Australian Forestry 1990, 53 (3), 200-214

Effects of Selection Logging on Rainforest Productivity

Jerome K. Vanclay

Queensland Forest Service, GPO Box 944, Brisbane 4000 Queensland, Australia

Abstract

An analysis of data from 212 permanent sample plots provided no evidence of any decline in rainforest productivity after three cycles of selection logging in the tropical rainforests of north Queensland. Relative productivity was determined as the difference between observed diameter increments and increments predicted from a diameter increment function which incorporated tree size, stand density and site quality. Analyses of variance and regression analyses revealed no significant decline in productivity after repeated harvesting. There is evidence to support the assertion that if any permanent productivity decline exists, it does not exceed six per cent per harvest.

Introduction

Hilton (1987) claimed that rainforest logging could disrupt nutrient cycling and cause impoverishment, and argued that new harvesting methods were required. He suggested that rainfall made a considerable contribution to forest nutrition, and could replace the nutrients removed or lost during harvesting, provided that the residual stand was well stocked. He concluded that “so little hard information is available that no comparison can be made between past and present yields in those areas of rainforest which are being logged for the second time. Although the growing stock may have been accurately assessed before the first harvest the rate of growth remains unknown. Thus it is impossible to see ... how much productivity has been affected, if it has, by logging”.

Enright (1978) reported that the growth rates of individual trees in the residual stand dropped markedly after logging. He also found that logging resulted in a temporary but marked decrease in nutrient levels after logging. However, both these studies concerned heavily logged stands. Enright (1978) reported that nearly all *Araucaria cunninghamii* (the dominant species comprising 54% of the stand) individuals exceeding 40 cm dbh were removed, and that extensive damage was caused to the residual stand.

Boxman *et al.* (1985) studied polycyclic logging followed by silvicultural treatment in Suriname and concluded that these contributed minimally to the loss of nutrients. Claims that polycyclic logging may lead to deterioration of the forest due to the progressive removal of the better genotypes have been refuted by Whitmore (1984), who argued that this was insignificant and academic.

The present study concerns the tropical rainforests of north-east Queensland. These forests had been managed for conservation and timber production for more than eighty years (Just 1987), before logging ceased following their World Heritage nomination in 1988. Although initial exploitation of these forests was largely uncontrolled, logging practices were progressively improved and harvesting in recent years has caused little environmental impact

---

Revised manuscript received 14 September 1990

(Just 1987). The earliest exploitation caused relatively little damage because of the highly selective nature of logging and modest horsepower involved. Environmental impacts probably peaked during the mid-1960's with the ready availability of heavy earth moving machinery. During the 1980's, timber harvests were obtained through selection logging which removed 7 to 10 trees per hectare, comprising not more than 25 per cent of the total standing basal area (Vanclay 1989b). Guidelines (Preston and Vanclay 1988) ensured that not more than 50 per cent of the canopy was removed. Such guidelines ensure rapid recovery of the rainforest canopy (Horne and Gwalter 1982). Key components of this selection logging system as practiced during the 1980's were:

- Logging guidelines were sympathetic to the silvicultural requirements of the forest, viz. ensuring retention of vigorous advance growth, harvesting only defective and fully mature trees, providing for adequate regeneration of commercial species and discouraging invasion by weeds;
- Treemarking by trained staff specified trees to be retained, trees to be removed and the direction of felling to ensure minimal damage to growing stock and minimal opening of the canopy;
- Logging equipment was appropriate and driven by trained operators to ensure minimal damage to the residual stand and minimal soil disturbance, compaction and erosion;
- Prescriptions ensured that adequate stream buffers and steep slopes were excluded from logging;
- Sufficient areas for scientific reference, feature protection and recreation were identified and excluded from logging;
- Deficiencies in an evolving system were recognised and remedied, leading to an improved system.

Several studies have examined impacts of timber harvesting in these forests. Gilmour (1971) found that effects of logging on streamflow and sedimentation were small scale and short lived. Gillman *et al.* (1985) examined soil chemical properties and found that most topsoil nutrients regained their initial levels within four years of logging. Whilst nutrient cycles were disrupted by logging, losses appeared to be small and quickly replaced by natural inputs, provided that logging was of low intensity, short duration and infrequent (Congdon and Lamb 1990).

Nicholson *et al.* (1988, 1990) and Crome *et al.* (1990) reported that whilst timber harvesting caused localized destruction, it did not lead to loss of any plant species. Logging tracks and canopy loss were confined to 5 and 20 per cent of the area respectively (Crome *et al.* 1990). However, the light climate may be altered in areas with no direct canopy loss. Stocker (1981, 1983), Unwin (1983, 1988) and Webb and Tracey (1981) have investigated other aspects of the dynamics and regenerative capacity of these rainforests. Crome and Moore (1989, 1990) discussed effects of logging on fauna.

It has been estimated that a timber harvest of 60 000 cubic metres per annum could be sustained from these forests (Preston and Vanclay 1988). Vanclay and Preston (1989) examined the long-term sustainability of such a harvest, and concluded that selection logging could be sustained by the growth of residual trees and regeneration, and need not rely upon trees missed during previous harvests. Research into the relationship between diameter (breast high or above buttress, over bark) and log volume provided no evidence to suggest that there was any increase in defect or any reduction in log length in trees harvested from previously logged stands (Henry 1989).

Rainforests appear to have the regenerative capacity to cope with the effects of a single selection logging, given sufficient time to recover (Hopkins 1990). Shugart *et al.* (1980) used a succession model to examine the effects of comparatively intensive harvesting on a 30 year cycle in subtropical rainforest in New South Wales, and concluded that such harvesting was sustainable, although the structure and composition of the forest would be altered. The present paper examines how the long term average growth rates of individual trees are influenced by repeated selection logging.

Data

The Queensland Department of Forestry (1983) research programme has provided an extensive database sampling virgin, logged and silviculturally treated forests. CSIRO (West *et al.* 1988) have also established 20 plots in relatively undisturbed stands sampling the full range of forest types in the region. The combined database represents over 250 permanent sample plots with a measurement history of up to 40 years (Appendix). Permanent sample plots range in size from 0.04 to 0.5 hectares, and have been re-measured frequently. All trees exceeding 10 cm dbh (diameter over bark at breast height or above buttressing) were uniquely identified and tagged, and were regularly measured for diameter (to nearest millimetre) using a girth tape. To improve the consistency of diameter measurement, field crews had access to previous records while in the field. Any trees exhibiting defects or bulges at or near the measurement height were noted and so identified on computer. Such trees have not been used in calculating diameter increments, and have only been used in calculating stand basal areas.

The data used in this study were identical to those used by Vanclay (1990) in developing a growth model for yield prediction (Vanclay and Preston 1989). Pairs of plot remeasurements were selected from the database to attain intervals between remeasurements of approximately five years, which did not span any logging or silvicultural activity. Tree diameters do not increase monotonically in size, but exhibit diurnal and seasonal fluctuations which may result in measured diameters smaller than previous values (Lieberman 1982). These, and measurement errors, may give rise to negative increments which may cause difficulties in data analysis. Ensuring a long interval between remeasurements (e.g. 5 years) so that the growth is large relative to the error, eliminates many of these decrements, but some remain. The logarithmic transformation used in the present analyses has long been recognised as an efficient way to satisfy assumptions implicit in regression analysis (linearity, normality, additivity and homogeneity of variance) (e.g. Schumacher 1939, Clutter 1963), but cannot accommodate negative increments. Some negative values can be accommodated by adding a constant before transforming, but any decrements exceeding 0.01 were omitted from the present analyses.

The data file created for statistical analysis contained 62 372 observations of diameter increment derived from 28 123 individual trees. The file also contained records of tree species and dbh, and stand variables such as site quality, stand basal area and soil parent material. Site quality for each plot was estimated using Vanclay's (1989a) Equation 13:

$$GI = \frac{\sum_{ij} Log(DI_{ij}+\alpha) - \sum_{ij} \left[\beta_{0i} + \beta_{1i} D_{ij} + \beta_{2i} Log(D_{ij}) + \beta_{3i} Log(BA) + \beta_{4i} OBA_{ij}\right]}{0.08808 \times \sum_{ij} Log(D_{ij})}$$

where *GI* is the growth index of the plot, D_{ij} *is* the diameter (breast high or above buttress, over bark, in *cm)* of tree *j* of species *i, DI* is its diameter increment *(cm* y^{-1}*),* OBA_{ij} is its “overtopping basal area”, the basal area of trees within the plot that are bigger than tree *ij* (m^2 ha^{-1}), *BA* is the plot basal area (m^2 ha^{-1}), and the *β*s are parameters estimated by linear regression. This equation estimates growth index, a measure of site productivity based on the diameter increment adjusted for tree size and competition, of all trees of eighteen reference species *(Acronychia acidula, Alphitonia whitei, Argyrodendron trifoliolatum, Cardwellia sublimis, Castanospora alphandii, Cryptocarya angulata, C. mackinnoniana, Darlingia darlingiana, Elaeocarpus largiflorens, Endiandra sp.* aff. E. *hypotephra, Flindersia bourjotiana, F. brayleyana, F. pimenteliana, Litsea leefeana, Sterculia laurifolia, Syzygium* *kuranda, Toechima erythrocarpum, Xanthophyllum octandrum)* using all available remeasures for the plot (except that where plots were remeasured more frequently, remeasurements were selected to achieve approximately 5 year intervals). The βs were estimated by fitting the equation

$$\mathit{Log}\ (\mathit{DI}+\alpha) = \mathit{Spp} + \mathit{D.Spp} + \mathit{Log}\ (D).\mathit{Spp} + \mathit{Log}\ (\mathit{BA}).\mathit{Spp} + \mathit{OBA.Spp} + \mathit{Log}\ (D)\mathit{Plot}$$

(where *Spp* and *Plot* are qualitative variables) simultaneously for all these reference species in the development data set (80 plots, a further 64 plots were used for validation studies). The parameter α was assigned the value 0.02 after inspection of residuals and examining the residual mean squares from a range of values (Vanclay 1989a). The value 0.08808 was subjectively determined to scale the growth indices into the range 0-10.

Table 1. Size and History of Plots used in Analyses.

Plot Area (ha)	Measurement History (Years) 0.10	10-19	20-29	30+	Total Plots
<0.10	2	31	3	2	38
0.1-0.19	4	47	6	10	67
0.2-0.29	15	42	3	27	87
≥0.30	5	9	0	6	20
Total	26	129	12	45	212

The present study omitted any plots for which the estimated site quality exceeded the range 0-10, or for which the variance of the estimated site quality exceeded 2. Valid estimates of site quality were obtained for 212 plots (Table 1).

Table 2. Logging History for Plot Data used in Analyses.

Harvests prior to First Measure	Total Harvests at Last Measure 0	1	2	3	Total Plots
0	9	1			10
1	-	136	38		174
2	-	-	26	2	28
Total	9	137	64	2	212

Table 3. Logging and Measurement Profile for Data used in Analyses

Year of Measure	Total Harvests prior to Measure 0	1	2	3	Total Plots
-1949		6	1		7
1950-54	4	45	1		50
1955-59	5	72	7		84
1960-64	5	86	6		97
1965-69	6	127	14		147
1970-74	6	121	27		154
1975-79	9	61	43	2	115
1980-	4	23	21	2	50

Unfortunately, no continuous record of growth data spanning two successive harvests was available (Table 2). Experiment 615 (Appendix) had two such plots but the two-year period from establishment until logging was too short to provide reliable increment data. The 66 plots which were logged twice had measurement records which commenced only after the first harvest, and only one plot had a measurement record spanning the first harvest. However, 38 plots provided measurement data spanning the second harvest (Table 2). Only two plots were logged three times, but these harvests differed from normal practice in that the first and second harvests were only seven years apart (Appendix, Experiment 615). The majority of plots (136) were in stands logged once, and had a measurement record which did not span any logging activity.

A further problem was that these experiments were not well replicated through time - most were first logged during the decade 1950-59, and were relogged during 1969-80 (Appendix). Table 3 shows that the different harvesting histories were well sampled, but these plots were not necessarily paired with suitable control plots. Thus differences detected during any given period could be due to site or management differences, as well as to harvesting history. Similarly, on any given plot, differences in increment between measurement periods could be due to prevailing weather conditions, as well as due to harvesting. Thus although extensive, the present database contained weaknesses which provided problems for the analysis and interpretation of the results.

The severity of these problems may be gauged through a correlation matrix of plot variables (Table 4). Ideally, the explanatory variables explored in an analysis should not be correlated, although in practice this is rarely possible. When explanatory variables are correlated, the ability to identify potentially causal relationships is reduced (explanatory variables do not have a unique sum of squares), and the magnitude of possible effects may not be able to be reliably determined (addition or subtraction of an explanatory variable may substantially change parameter estimates for a model, standard errors of estimates may be inflated). However, multicollinearity does not inhibit the ability to obtain a good fit, nor does it affect inferences about responses or predictions within the region of observations (Neter and Wasserman 1974:341). Correlations between explanatory variables considered in the present analysis are not serious (Table 4). The high correlation between number of harvests and time since logging (-0.64) is partly due to the encoding convention adopted (for unlogged plots, time since logging = 99), and the correlation for logged plots is lower (-0.43).

Hypothesis and Analyses

The analyses test the hypothesis that selection logging leads to a reduction in productivity in these rainforests and that this reduction may comprise two components, a transient and a permanent loss of productivity. Figure 1 illustrates the pattern of productivity decline that the analyses attempt to detect. The null hypothesis was that there is no reduction in productivity, whilst the alternative hypothesis was that a reduction in productivity following logging can be detected. The analyses endeavour to produce evidence to reject the null hypothesis.

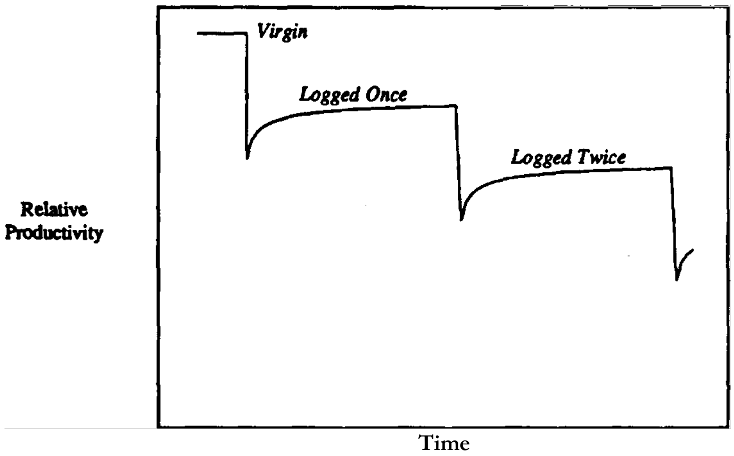

Figure 1. Hypothetical effect of logging on productivity.

Table 4. Correlation Matrix for Plot Variables:

Source	No of harvests	Time since treatment	Time since logging	Site quality	Basal Area	Mean Residual
Year of measure	0.272*	0.071	0.088*	-0.019	0.040	-0.092*
No of harvests	1.000	-0.252*	-0.639*	-0.084*	-0.230*	-0.079*
Time since treatment		1.000	0.473*	0.326*	0.741*	-0.055
Time since logging			1.000	0.207*	0.588*	0.019
Site quality				1.000	0.615*	0.006
Stand basal area					1.000	0.101*

* indicates correlation significant at $P<0.05$

Unfortunately, a suitable measure of "productivity" is neither easy to define nor to measure. Biomass production may seem a good measure of productivity, but has several weaknesses. It cannot be measured directly, and is difficult to determine. Nett biomass production is near zero in unlogged stands (any growth is offset by mortality) and increases following logging due in part to a reduction in competition. Gross biomass production overcomes the problem of mortality, but is dependent upon stocking, and a reduction in production following logging could be due to the reduced occupancy of the site. This problem of distinguishing the effects of site occupancy from the effects of logging is common to all stand level measures, including volume and basal area increment per hectare. Thus we need to consider individual trees, and could seek to monitor the growth of a "standard reference tree" in each plot. However, suitable trees having the same species, size and competition do not exist in each plot. Even if such trees could be found in a number of plots, logging would reduce competition and bias comparisons with unlogged plots. One solution to this dilemma is to fit a regression equation to the individual tree increments, and examine the residuals obtained from comparing the observed and expected increments. This approach is widely used in many disciplines, most commonly to derive seasonally adjusted figures (e.g. below average temperatures for June take into account that it is winter; seasonally adjusted employment figures account for school-leavers in December). Keenan and Candy (1983) used residuals about a height-age curve to investigate site factors influencing *Eucalyptus delegatensis* regrowth.

Suitable residuals can be generated from published increment equations. Vanclay (1990) presented 41 equations to predict the diameter increment of the 400 species occurring in the database. These equations had the form:

$$Log(DI+0.02) = \beta_0 + \beta_1 \times D + \beta_2 \times Log(D) + \beta_3 \times Log(D) \times SQ + \beta_4 \times Log(BA) \qquad (1)$$

$$+ \beta_5 \times OBA + \beta_6 \times PS + \beta_7 \times TST \times e^{-TST/5}$$

where *DI* is diameter increment *(cm y^{-1}), D is dbh (cm),* SQ is site quality (Vanclay 1989a), *BA* is stand basal area *(m^2 ha^{-1})* of trees exceeding 10 cm dbh, *OBA* is overtopping basal area *(m^2 ha^{-1}),* defined as the basal area of stems whose diameter exceeds that of the subject tree, *TST* is time *(years)* since silvicultural treatment, PS is a binary variable which takes the value one if the species is growing on a "preferred soil parent material" and zero otherwise, and the *β*s are parameters specific to each species group.

This equation does not include expressions of the number of harvests or of the time since logging. Thus the residuals should indicate the effects of logging and other factors not considered in Equation (1). Figure 2 illustrates these residuals (representing means of 8000, 4000, 3000 and 450 tree remeasurements for 0, 1, 2 and 3 harvests respectively). These suggest some productivity change with time since logging, but little effect attributable to number of harvests and little resemblance to Figure 1.

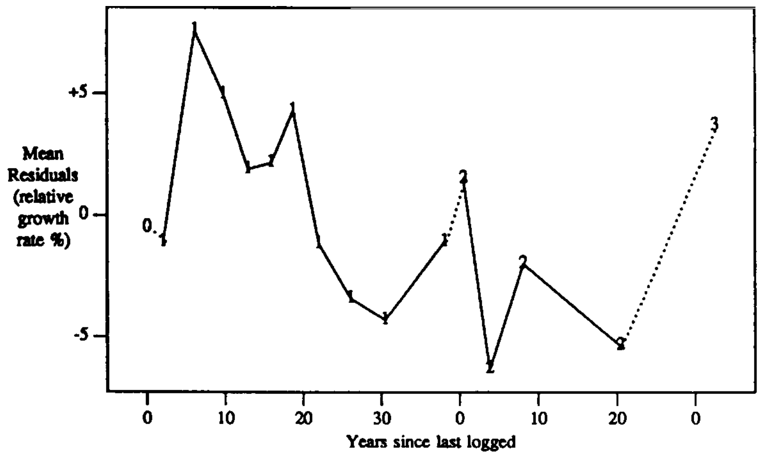

Figure 2. Difference between observed and predicted diameter increments for virgin stands (0) and stands logged once (1), twice (2) or three times (3).

An analysis of variance of the residuals about Equation (1) enables a formal statistical test of the hypothesis to be made. However, such an analysis of variance can be conducted in several different ways, and can test several different factors. In compiling the analysis then, it is essential to take account of the particular characteristics of the present data. In particular, we have data from 62 372 remeasurements on individual trees to infer the effects of logging on 212 plots. These individual tree data may give an inflated estimate of precision and may place undue emphasis on well stocked plots, so it is appropriate to calculate the mean residual for each plot remeasurement and use that in further analyses. Not all plot remeasurements give rise to a mean residual of equal precision, so it is appropriate to weight the analysis by the inverse of the variance associated with the mean residual for each plot remeasurement. Such weighting ensures that those plots which exhibit the most consistent growth patterns have greater influence on the analysis. Some plot remeasurements exhibited very small variances which would have given rise to inappropriately large weights. Thus 12 data with small variances were assigned the value 0.1. Weights were adjusted so that the sum of the weights equalled the number of data, and the final weights ranged from 0.1 to 4.2.

Table 5 reports several factors examined in an analysis of variance. Time since last logging was represented as six intervals of five years (0-4, 5-9, ..., 25+ years), and other periodic effects were taken into account through several approximately five year intervals (pre-1955, 1955-59, ..., 1980+). This analysis revealed that soil parent material, period of observation and the interaction between soil and time since logging were significant ($P < 0.05$) in influencing the differences between observed and expected diameter increments. The significant factors could be due to management practices as well as to environmental effects. Soil parent material influences topographic slope as well as soil type, and slope is a major determinant of logging damage (Vanclay 1989b). A problem with multicollinear data is that the explanatory variables do not have a unique sum of squares (Neter and Wasserman 1974:341), and that the significance associated with a variable may depend on the order in which the variables were included in the model. One way to overcome this is to determine the sum of squares for each variable by subtracting it from the maximal model. Whilst this ensures unique sums of squares for each variable, an additional entry in the analysis of variance table is required to reconcile the sums of squares (e.g. Table 5). This entry also indicates the extent of multicollinearity.

Table 6 reports the changes in productivity estimated through the analysis of variance. None of the estimates in Table 6 differ significantly from zero, and there is no suggestion of productivity decline. Table 6 does not aid in the detection of long-term decline, as the fluctuating response suggested does not enable forecasts. To detect a long term trend, we need to reformulate the model with number of harvests as a linear variate rather than a factor. This has the effect of estimating an equal and cumulative change in productivity following each successive harvest, as is illustrated in Figure 1. Two linear transformations of time since logging were also explored. One option is to use the inverse of time since logging, implying the asymptotic trend illustrated in Figure 1. Another option is to use a transformation similar to that used for the response to silvicultural treatment ($te^{-t/\alpha}$) which predicts a maximum response in year a followed by an asymptotic return to zero. The present data support the latter transformation (te^{-t}) with a very short-lived response ($\alpha = 1$). This linear transformation provided a better fit with fewer degrees of freedom than the inclusion of time since logging as a factor. However, the present data were derived from measurements over approximately 5-year intervals and are not suited for determining the exact nature of this short-term response. Including the number of harvests as a linear variate rather than a factor led to a slight increase in the residual sum of squares ($P = 0.13$). The analysis of variance (Table 7) was not greatly affected by the use of linear variates; time since logging was significant ($P < 0.05$) as a linear variate whilst number of harvests remained non-significant ($P > 0.05$).

Table 5. Analysis of Variance of Mean Plot Residuals using four Factors with Interactions.

Source of Variation	Degrees of Freedom	Residual Sum of Squares	Residual Mean Square	Test Statistic: F-ratio	Probability	Significance
MAIN EFFECTS						
Soil parent material	5	1.920	0.3840	4.69	0.0005	***
5-year period	6	1.357	0.2262	2.76	0.012	*
No. of harvests	3	0.411	0.1369	1.67	0.2	
Time since logging	5	0.405	0.0811	0.99	0.6	
Multicollinearity	0	0.981				
INTERACTIONS						
Soil-Time	15	2.470	0.1647	2.01	0.013	*
Soil-Harvests	4	0.343	0.0858	1.05	0.4	
Period Time	27	2.196	0.0813	0.99	0.5	
Period-Harvests	13	1.020	0.0785	0.96	0.5	
Period-Soil	18	1.325	0.0736	0.90	0.6	
Harvests-Time	5	0.304	0.0608	0.74	0.6	
Multicollinearity	6	0.3671				
Residual	**65**	53.967	0.0819			
Total	766	67.066				

Table 6. Productivity of Logged Forest relative to Virgin Forest..

Factors Considered	Number of Harvests		
Number of Harvests only, significant terms omitted	+3%	-5%	+4%
All Main Effects except time since logging	+5%	-3%	+20%
All Main Effects including time since logging	+8%	+2%	+27%
All Main Effects & Significant Interactions	+7%	+5%	+16%

N.B. None of these estimates is significantly different from zero.

A number of alternative approaches can be used to explore the proposed hypothesis. One alternative is to perform an analysis of variance on the individual tree data, ignoring the implications of the inflated degrees of freedom and unequal weighting of plots (Table 8, Model 2). Another possibility is to fit Equation (1) simultaneously to all 41 species groups, and to include additional variables for number of harvests, time since logging, time period and soil parent material (Table 8, Model **3).** Both these approaches indicated that both number of harvests and time since logging were not significant ($P > 0.2$), whilst five-year period and soil parent material remained significant ($P < 0.001$). .

Yet another technique is to identify comparable plots with different logging histories, and to eliminate other factors which may confound the result. Selection of plots was based on several objective criteria:

- Plots at least 0.2 hectares in area
- Established prior to 1960
- Maintained at least until 1980
- Measurement history spanning at least 30 years, and
- Plot site quality determined with variance not exceeding 0.1.

The majority of the plots satisfying these criteria were located on soils derived from coarse-grained granites, so selection was further restricted to the 16 plots with this soil parent material. This selection included (see Appendix) Experiments 591, 612, 613 (Plots 1& 3), 615, 616 and 619 (Plot 1). Analysis of variance and regression analysis indicated that none of the factors considered (number of harvests, time since logging, 5-year period) were significant ($P > 0.05$).

Table 7. Analysis of Variance of Mean Plot Residuals using Linear Variates.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Test Statistic: F-ratio	Probability	Significance
5-year period	6	1.923	0.321	3.87	0.0011	**
Soil parent material	5	1.740	0.348	4.20	0.0012	**
Time since last logged	1	0.524	0.524	6.32	0.012	*
No. of harvests	1	0.021	0.021	0.25	0.6	
Multicollinearity	0	0.502				
Residual	753	62.356	0.083			
Total	766	67.066				

The parameter estimates given in Table 8 enable the effects of time since logging and logging history to be assessed. The test statistic (student's t) indicates the statistical significance of the response, and parameter estimates enable the effect of logging to be quantified. For example, the mean plot residuals (Table 8, Model 1) give rise to a parameter estimate of -0.01308 for number of harvests which suggests that productivity will decrease relative to the unlogged condition to $e^{-0.01308} = 0.987$ after the first harvest, to 0.974 after the second, etc. Similarly, the transient response (time since logging) predicts a decrease of $e^{-0.3117t/e^{t}} = 0.892$ in the first year after logging, 0.919 in the second year, and 0.990 in year 5.

Table 8. Parameter Estimates and Implied Productivity Change due to Selection Logging.

	Number of Harvests (Permanent Change)				Time since Logging (Transient Change)			
Model	Parameter Estimate	Standard Error	Student's t	Implied Change	Parameter Estimate	Standard Error	Student's t	Implied Change
All available data:								
1) Mean Residuals	-0.01308	0.02592	0.505	-1%	-0.3117	0.1239	2.516*	-11%
2) Individual Trees	-0.00111	0.00597	0.186	0%	-0.0649	0.0390	1.664	-2%
3) Expanded Model	+0.00165	0.00712	0.232	0%	-0.0556	0.0406	1.369	-2%
Subset only:								
4) Mean Residuals	-0.00856	0.03251	0.263	-1%	+0.0288	0.2289	0.126	+1%
5) Individual Trees	+0.01108	0.01085	1.021	+1%	+0.1050	0.0918	1.144	+4%

* indicates significantly different from zero at $P< 0.05$

Discussion

The analysis of variance of mean plot residuals reported in Table 7 provides no evidence to reject the null hypothesis that harvesting causes no permanent decline in productivity. Model 1 provides evidence to support the existence of a transient decline in productivity during the few years following logging. Other analyses of individual tree data, and of the selected subset of data (Table 8) provided no evidence to reject the null hypothesis.

The parameter estimates for the terms reflecting the permanent impact of harvesting (number of harvests) are always close to zero, never significantly different from zero, and do not differ significantly from one another despite their different signs (Table 8). Because these parameters are very close to zero, one should not place too much emphasis on this change of sign, but it may be attributed, in part, to the non-orthogonal nature of the data. This weakness is inevitable in opportunistic analyses of this sort, and can only be overcome by properly designed and replicated experiments. Unfortunately, the large areas of virgin rainforest and long time period required to conduct such a properly designed experiment probably render such experimental results unattainable. In any case, such an experiment would not yield useful results for several decades, so the present data provide the only means currently available to assess the long term effects of repeated logging. Fortunately, multicollinearity does not inhibit our ability to develop a good model from the data, or to make inferences from that model (Neter and Wasserman 1974:341).

The parameter estimate for the transient decline in productivity (time since logging) from Model 1 differs significantly those obtained from other approaches. This analyses of plot mean residuals (Model 1) found a significant but short-lived transient decline in productivity. It is beyond the scope of the present study to determine possible causes: it may be that logging created an environment less favourable for growth; it may equally well be that trees were directing photosynthates into canopy expansion rather than diameter increment. This significant transient decline in productivity was not detected in Models 2-5, the parameter estimates of which did not differ significantly from zero or from one another.

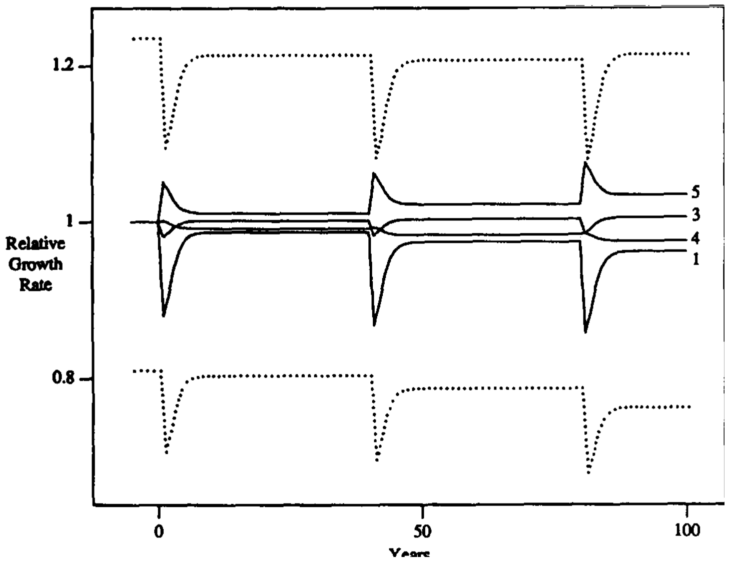

Figure 3. Predicted effects of logging on productivity. Models are indicated by numbers. Dotted lines represent 95% confidence limits.

The implications of Models 1, 3, 4 and 5 of Table 8 are illustrated in Figure 3. Approximate 95% confidence intervals for Model 1 are also shown, and indicate that the illustrated models do not differ significantly from the unlogged condition. Thus the principle of parsimony leads us to accept the null hypothesis that logging has no permanent effect on productivity. There is no evidence to reject the null hypothesis and support the alternate hypothesis, as any apparent change in productivity is not significant and may be due to random variation.

Which is the most appropriate model? This question is largely academic as no model supports the existence of a permanent decline in productivity. As previously argued, Models 1 and 4 which examine the plot mean residuals, are attractive. Model 3 estimates the logging effects directly from the raw data rather from partial residuals and may be less subject to effects multicollinearity, but has inflated degrees of freedom and may underestimate the standard errors.

Tests so far have adopted the conventional parsimonious approach of accepting the null hypothesis (that logging causes no decline in productivity) unless there is strong evidence to the contrary. However, statistical tests can also be formulated to test the null hypothesis that logging causes an x per cent decline in productivity, and to reject this only if there is strong evidence that any decline is less than this specified amount. This places the burden of proof on the forest manager. Suppose we have reason to suspect that each harvest causes a permanent and cumulative five per cent decline in productivity (this assumes a parameter estimate of -0.05130 for number of harvests). The data tabulated in Table 9 provide evidence to reject this contention ($P < 0.1$ for Models 1& 4, $P< 0.0001$ for Models 2, 3 & 5). It is also interesting to examine the critical values x which would just lead to the rejection of the null hypothesis that logging led to a decline in productivity of (or exceeding) x per cent (Table 9). The models based on plot mean residuals (Models 1& 4) are cautious models and allow the possibility of a small productivity decline not admitted by models based on individual tree data (Models 2, 3 & 5). This may be attributed in part to the inflated degrees of freedom and underestimation of standard errors in the individual tree models (2, 3 & 5). However, the multicollinearity evident in the data (Table 4) would lead to inflated estimates of standard error (Neter and Wasserman 1974:341) with the result that the critical values for Models 1 and 4 (Table 9) may be unnecessarily cautious.

Table 9. Critical Values for Rejection of the Hypothesis that Logging Causes Productivity Decline.

Model	Critical Values to Reject Permanent Decline			Probability of Permanent Decline	
	P=0.05	P=0.01	P=0.01	2%	5%
1	-5.4%	-7.1%	-9.1%	0.4	0.07
2	-1.1%	-1.5%	-2.0%	0.001	< 0.0001
3	-1.0%	-1.5%	-2.1%	0.0013	< 0.0001
4	-6.0%	-8.1%	-10.6%	0.4	0.09
5	-0.7%	-1.4%	-2.3%	0.002	< 0.0001

It is appropriate to observe that no evidence exists of any long-term decline in productivity following repeated harvesting. Whilst there is insufficient evidence to reject the possibility of a small decline, there is evidence to support the assertion that any decline does not exceed six per cent per harvest.

Conclusion

These analyses reveal no evidence to suggest any long-term decline in rainforest productivity after three cycles of selection logging. Despite an extensive database incorporating over 200 plots, some established more than 40 years, the data are inadequate for conclusive studies on the long term effects of rainforest harvesting. Continued monitoring and additional harvesting of experimental plots will be necessary to conclusively demonstrate the long term effects of logging.

However, the present analyses provide no evidence of any long-term decline in productivity following three cycles of conservative polycyclic selection logging, and provide evidence that any decline does not exceed six per cent per harvest. These results should not be extrapolated to infer the sustainability of more intensive harvesting systems.

Acknowledgements

Many officers of the Queensland Department of Forestry have contributed to the establishment and maintenance of experiments and the database. It is due to their diligence that analyses such as these are possible. Special thanks are due to Greg Unwin for providing data from the CSIRO EP series of plots, and to John Rudder for assistance with data processing. Drs. H. C. Dawkins, D. Doley, D. Lamb and an anonymous referee provided helpful comment on an earlier manuscript.

References

Boxman, O., Graaf, N.R.de, Hendrison, J., Jonkers, W.B.J., Poels, R.L.H., Schmidt, P. and Tjon Lim Sang, R. (1985) - Towards sustained timber production from tropical rain forests in Suriname. *Neth. J. Agric. Sci. 33:* 125-132.

Clutter, J.L. (1963) - Compatible growth and yield models for loblolly pine. *Forest Sci. 9(3):* 354-371.

Congdon, R.A. and Lamb, D. (1990) - Essential nutrient cycles. P. 105-113 in L.J. Webb and J. Kikkawa (eds) *`Australian Tropical Rainforests: Science - Values - Meaning'.* CSIRO, Melbourne, 185 p.

Crome, F.H.J. and Moore, L.A. (1989) - Display site constancy of bowerbirds and the effects of logging on Mt. Windsor Tableland, North Queensland. *Emu* 89: 47-52.

Crome, F.H.J. and Moore, L.A. (1990) - The effects on birds and small mammals of logging virgin upland rainforest in north Queensland, Australia. *Ecology* (in press).

Crome, F.H.J., Moore, L.A. and Richards, G.C. (1990) - A study of logging damage in upland rainforest in north Queensland, Australia. *For Ecol. Manage.* (in press).

Enright, N.J. (1978) - The effects of logging on the regeneration and nutrient budget of *Araucaria cunninghamii* dominated tropical rainforest in Papua New Guinea. *Malaysian Forester 41:* 303-318.

Gillman, G.P., Sinclair, D.F., Knowlton, R. and Keys, M. (1985) - The effect on some soil chemical properties of the selective logging of a north Queensland rainforest. *For. Ecol. Manage. 12:* 195-214.

Gilmour, D.A. (1971) - The effects of logging on streamflow and sedimentation in a north Queensland rainforest catchment. *Commonw. For Rev.* 50: 38-48.

Henry, N.B. (1989) - One-way equations for north Queensland rainforest species. Qld. Dep. For. Unpublished Report, 1989. 11 pages.

Hilton, R.G.B. (1987) - Nutrient cycling in tropical rainforests: Implications for management and sustained yield. *For Ecol. Manage.* 22: 297-300.

Hopkins, M.S. (1990) - Disturbance - the forest transformer. In L.J. Webb and J. Kikkawa (eds) *`Australian Tropical Rainforests: Science - Values - Meaning”* CSIRO, Melbourne, pp. 40-52.

Horne, R. and Gwalter, J. (1982) - The recovery of rainforest overstorey following logging. I. Subtropical rainforest. *Aust. For. Res.* 13: 29-44.

Just, T.E. (1987) - Management of tropical rainforests in north Queensland. Proceedings of Conference of Institute of Foresters of Australia, Perth 1987.

Keenan, R.J. and Candy, S. (1983) - Growth of young *Eucalyptus delegatensis* in relation to variation in site factors. *Aust. For. Res. 13:* 197-205.

Lieberman, D. (1982) - Seasonality and phenology in a dry tropical forest in Ghana. *J. Ecol. 70:* 791-806.

Neter, J. and Wasserman, W. (1974) - “Applied Linear Statistical Models: Regression, Analysis of Variance and Experimental Designs” Richard Irwin, Illinois, 842 p.

Nicholson, D.I., Henry, N.B. and Rudder, J. (1988) - Stand changes in north Queensland rainforests. roc. *Ecol. Soc. Aust.* 15: 61-80.

Nicholson, D.I., Henry, N.B. and Rudder, J. (1990) - Reply: Disturbance regimes in north Queensland rainforests: A re-evaluation of their relationship to species richness and diversity. *Aust. J. E.* 15(2): 245-246.

Preston, R.A. and Vanclay, J.K. (1988) - Calculation of timber yields from north Queensland rainforests. Queensland Department of Forestry Technical Paper No. 47. 16 pp.

Queensland Department of Forestry (1983) - Rainforest research in north Queensland. Queensland Department of Forestry Position Paper. 52 pp.

Schumacher, EX. (1939) - A new growth curve and its application to timber yield studies. *J. For. 37:* 819-820.

Shugart, H.H., Hopkins, M.S., Burgess, LP and Mortlock, A.T. (1980) - The development of a succession model for subtropical rain forest and its application to assess the effects of timber harvest at Wiangaree State Forest, New South Wales. *J. Environ. Manage.* 11: 243-265.

Stocker, G.C. (1981) - Regeneration of a north Queensland rain forest following felling and burning. *Biotropica 13:* 86-92.

Stocker, G.C. (1983) - Aspects of the dynamics of rainforests in north-east Australia. Ph.D. Thesis, University of New England. 400 pp.

Tracey, J.G. and Webb, L.J. (1976) - Key to the vegetation of the humid tropical region of north Queensland. Map Series, Rain Forest Ecology Unit, CSIRO.

Unwin, G.L. (1983) - Dynamics of the rainforest-eucalypt forest boundary in the Herberton Highland, north Queensland. M. Sc. Thesis, James Cook Univ., Townsville.

Unwin, G.L., Applegate, G.B., Stocker, G.C. and Nicholson, D.I. (1988) - Initial effects of cyclone 'Winifred' on forests in north Queensland. *Proc. Ecol Soc. Aust.* 15: 283-296.

Vanclay, J.K. (1989a) - Site productivity assessment in rainforests: an objective approach using indicator species. In Wan Razali Mohd., H .T. Chan and S. Appanah (eds) “Proceedings of the Seminar on Growth and Yield in Tropical Mixed/Moist Forests, 20-24 June 1988, Kuala Lumpur:” Forest Research Institute Malaysia, pp. 225-291.

Vanclay, J.K. (1989b) - Modelling selection harvesting in tropical rainforests. *J. Trop. For. Sci. 1(3):* 280-294.

Vanclay, J.K. (1991) - Aggregating tree species to develop diameter increment equations for tropical rainforests. *For Ecol. Manage.* 42:143-168.

Vanclay, J.K. and Preston, R.A. (1989) - Sustainable timber harvesting in the rainforests of northern Queensland. In Forest Planning for People, Proceedings of 13th biennial conference of the Institute of Foresters of Australia, Leura, NSW, 18-22 September 1989. Institute of Foresters of Australia, Sydney, pp. 181-191.

Webb, L.J. and Tracey, J.G. (1981) - Australian rainforests: pattern and change. In: A. Keast (ed.) “Ecological Biography of Australia” Vol 1. Junk, The Hague. pp. 606-694.

West, .W., Stocker, G.C. and Unwin, G.L. (1988) - Environmental relationships and floristic and structural change in some unlogged tropical rainforest plots of north Queensland. *Proc. Ecol. Soc. Aust.* **15:** 49-60.

Whitmore, T.C. (1984) - “Tropical Rainforests of the Far East” 2nd ed. Clarendon Press, Oxford. 352 pages.

Appendix

The following is a list of permanent sample plots in Queensland Forest Service rainforest database at the time this study was commenced. Only those plots with a valid site quality were used in the present analyses. Geological types are Alluvial (AL), Acid Volcanic (AC), Basic Volcanic (BV), Coarse-grained Granite (CG), Sedimentary and Metamorphic (SM) and Tully fine-grained Granite (TG). Rainforest structural types follow Tracey and Webb (1976). Brief descriptions of the origin of the various plot types are given below.

Expt No	Plot No	State Forest	AMG Grid Ref.	Area (ha)	First measure	Last measure	Geol type	Site qual	Alt. (m)	Aspect	Slope (deg)	Rain (mm)	Struct type	Years logged	Years treated	Plot type
69	1	185	55 349700 8101050	0.4047	48	59	SM	5.0	670	WSW	5	1320	6			1
77	1	185	55 348800 8101300	0.4047	48	57	SM	6.0	670	N	10	1320	6	43		1
77	2	185	55 348860 8101300	0.4047	48	57	SM	7.4	670	N	10	1320	6	43,52	52	1
78	1	185	55 349690 8100330	0.4047	48	87	BV	7.8	680	NNW	5	1320	6	43		1
78	2	185	55 349690 8100290	0.4047	48	87	SM	2.0	680	NNW	5	1320	6	43,49	49	1
79	1	185	55 349100 8101300	0.4047	49	57	SM	4.9	670	N	10	1320	6	43	51	1
79	2	185	55 349160 8101300	0.4047	49	57	SM	5.5	670	N	10	1320	6	43	51	1
89	1	191	55 340090 8082800	0.0405	51	64	BV	9.0	680	-	0	1400		27	51	2
89	2	191	55 340090 8082780	0.0405	53	64	B V	-	680		0	1400		27	51	2
99	1	191	55 339030 8082560	0.1036	52	70	BV	-	680		0	1400		28	53	2
99	2	191	55 339030 8082560	0.1036	52	70	BV	-	680	SE	5	1400		28	53	2
99	3	191	55 339030 8082560	0.1012	52	70	BV	-	680		0	1400		28	53	2
99	4	191	55 339030 8082560	0.1012	61	73	BV	-	680		0	1400		28	53	2
99	5	191	55 339030 8082560	0.0838	52	70	BV	-	680	SE	5	1400		28	53	2
99	6	191	55 341100 8082510	0.0979	52	87	BV	-	680		0	1400		28	52	2
99	7	191	55 341190 8082580	0.1024	52	87	BV	-	680		0	1400		28	52	2
110	2	310	55 361090 8086740	0.1012	52	68	BV	5.6	670	N	5	2000		30,68	30,53	3
111	1	185	55 350120 8099160	0.1578	52	68	SM	5.5	680	N	10	1320	6	39		4
111	2	185	55 350020 8099130	0.1348	52	68	SM	-	670	W	10	1320	6	39	52	4
111	3	185	55 350200 8099090	0.1643	52	68	SM	7.6	680	SE	10	1320		39	52	4
137	1	194	55 331410 8086410	0.1060	54	77	CG	4.6	1080	W	5	1650		53,80	53,57	5
159	1	191	55 339670 8082920	0.1012	54	70	BV	-	680		0	1400	5b	33	54,62	5
159	2	191	55 339580 8082900	0.1012	54	70	BV	1.4	680		0	1400	5b	33	54,62	5
159	3	191	55 339580 8082990	0.1012	54	70	BV	5.0	680		0	1400	5b	33	54,62	5
159	4	191	55 339660 8083000	0.1012	54	70	BV	3.0	680		0	1400	5b	33	54,62	5
159	5	191	55 339650 8083080	0.1012	55	70	BV	4.6	680		0	1400	5b	33	54,58,62	5
159	6	191	55 339610 8083070	0.1012	55	70	BV	2.0	680	-	0	1400	5b	33	54,58,62	5
159	7	191	55 339570 8083060	0.1012	55	70	BV	-	680	-	0	1400	5b	40	54,58,62	5
166	1	251	55 347980 8038080	0.4047	69	83	BV	7.0	720	W	10	1800		55	56,57,62	5
166	2	251	55 347960 8038060	0.4047	69	83	BV	7.1	720	W	10	1800		55	56,57,62	5
167	1	194	55 331660 8086520	0.3541	54	63	CG	4.0	1060	-	0	1650		53	54	5
167	2	194	55 331640 8086570	0.2023	55	63	CG	7.2	1060	-	0	1650		53	54	5
174	1	310	55 361450 8086720	0.1010	54	68	BV	5.3	670	SSW	5	2000		29,68	29,54	3
174	2	310	55 361450 8086720	0.1008	54	68	BV	5.0	670	ESE	5	2000		29,68	29,54	3
178	1	1229	55 350960 8146940	0.0283	55	62	SM	0.2	440	-	0	2090	12c	50,78	55,62	5
178	2	1229	55 350980 8146940	0.0809	55	76	SM	3.2	440	N	5	2090	12c	50,78	55,62	5

178	3	1229	55 351060 8146940	0.0348	55	62	SM	3.7	440	-	0	2090	12c	50,78	55,62	5
180	1	1229	55 351300 8147000	0.0769	56	78	SM	5.7	440	-	0	2030	2a	51,77	56	5
184	1	310	55 357970 8090050	0.4047	55	68	BV	4.7	720	-	0	2030	1b	58	59	1
184	2	310	55 358100 8089950	0.4047	55	68	BV	6.2	720	-	0	2030	1b	58	59	1
207	1	194	55 332850 8087000	0.1012	56	68	CG	8.8	1130	N	5	1650	9	68		6
222	1	310	55 361180 8086730	0.1036	58	68	BV	6.2	670	NNW	5	2000		28	29	3
222	2	310	55 361130 8086680	0.1012	58	68	BV	5.8	670	NNW	5	2000		28	29,58	3
222	3	310	55 361060 8086610	0.1012	58	68	BV	5.8	670	NNW	5	2000		28	29,58	3
222	4	310	55 361110 8086680	0.1004	58	68	BV	5.9	670	NNW	10	2000		28	29,58	3
224	1	310	55 361470 8086320	0.1012	58	68	BV	7.4	670	SW	10	2000		28	29	3
224	2	310	55 361470 8086390	0.1000	58	68	BV	8.0	670	SW	10	2000		28	29,58	3
224	3	310	55 361560 8086360	0.1012	58	68	BV	6.1	670	SW	5	2000		28	29,58	3
224	4	310	55 361580 8086360	0.1012	58	68	BV	5.9	670	SW	5	2000		28	29,58	3
224	5	310	55 361330 8086390	0.1008	58	68	BV	6.0	670	NE	5	2000		28	29,58	3
224	6	310	55 361330 8086440	0.1020	58	68	BV	7.1	670	NE	5	2000		28	29,53	3
226	1	310	55 358520 8090320	0.0777	58	74	BV	-	670	NNE	5	1800		57	58	5
241	1	310	55 358600 8090400	0.1267	59	75	BV	6.4	720	NE	25	2030	1b	58	59	5
242	1	194	55 331700 8084050	0.1117	59	74	AV	4.6	1035	N	25	1650	9	58	58	5
243	1	194	55 332870 8089170	0.2598	59	74	CG	3.8	980	W	10	1650		54	56,59	5
245	1	1229	55 349910 8147220	0.2068	59	72	SM	3.2	440	-	0	2030	2a	58	59	5
245	2	1229	55 349880 8147260	0.2262	59	72	SM	4.2	440	-	0	2030	2a	58	59	5
245	3	1229	55 349940 8147260	0.1941	59	72	SM	2.3	440	-	0	2030	2a	58	59	5
246	1	1229	55 351480 8146450	0.2582	59	79	SM	3.4	440	-	0	2030	12c	52	58	5
246	2	1229	55 351480 8146450	0.2145	59	79	SM	4.1	440	-	0	2030	12c	52	58	5
246	3	1229	55 351750 8146450	0.2307	59	79	SM	4.4	440	W	10	2030	12c	52	58	5
246	4	1229	55 351750 8146540	0.1959	59	79	SM	7.1	440	W	10	2030	12c	52	58	5
250	1	1229	55 352220 8145720	0.1214	60	75	SM	4.1	430	ESE	5	2030	2a	49	59,61,70	5
250	2	1229	55 352300 8145580	0.1012	60	75	SM	4.7	430	N	S	2030	12c	49	59,61,70	5
282	1	194	55 331950 8084360	0.1068	61	74	AV	7.6	1040	W	15	1650	9	60	60,61	5
282	2	194	55 331950 8084460	0.1166	61	74	AV	-	1040	W	15	1650	9	60	60,61	5
282	3	194	55 332040 8084460	0.1216	61	70	AV	-	1040	W	15	1650	9	60	60,61	5
283	1	194	55 332750 8089530	0.1445	61	74	CG	9.6	1040	W	5	1650	9	57	57,61	5
283	2	194	55 332750 8089550	0.1538	61	74	CG	6.9	1040	W	5	1650	9	57	57,61	5
283	3	194	55 332750 8089590	0.1194	61	70	CG	7.4	1040	W	5	1650	9	57	57,61	5
310	1	310	55 358300 8090150	0.0911	55	75	BV	4.1	670	W	5	2030	1b	55	55,65	5
311	1	194	55 332200 8084450	0.1012	61	87	AV	9.2	1040	SW	15	1650	16c	60	60	5
317	1	185	55 349950 8101010	0.1012	62	67	SM	-	730	-	0	1320		43,51	62	5
321	1	185	55 354030 8105410	0.1012	61	71	SM	5.0	730	NE	10	1650		45,60	60	5
322	1	1229	55 351060 8145760	0.1012	61	79	SM	7.2	488	WNW	15	2030	2a	56	61,75	5
324	1	1229	55 349920 8146860	0.0777	63	74	SM	5.4	460	E	5	2100		48	62	5
329	1	1137	55 400400 8026150	0.1590	63	82	SM	6.6	30	-	0	4000	2a	60	62,65	5
329	2	1137	55 400450 8026250	0.1348	63	82	SM	-	30	SW	15	4000	2a	60	62,65	5
331'	1	185	55 352940 8105580	0.1012	61	71	CG	-	730	SE	15	1650		58	62	5
332	1	1229	55 351630 8144880	0.1012	62	79	SM	7.0	560	W	10	2080		57	62,74	5
333	1	310	55 360510 8089250	0.1064	61	78	SM	2.5	670	SW	10	2090		58	61,73	5

347	1	310	55 358110 8089430	0.1012	59	74	BV	7.2	670	WNW	5	2000		55	55,59	5
350	1	458	55 351100 8024380	0.2015	65	66	CG	-	600			1500		64	65	5
352	1	185	55 352590 8101460	0.2764	65	75	SM	7.8	680	SE	5	1320		30	65,71	5
370	1	605	55 351150 8024300	0.2023	69	84	TG	5.0	760	NE	5	2000	8	52		1
370	2	605	55 351200 8024300	0.2023	69	80	TG	2.5	760	NE	5	2000	8	52	65,68	1
380	1	1229	55 351300 8146920	0.0405	66	84	SM	0.6	440	SE	5	2030		52,77	54	7
380	2	1229	55 351280 8146910	0.0405	66	84	SM	4.4	440	SE	5	2030		52,77	54	7
380	3	1229	55 351360 8146850	0.0405	66	84	SM	4.1	440	SE	5	2030		52,77	54	7
380	4	1229	55 351360 8146790	0.0405	66	84	SM	3.2	440	SE	5	2030		52,77	54,68	7
380	5	1229	55 351300 8146830	0.0405	66	84	SM	1.6	440	SE	5	2030		52,77	54,68	7
380	6	1229	55 351240 8146870	0.0405	66	84	SM	2.5	440	SE	5	2030		52,77	54,68	7
380	7	1229	55 351290 8146770	0.0405	66	84	SM	4.5	440	SE	5	2030		52,77	54,68	7
380	8	1229	55 351180 8146770	0.0405	66	84	SM	0.6	440	SE	5	2030		52,77	54,68	7
380	9	1229	55 351230 8146740	0.0405	66	84	SM	2.0	440	SE	5	2030		52,77	54,68	7
380	10	1229	55 351360 8146720	0.0405	66	84	SM	6.7	440	SE	5	2030		52,77	54	7
380	11	1229	55 351310 8146690	0.0405	66	84	SM	5.6	440	SE	5	2030		52,77	54	7
380	12	1229	55 351350 8146650	0.0405	66	84	SM	6.1	440	SE	5	2030		52,77	54	7
380	13	1229	55 351340 8146570	0.0405	66	84	SM	4.8	440	SE	5	2030		52,77	54,68	7
380	14	1229	55 351320 8146620	0.0405	66	84	SM	7.0	440	SE	5	2030		52,77	54,68	7
380	15	1229	55 351250 8146640	0.0405	66	84	SM	5.4	440	SE	5	2030		52,77	54,68	7
380	16	1229	55 351200 8146660	0.0405	66	84	SM	3.4	440	SE	5	2030		52,77	54,68	7
380	17	1229	55 351180 8146720	0.0405	66	84	SM	1.4	440	SE	5	2030		52,77	54,68	7
380	18	1229	55 351120 8146710	0.0405	66	84	SM	4.0	440	SE	5	2030		52,77	54,68	7
381	11	194	55 332330 8085780	0.0405	66	84	CG	8.9	1180	NE	10	1650		56,80	53	7
381	12	194	55 332350 8085790	0.0405	67	84	CG	6.8	1180	NE	10	1650		56,80	53	7
381	17	194	55 331950 8085970	0.0405	67	84	CG	8.4	1180	SW	5	1650		56,80	53,67	7
381	18	194	55 331950 8085920	0.0405	67	77	CG	5.2	1180	SW	10	1650		56	53,67	7
381	21	194	55 331790 8085870	0.0405	67	84	CG	2.5	1180	SE	5	1650		56,80	53,67	7
381	22	194	55 331750 8085890	0.0405	67	84	CG	6.0	1180	SE	5	1650		56,80	53,67	7
381	24	194	55 331930 8086000	0.0405	67	84	CG	-	1180	SW	5	1650		56,80	53,67	7
381	25	194	55 331910 8086000	0.0405	67	84	CG	2.5	1180	SW	10	1650		56,80	53,67	7
381	26	194	55 331730 8085970	0.0405	70	84	CG	-	1180	E	10	1650		56,80	53,67	7
381	27	194	55 331750 8085920	0.0405	67	84	CG	3.9	1180	E	5	1650		56,80	53	7
381	28	194	55 331650 8085970	0.0405	67	84	CG	8.6	1180	NE	10	1650		56,80	53	7
381	29	194	55 331640 8085900	0.0405	71	84	CG	4.7	1180	E	10	1650		56,80	53,67	7
381	30	194	55 331640 8085930	0.0405	71	84	CG	7.2	1180	E	10	1650		56,80	53,67	7
408	41	194	55 331690 8087040	0.2023	69	75	CG	6.2	1130	S	10	1650		69		4
408	42	194	55 331600 8086960	0.2023	69	75	CG	6.1	1130	SW	10	1650		69		4
408	43	194	55 331500 8087040	0.2023	69	75	CG	3.7	1130	S	10	1650		69	69	4
408	44	194	55 331400 8086960	0.2023	69	75	CG	3.8	1130	S	10	1650		69	69	4
408	45	194	55 331300 8087040	0.2023	69	75	CG	4.4	1130	SW	5	1650		69	69	4
408	46	194	55 331210 8086960	0.2023	69	75	CG	4.8	1130	SW	5	1650		69	69	4
408	47	194	55 331400 8087220	0.2023	69	75	CG	3.9	1130	NE	5	1650		69	69	4
408	48	194	55 331500 8087170	0.2023	69	75	CG	4.7	1130	NE	5	1650		69	69	4
423	1	756	55 354920 8052880	0.2023	68	76	BV	-	820	NE	20	2500		45,64	68	5

423	2	756	55 355080 8052650	0.2023	68	73	BV	-	820	NE	20	2500		45,64	68	5
423	3	756	55 355030 8052720	0.2023	68	73	BV	6.2	820	NE	20	2500		45,64	68	5
423	4	756	55 354970 8052800	0.2023	68	73	BV	-	820	NE	20	2500		45,64	68	5
423	5	756	55 355020 8052860	0.2023	68	73	BV	-	820	NE	20	2500		45,64	68	5
423	6	756	55 354960 8052920	0.2023	68	73	BV	-	820	NE	20	2500		45,64	68	5
423	7	756	55 355200 8052740	0.2023	68	73	BV	-	820	SW	10	2500		45,64	68	5
423	8	756	55 355140 8052800	0.2023	68	73	BV	6.2	820	SW	10	2500		45,64	68	5
423	9	756	55 355130 8052950	0.2023	68	73	BV	5.7	820	SW	10	2500		45,64	68	5
423	10	756	55 355190 8052830	0.2023	68	73	BV	7.4	820	SW	10	2500		45,64	68	5
423	11	756	55 355260 8052780	0.2023	68	73	BV	-	820	SW	10	2500		45,64	68	5
423	12	756	55 355070 8053020	0.2023	68	73	BV	4.8	820	SW	10	2500		45,64	68	5
431	1	1137	55 401150 8025700	0.1012	64	87	SM	7.2	30	-	0	4000	2a	50	56,64	1
431	2	1137	55 400700 8025700	0.1012	64	87	SM	-	30	N	5	4000	2a	50	56,64	1
434	1	310	55 361160 8086590	0.2023	70	83	BV	6.5	670	W	10	2000		30,69	29	3
434	2	310	55 361160 8086630	0.2023	70	83	BV	5.8	670	SE	10	2000		30,69	29,70	3
434	3	310	55 361150 8086830	0.2023	70	83	BV	5.9	670	W	10	2000		30,69	29,70	3
434	4	310	55 361150 8086920	0.2023	70	83	BV	6.5	670	W	10	2000		30,69	29,70	3
434	5	310	55 361270 8086670	0.2023	70	83	BV	6.1	670	W	10	2000		30,69	29,70	3
434	6	310	55 361360 8086673	0.2023	70	83	BV	6.2	670	W	10	2000		30,69	29,70	3
434	7	310	55 361410 8086630	0.2023	70	83	BV	6.5	670	S	10	2000		30,69	29,70	3
434	8	310	55 361410 8086550	0.2023	70	83	BV	9.4	670	N	10	2000		30,69	29,70	3
434	9	310	55 361550 8086550	0.2023	70	83	BV	5.8	670	S	10	2000		30,69	29,70	3
434	10	310	55 361500 8086620	0.2023	70	83	BV	6.6	670	S	10	2000		30,69	29	3
434	11	310	55 361630 8086590	0.2023	70	83	BV	5.6	670	S	20	2000		30,69	29,70	3
434	12	310	55 361630 8086520	0.2023	70	83	BV	5.2	670	SE	20	2000		30,69	29	3
450	1	310	55 366880 8079880	0.2023	70	84	BV	1.2	760	NW	5	2000		51,70	70,73	5
450	2	310	55 366735 8079950	0.2023	70	72	BV	1.4	760	NW	5	2000		51,70	70,73	5
450	3	310	55 366770 8079830	0.2023	70	84	BV	2.2	760	NW	5	2000		51,70	70,73	5
450	4	310	55 366690 8079855	0.1214	70	72	BV	-	760	NW	5	2000		51,70	70,73	5
450	5	310	55 366675 8079805	0.1214	70	72	BV	4.5	760	NW	5	2000		51,70	70,73	5
450	6	310	55 366760 8079770	0.1214	70	72	BV	5.4	760	NW	5	2000		51,70	70,73	5
450	7	310	55 366830 8079750	0.1214	70	72	BV	-	760	NW	5	2000		51,70	70,73	5
456	2	194	55 331660 8086520	0.1518	69	77	CG	8.8	1060	N	5	1650		54	54	5
469	11	607	55 353550 8126520	0.1619	70	82	CG	4.8	460	S	5	1800		59	70	8
469	12	607	55 353560 8126500	0.1619	70	82	CG	4.6	460	S	5	1800		59	70	8
469	13	607	55 353570 8126500	0.1619	70	82	CG	3.4	460	S	5	1800		59	70	8
469	14	607	55 353540 8126520	0.1619	70	82	CG	5.1	460	S	5	1800		59	70	8
469	21	607	55 353510 8126510	0.1619	70	82	CG	4.9	460	W	5	1800		59	70	8
469	22	607	55 353530 8126490	0.1619	70	82	CG	6.2	460	W	5	1800		59	70	8
469	23	607	55 353510 8126480	0.1619	70	82	CG	6.5	460	W	5	1800		59	70	8
469	24	607	55 353540 8126500	0.1619	70	82	CG	9.1	460	W	5	1800		59	70	8
469	31	607	55 353530 8126530	0.1619	70	82	CG	1.9	460	SW	5	1800		59	70	8
469	32	607	55 353540 8126510	0.1619	70	82	CG	5.2	460	SW	5	1800		59	70	8
469	33	607	55 353550 8126530	0.1619	70	82	CG	6.1	460	SW	5	1800		59	70	8
469	34	607	55 353560 8126510	0.1619	70	82	CG	6.2	460	SW	5	1800		59	70	8

576	1	756	55 362000 8038200	PRISM	78	87	BV	-	760	SW	10	2500		77		9
577	1	144	55 294450 8198710	PRISM	77	86	CG	-	1006	E	18	1036		77		9
582	1	144	55 292680 8200130	PRISM	77	87	CG	-	1070	S	13	1970		77		9
591	1	607	55 353600 8115540	0.4087	52	84	CG	8.2	730	SW	15	2200	8/9			10
594	1	310	55 357900 8089980	0.0741	51	83	BV	7.0	720	NE	5	2030	1b			10
594	2	310	55 357900 8090000	0.1437	51	83	BV	8.3	720	NE	5	2030	1b			10
594	3	310	55 357900 8090020	0.0660	51	83	BV	7.1	720	NE	5	2030	1b			10
595	1	310	55 361020 8086910	0.3237	51	83	BV	5.9	670	SW	10	2000		29	29	10
598	1	755	55 358550 8073100	PRISM	78	85	BV	-	520	SW	5	2540		62		9
606	1	185	55 357120 8098500	0.1012	50	83	BV	7.5	720	SW	5	1850		16	53,65	11
608	1	310	55 364300 8078600	0.2023	51	87	BV	7.4	760	N	5	2290	1b	49		4
608	2	310	55 364300 8078600	0.1955	53	87	BV	6.9	760	E	5	2290	1b	49,72	53,66	4
608	3	310	55 364300 8078600	0.2064	56	87	BV	6.4	760	E	S	2290		49	56,66	4
609	1	2S1	55 343480 8041060	0.1S18	51	87	AV	S.6	770	S	10	1700	9	50		4
609	2	2S1	55 343520 8041040	0.2003	52	87	AV	3.8	770	S	20	1700	9	50	52	4
610	1	1229	55 352380 8145710	0.2023	51	87	SM	7.3	440	E	S	2030	12c	49		4
610	2	1229	55 352340 8145750	0.2023	52	87	SM	S.8	440	E	S	2030	12c	49	52,66	4
610	3	1229	55 352320 8145780	0.2023	55	87	SM	6.0	440	NE	S	2030		49	55	4
611	1	VCL	55 376200 8022500	0.2023	51	68	AL	3.4	20	N	S	3800	la	50		4
611	2	VCL	55 376250 8022500	0.2064	52	68	AL	S.2	20	N	S	3800	la	50	52,58	4
611	3	VCL	55 375700 8022500	0.2023	55	68	AL	6.4	20	N	S	3800	la	50	55	4
612	1	268	55 409800 7904700	0.2023	51	86	CG	7.3	550	N	S	1900	8/6	51		4
612	2	268	55 409700 7904600	0.2023	52	86	CG	S.1	550	N	S	1900		51	52,66	4
612	3	268	55 409800 7904700	0.2023	55	86	CG	7.1	550	N	S	1900		51	55,73	4
613	1	344	55 367550 7987550	0.2023	51	86	CG	6.8	600	E	S	1300	2a	47		4
613	2	344	55 367530 7987570	0.2023	52	86	CG	3.3	600	E	S	1300	2a	47	52,66	4
613	3	344	55 367580 7987590	0.2023	55	86	CG	7.2	600	E	S	1300		47	55,66	4
614	1	1137	55 401650 8020500	0.2193	52	87	SM	3.8	30	E	1S	4000	2a	50		4
614	2	1137	55 401650 8020620	0.2193	52	87	SM	5.0	30	E	20	4000		50	52	4
614	3	1137	55 401560 8020410	0.2023	55	87	SM	S.6	30	SSW	20	4000		50	55,66	4
61S	1	194	55 335650 8079850	0.2023	52	85	CG	7.7	1100	E	20	1650		47,54,77	52,66	4
61S	2	194	55 335600 8079900	0.2024	52	85	CG	8.4	1100	E	20	1650		47,54,77	52,66	4
61S	3	194	55 335100 8079600	0.2185	52	85	CG	8.4	1100	W	10	1650	14a	47,54		4
61S	4	194	55 334700 8079200	0.2023	52	85	CG	7.2	1100	S	S	1650		47	52,66	4
61S	S	194	55 334600 8079300	0.2023	52	85	CG	9.1	1100	S	S	1650		47,54	52,66	4
61S	6	194	55 334650 8079200	0.2064	52	85	CG	9.8	1100	S	S	1650	14a	47,54		4
616	1	194	55 332050 8086220	0.2084	52	87	CG	9.2	1100	NE	S	1650	9	51,80		4
616	2	194	55 332070 8086280	0.2023	52	87	CG	7.1	1100	NE	S	1650	9	51,80	52,66	4
616	3	194	55 332050 8086280	0.2023	52	87	CG	6.8	1100	NE	S	1650	9	51,80	52,66	4
617	1	194	55 331850 8086100	0.1012	53	87	CG	7.6	1130	E	10	1650		51,80	53	4
617	2	194	55 331800 8086150	0.1012	53	87	CG	7.7	1130	E	10	1650		51,80	53,60	4
617	3	194	55 331700 8086150	0.1016	53	87	CG	S.7	1130	-	0	1650		51,80	53,60	4
617	4	194	55 331700 8086100	0.1016	53	87	CG	8.3	1130	E	20	1650		51,80	53,60	4
617	S	194	55 331750 8086100	0.1028	53	87	CG	6.6	1130	E	20	1650		51,80	53,60	4
617	6	194	55 331900 8086050	0.1416	53	87	CG	3.9	1130	NE	S	1650		51,80	52,60,66	4

618	1	2S1	55 348080 8038100	0.2003	54	87	BV	9.1	740	-	0	1800	5a	52,67		4
618	2	2S1	55 348060 8037340	0.2023	56	87	BV	6.2	760	SE	S	1800	5a	52,67	56	4
618	3	2S1	55 348080 8038050	0.2023	56	87	BV	6.5	740	-	0	1800		52,67	56	4
619	1	4S8	55 375500 7928410	0.3966	54	86	CG	8.7	600	NW	S	1500	8	47,73		4
619	2	4S8	55 375500 7928350	0.4047	54	66	CG	7.7	600	NW	5	1500	8/6	47	54	4
619	3	458	55 375550 7928350	0.1619	66	86	CG	4.9	600	NW	5	1500	8/6	47,73	54,66	4
619	4	4S8	55 375450 7928350	0.1619	66	86	CG	S.6	600	NW	S	1500		47,73	54,66	4
620	1	1229	55 351180 8146840	0.4047	55	87	SM	3.0	440	E	10	2030	12c	52,76	55,76	4
621	1	194	55 332710 8087400	0.2023	68	85	CG	7.4	1100	W	1S	1650	9	64		4
621	2	194	55 332450 8087360	0.2023	68	85	CG	4.7	1100	SE	1S	1650	9	64	68	4
622	1	310	55 360500 8091400	0.2023	68	85	BV	6.0	640	NW	S	2030	1b	67		4
622	2	310	55 360620 8091400	0.2023	68	85	BV	6.6	640	SE	10	2030	1b	67	68	4
623	1	1229	55 349600 8148520	0.2023	68	84	SM	6.1	430	NW	S	2030	2a	57		4
623	2	1229	55 349680 8148550	0.2023	68	84	SM	7.4	430	NW	S	2030	2a	57	68	4
623	3	1229	55 349660 8148580	0.2023	68	84	SM	7.S	430	NW	S	2030	2a	57	68	4
624	1	60S	55 352200 8025050	0.2023	68	84	TG	S.8	760	NE	20	2000	8	51		11
624	2	60S	55 351980 8024650	0.2023	68	84	TG	6.6	760	NE	S	2000	8	52		11
624	3	60S	55 352980 8024550	0.2023	68	84	TG	4.7	760	SW	1S	2000	8	51		11
624	4	60S	55 352680 8024180	0.2023	68	84	TG	7.2	760	W	2S	2000	8	51		11
624	S	60S	55 349850 8024060	0.2023	68	84	TG	S.8	760	SW	S	2000	8	52,80		11
62S	1	18S	55 354400 8106740	0.2023	68	84	CG	9.6	700	W	1S	1650	8	52		11
62S	2	18S	55 350510 8107810	0.2023	69	84	CG	8.8	94S	S	2S	1650	8/9			11
62S	3	185	55 352310 8108900	0.2023	68	84	CG	8.8	1065	SW	2S	1650	9	65		11
62S	4	18S	55 351200 8107360	0.2023	68	84	CG	6.9	790	E	1S	1650	8/9	52		11
62S	S	185	55 351150 8106620	0.2023	68	84	CG	7.2	730	SE	20	1650	8	70		11
626	1	1229	55 355500 8143090	0.2023	69	87	SM	S.4	360	SSW	S	2030	2a	54		11
626	2	1229	55 354760 8143540	0.2023	69	87	SM	7.0	360	NE	10	2030	2a			11
640	1	7S6	55 361100 8052500	PRISM	79	86	BV	-	720	N	15	2000		62,80		9
679	1	144	55 290900 8201600	PRISM	80	85	CG	-	1100	N	S	1036		80		9
679	2	144	55 290600 8201700	PRISM	80	85	CG	-	1060	NE	S	1036				9
701	1	756	55 371650 8047300	PRISM	85	88	CG	-	400			2000		87		9
EP	2	185	55 349550 8103510	0.5000	71	87	CG	-	720	SE	5	1200		43		12
EP	3	607	55 350290 8110090	0.5000	71	87	CG	-	1120	NE	15	2400				12
EP	4	933	55 337490 8129060	0.5000	72	88	CG	6.4	80	SW	5	2500		59		12
EP	9	185	55 354440 8106960	0.5000	72	88	CG	-	710	E	20	1650		63		12
EP	18	143	55 311100 8169830	0.5000	73	87	CG	-	1100	W	5	2500				12
EP	19	750	55 368800 7954780	0.5000	75	87	CG	-	620	SE	10	2000				12
EP	29	650	55 345710 8059260	0.5000	75	87	AV	-	1200	SE	15	2700				12
EP	30	144	55 293260 8199380	0.5000	76	88	CG	-	980	W	5	1500				12
EP	31	755	55 375510 8061530	0.5000	76	88	SM	6.0	80	S	5	4000				12
EP	32	TR 14	54 752330 8479700	0.5000	75	87	SM	2.8	450	SW	5	2000				12
EP	33	452	55 348100 8088250	0.5000	76	88	BV	-	720	-	0	1400		52		12
EP	34	755	55 369440 8074860	0.5000	76	88	AL	-	380	SW	5	4000				12
EP	35	TR 55	55 322210 8190920	0.5000	77	87	SM	-	230	SE	10	2900				12
EP	37	679	55 660835 7649387	0.5000	77	87	BV	-	920	SE	5	2400				12

EP	38	194	55 338220 8073640	0.5000	77	87	AV	-	1000	SE	10	1800	12
EP	40	144	55 297320 8198970	0.5000	78	88	CG	-	800	N	10	1300	12
EP	41	NP	55 333200 8215260	0.5000	77	87	AL	-	15	SE	5	3500	12
EP	42	CL	54 745020 8590560	0.5000	77	87	AL	-	30	SE	10	2200	12
EP	43	194	55 333560 8085620	0.5000	78	88	AV	-	1120	S	20	2000	12
EP	44	144	55 295120 8205880	0.5000	80	88	CG	-	880	NW	5	2500	12

Plot Types:
1. Paired treatment plots comparing growth with and without silvicultural treatment.
2. Plots monitoring the development of regeneration.
3. Experiments monitoring development of enrichment plantings following thinning to various spacings.
4. Experiments monitoring development of rainforest following application of different silvicultural treatment prescriptions. 5. Experiments monitoring development of enrichment plantings.
6. Experiment examining benefits of silvicultural treatment 10 years prior to logging, with a view to getting more regeneration. 7. Experiments monitoring effects of re-treatment 15 years after initial silvicultural treatment. 8. Treatment of unproductive rainforest attempting to produce a viable timber harvest.
9. Logging damage studies.
10. Plots monitoring development of dense stands of rainforest.
11. Plots monitoring growth and yield in rainforest under routine management. These plots were deliberately located to sample good, average and poor rainforest.
12. CSIRO growth monitoring plots described in West *et al.* (1988).