 0.15 |
| | Total | | 25.3 | 26.8 | 30.5 | 30.5 |

Eco Group: *P* = primary species, *I* = intermediate species and *S* = secondary species

-- not present