DETERMINATION OF TROPICAL FOREST STATUS USING SELECTED ECOLOGICAL CRITERIA AND INDICATORS

(A case study of Labanan concession, East Kalimantan, Indonesia)

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by

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ABSTRACT

Tropical forest degradation and/or deforestation are issues raising great concern among conservation scientists the world over. In particular, the rate of destruction of tropical forests, through the large extent of commercial logging has attracted a lot of attention. Moreover, many studies and reports indicate that this destruction is on the increase, given the rising demand for wood products from tropical forests, with the rising world population. As tropical forest destruction increases, so does the demand for their sustainable management from sections of people with environmental or conservation concerns. Consequently, at both international and national levels, a number of initiatives have come with suggestions of criteria and indicators for sustainable forest management determination. However, most of their propositions are still very broad and rarely find appropriate applicability at the Forest management unit level. This study looks at ecological criteria and indicators developed by one such type of organisation in Indonesia, known as Lembaga Ekolabel Indonesia (LEI).

Within the framework of this study, one ecological criterion, two indicators and five verifiers were selected from a list already developed by LEI. The overall aim was to use these verifiers in an attempt to determine tropical forest status from an ecological point of view, as well as assess how the verifiers are being measured, and used to assess sustainability of Natural tropical forest by a certification body which is accredited by LEI. The methods of assessment of the verifiers used in this study were then compared to the methods used by the certification body, with suggestions for improvement where weaknesses were observed.

Specifically, the study aimed at comparing the tree species composition of areas of primary or undisturbed forest, with areas that were logged more than 20 years ago, as well as with areas that are planned for logging, but have not yet been logged. The Sorensen coefficient of similarity was used for this purpose. Results showed that for the seedling and tree categories, the unlogged forest area was more similar to primary forest than the area that was logged more than 20 years ago, whereas for the sapling species, the similarity coefficient was the same for the two areas. Also, the species abundances of areas logged from 1 to 10 years ago, 11 to 20 years ago, more than 20 years ago and unlogged forest area, were compared with a primary forest area. Using the Mann Whitney test of significance, no difference was found between the abundances of these areas and the unlogged forest area at (α = 0.05). Patterns of change of tree species diversity with time across areas harvested at different times were also studied using the Shannon and Simpson indices as measures of tree species diversity. Mean diversity indices were computed for different areas logged at five-year intervals, which were then plotted against the five-year periods. Results revealed that the Simpson index did not fluctuate as much as the Shannon index did, with the five-year periods.

The study also attempted to assess the extent of forest ecosystem damage at two different times within a river-protected area, which was defined as being 100 metres to both sides of the river. Agricultural encroachment areas within the river-protected area were determined, and their areas summed up and taken as a proportion of the total river protected area. This proportion was then related to the LEI intensity scale of indicators for Sustainable Natural Production Forest Management.

It was also attempted to find out whether a relationship existed between reflectance values of Landsat TM and tree diversity indices, with the hope that if this yielded a considerable relationship, then it would provide a basis for tree diversity estimation, which would consequently reduce the costs usually

encountered in carrying out field surveys. However, no observed relationship was found in this respect.

With regard to rating on the intensity scale of indicators for Sustainable Natural Production Forest Management, the overall rating for tree species diversity was rated “POOR”, whereas that of intensity of damage within the river-protected area was “GOOD”. Using the similarity index, the overall rating was “FAIR”. Comparatively, the assessors assessed the forest both in terms of species diversity as well as intensity of damage within the protected area as “FAIR”.

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DEDICATION

This work is dedicated to my parents Mr and Mrs. Aguma for their relentless efforts that saw me through the earlier part of my education and to my brothers Michael, Rogers, William and sister Agnes for being very wonderful.

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1. INTRODUCTION

1.1. Background

The issue of tropical forest degradation/deforestation has been at the centre stage of controversy in terms of its environmental consequences for almost three decades. This has raised a lot of concern at international scale, particularly regarding the impact of logging activities on the sustainable function of forests. According to (Poore, 1989) a study by the International Timber Trade Organization reports that less than one-tenth of tropical forests are managed on a sustainable basis. The growing international concern has led to an increasing demand for the sustainable management of forests, which has led to the development of criteria and indicators for assessing sustainable forest management by various organizations, processes or pacts (Appendix 1). The various bodies have been attempting to develop certification standards for assessing sustainable forest management for the past decade (Agung and Hinrichs, 2000). Whereas the efforts of these certifying bodies are commendable, at operational scale there is still a lack of understanding of how to optimally evaluate forest management activities in order to come up with a true picture of sustainability. Many of the existing indicators are either too broad to be used directly at local scale, or, the regulations are often too demanding, time consuming, and cannot easily be applied over a wide range of areas. Besides, most forest certification programs are largely based on public or stakeholder opinion instead of scientific understanding (Kneeshaw et al., 2000). Common to all certification initiatives, is the hierarchical framework within which the criteria and indicators for sustainable forest management fit i.e. working down from the goal (sustainable forest management itself), to the principle, criterion, indicator and then to the verifier (Figure 1-1).

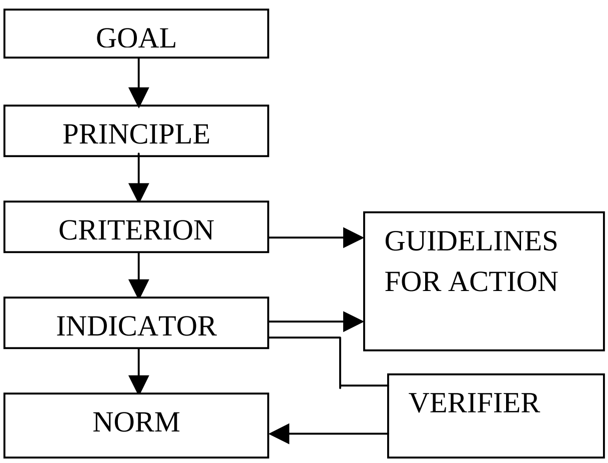


Figure 1-1: The Hierarchical levels of Sustainable Forest Management [Source: Geleens, 2001]

Definitions of the above terms by CIFOR (Center for International Forestry Research) cited in (Stock, 1997) are as given below:

A principle:

"A fundamental truth or law as the basis of reasoning or action." In the context of sustainable forest management, principles provide the primary framework for managing forests in a sustainable way. They provide the justification for criteria, indicators and verifiers. An example of a principle is "ecosystem integrity is maintained or enhanced".

A criterion:

"A standard that a thing is judged by." A criterion is a second order principle that adds meaning and operationability to a principle without itself being a direct measure of performance. They are intermediate points to which the information provided by indicators can be integrated and where interpretable assessment crystallizes. An example of a criterion is "Processes that maintain biodiversity are maintained".

An indicator:

"Any variable or component of the forest ecosystem or the relevant management systems used to infer attributes of the sustainability of the resource and its utilization." Indicators should convey a single meaningful message, which is regarded as information. An indicator is a combination of one or more data elements with certain established relationships. An example of an indicator is "landscape pattern is maintained."

A verifier:

"Data or information that enhances the specificity or the ease of assessment of an indicator." Verifiers provide specific details that would indicate or reflect a desired condition of an indicator. They may also be defined as "procedures needed to determine satisfaction of the conditions postulated in the indicator concerned." Verifiers add meaning, precision and site specificity to an indicator. An example of a verifier is "a real extent of each vegetation type in the intervention area relative to the area of the vegetation type in the forest management unit."

A Norm:

The reference value of an indicator and is established for use as a rule or a basis of comparison. Comparing the norm with the actual measured value demonstrates the degree of fulfilment of a criterion and compliance with a principle (Geleens, 2001).

1.2. Definition and concept of Sustainable Forest Management

The term "Sustainable Forest Management" has been used in forestry for a long time (Bouman, 1997). Different authors define it in different perspectives. Mok and Poore (1991) define it as "the process of managing forest land to achieve one or more clearly specified objectives of management without undue reduction of its inherent values and future productivity or undesirable effects on the physical and social environment". Alternatively, CIFOR cited in Mawdsley (1999), defines

Sustainable Forest Management as "a set of objectives, activities and outcomes consistent with maintaining or improving the forest's ecological integrity[1] and contributing to peoples well being both now and in the future." The former definition focuses more on not compromising the future production capacity of the forests, whereas the second is more on the side of maintaining ecological stability.

When translated into practice, the concept encompassed by the two definitions of sustainability can be summarized as operating at four levels; production of goods, services and benefits, maintaining environmental and conservation benefits, maintaining yields of timber and non-timber products and the provision of income over generations. These should neither compromise the productive capacity of the forests nor degrade the environment in the long term (Salleh, 1995) cited in Bouman (1997).

1.2.1. Forest status determination and sustainable forest management

The focus of this study is on ecological criteria and indicators, selected from a list already developed by the Indonesian Ecolabeling Institute otherwise known as the Lembaga Ekolabel Indonesia (LEI). A total of 57 indicators, grouped under 10 criteria have been listed, out of which 21 fall under production function (grouped under 3 criteria), 19 under ecological function (grouped under 2 criteria) and the remaining 17 under social function (grouped under 5 criteria) (http//: www.lei.or.id/eng/system/index.php3?ar=3&sub=0) [Accessed 19th November 2001].

Since this study uses selected ecological criteria and indicators, it is intended to assess forest status, through the assessment of the chosen criteria and indicators of sustainable forest management. A bigger scale assessment of Sustainable Forest Management would require overall assessment of all the criteria and indicators, which is beyond the scope of this study.

1.3. Reason for choice of the system of criteria and indicators

Out of the various organizations involved in certification (Appendix 1), the criteria and indicators developed by LEI were chosen since they were developed referring to standards set by ITTO and FSC, as well as the environmental management system set by ISO (Agung and Hinrichs, 2000). LEI has developed a complete certification system for SFM, which is to be used as a reference procedure for certification at national level. In addition, its system is considered the most practical and relevant since it is more locally adapted with regard to Indonesia. Also LEI is still in the process of evolving a credible certification system. This allows room for research into relevant areas for improvement, in particular, the criteria and indicators.

[1]Ecological integrity is the ability to support and maintain a balanced, integrated, adaptive biological community having a species composition, (bio) diversity and functional organization comparable to that of natural habitat in the region.

1.4. Selected Ecological Criteria, Indicators and Verifiers

As mentioned in section 1.2.1, the ecological criteria, indicators and verifiers used in this research were selected from among a set already developed by the Indonesian Ecolabeling Institute or Lembaga Ekolabel Indonesia (LEI). LEI was first established in 1994 as a working group to prepare the implementation of sustainable forest management certification. It was then formally established as a non-profit making legal entity in 1998 (Lembaga Ekolabel Indonesia, 1998, (http://www.lei.or.id/eng/profile/index.php3) (Access date 19th November 2001, see history of LEI). As a first step of working towards a credible forest certification system, LEI has come up with a list of criteria and indicators grouped under the three major categories of; productive, social and ecological functions (http://www.lei.or.id/eng/system/index.php3?ar=3&sub=0). (Access date-19thNovember 2001). Under the ecological functions, 2 criteria and 19 indicators have been listed, categorized as: Criterion 1 (the stability of ecosystem) with 11 indicators, and criterion 2 (the survival of endangered/endemic/protected species), with 8 indicators (Appendix 4). From the set of indicators listed under criterion 1, 2 indicators (E 1.3 and E 1.4) and five verifiers have been selected as follows:

Table 1-1: Selected ecological criteria, indicators and verifiers

Criterion	Indicator	Selected Verifiers
Stability of ecosystem	E 1.3 The intensity of damage in the protected areas which includes the danger of forest fires	-Size and type of damaged protected area. -Condition of damaged protected area
	E 1.4* Condition of tree species diversity in protected area in various forest formations/types within management units	-Tree species diversity in virgin (unlogged forest) -Tree species diversity in logged over area -Tree species diversity in protected area.

***This indicator and its associated verifiers have been modified to cover "tree species diversity" instead of "flora and fauna diversity" in order to fit them within the scope of this work.**

1.4.1. Basis for selecting the above mentioned criteria

The two criteria were selected from the LEI list of criteria and indicators since they were also selected on a scientific basis by (Mendoza, 1999), in a case study carried out in Kalimantan using the multicriteria decision-making technique. This study used the criteria and indicators developed by CIFOR, as a basis for their selection. Since the CIFOR toolbox of criteria and indicators is of renowned scientific value, then the selected criteria and indicators were also considered appropriate for this study. In the case study itself, an assessment team consisting of national and international experts drawn from various disciplines was chosen to conduct an assessment of a forest concession in Kalimantan. Their basis of assessment was a generic template of criteria and indicators, which was developed by Prabhu (et al., 1998) cited in (Mendoza, 1999). The purpose of the study was to examine the use of multiple criteria decision-making (MCDM) techniques as decision tools for applying the generic criteria and indicator template. The MCDM was applied at different stages and levels of the criteria and indicator assessment. At level 1, (Principle level), the team met and discussed and debated the different principles after which they expressed their opinion on the significance of each principle without divulging specifically how they voted on the individual principles. At level 2 (criteria level) the team was divided into two subgroups each with three members. One of the subgroups was inclined to policy and social principles, while the other was related to ecology and production principles. Each subgroup discussed and debated the criteria under their respective principles and scored them individually. The experts were consistent in their judgements while using the ranking and rating approaches. As seen in Appendix 2, principles P1, P2 and P6 were deemed most important. Thus from this set of principles, principle P2 "maintenance of ecosystem stability" which is relevant to this study was selected. The meanings of the other principles can be seen in Appendix 2. Out of the four criteria falling under this principle, criterion C 2.2 which is "the processes that maintain biodiversity in managed forests are conserved," was rated highest with a combined weight of 33%. Furthermore, the assessment team made revisions to the CIFOR set of criteria and indicators, in order to make the set more relevant to the local conditions within in the forest concession. Since the study was carried out in Kalimantan, then the Criteria and indicators were considered relevant to the study area (Labanan concession, East Kalimantan).

1.5. Loop-holes in the current measurement/verification method of the chosen criteria

1.5.1. Loopholes related to criterion E 1.3

For each indicator and verifier, LEI has developed a list of primary and secondary data requirements. The data requirements associated with indicator E 1.3 i.e. "the intensity of damage in the protected areas including damage from fire hazards" are listed in Appendix 3. While conducting the assessment, the following verification methods are specified; interviews with forest rangers and the local community, studying of forest security documents, followed by investigation on size and condition of protected area and forest security facilities and infrastructure. Analysis is directed at obtaining an indicator score based on size and intensity of damage to the protected area and the effective efforts by the management unit towards damage control.

From the verification methods mentioned above, as well as the report by P.T.Mutu Agung Lestari, the certification body accredited by LEI, it can be established that no exhaustive data analysis is done especially pertaining to the size of protected area damaged (P.T.Mutuagung Lestari, 2001). Whereas the use of aerial photographs and Landsat TM images is mentioned within the list of secondary data sources to be used for establishing the condition and extent of damage of the protected area, no claim of the use of this information is given in the report. The assessment is instead based on information contained in reports made by the management unit. The verification method associated with indicator 1.3 does not spell out clearly, the technique to be used in determining the quantitative rating associated with this indicator, yet in the intensity scale of criteria for Sustainable Production Forest Management, given in Table 1-2 below, emphasis is put on quantification of areas damaged, which are then expressed as a percentage of the total protected area. In addition, the P.T.Mutu Agung Lestari report does not give a definite percentage of area damaged when expressed over the total, but instead gives an overall assessment based entirely on observation. Much of the assessment is done qualitatively. In this regard, it is the aim of this study to attempt to make use of remote sensing imagery in the assessment of areas of damage within specified protected areas. The idea is to demonstrate its applicability as a means of trying to improve the certification system.

The rating intensity scale, as given by LEI, and which is used as a reference during assessment, can be summarized as in the Table 1-2:

Table 1-2: The intensity scale for indicator E 1.4 (From intensity scale for SPFM)

Area size of damaged protected area	Damage expressed as a percentage of total	Degree of damage	Control efforts	Rating
Excellent	0%	None	Adequate	Excellent
Very small	<10%	Moderate	Adequate	Good
Small	<25%	Low	Adequate	Fair
Small	<25%	Low	Inadequate	Fair
Very Small	<10%	High	Adequate	Fair
Small	<25%	High	Unspecified	Poor
Moderate	<50%	Low to moderate	Adequate	Poor
Bad	>50%	Unspecified	Unspecified	Bad

(Summarized from LEI document - 02)

Some of the types of protected area recognized in the Indonesian forest management system are listed in Appendix 6. According to P.T.Mutuagung Lestari (2001) the current assessors accredited by LEI, the forest management unit does not have records of disturbance neither does it have information regarding the condition of the protected area. According to their recent assessment of the concession, most of the protected areas of slope greater than 40% are logged over but are in a good condition. The protected areas around riverbanks are the most insecure, and the management unit does not know exactly how much of this area is allocated for protection purposes. However, according to the Indonesian regulations, if the width of the river is up to 4 metres, then a 50 metre wide buffer zone is considered as protected on both sides of the river, whereas if it is wider than 4 metres, then a 100-metre buffer zone is considered protected. These clear definitions of river-protected area are a potential for the application of a combination of GIS and remote-sensing techniques in the assessment of damage within the river protected areas. Based on the P.T.Mutuagung Lestari report, the emphasis in this study is put on the river-protected area, by which means of quantifying the damage within this area, and expressing it as a percentage of the total is developed.

1.5.2. Loopholes related to assessment of criterion E 1.4

The LEI list of secondary and primary data requirements relating to indicator E1.4 is given in Appendix 3. Whereas one of the verification methods is specified as field observation and measurement, only field observation is used in the analysis of this particular indicator, in addition to the results of interviews with officers and local communities, as well as reviewing of reports. Yet, the analysis is aimed at obtaining an indicator score based on the flora and fauna level of diversity as a result of a comparative study between the protected area, virgin forest and area logged over more than 20 years ago. Whereas comparison of the flora and fauna diversities would require field data collection, according to P.T.Mutuagung Lestari (2001), the assessors look generally at the condition of vegetation, which they compare with previous research reports in order to come up with an assessment of biodiversity. Looking at the aim of analysis, the methods of verification with regard to interviews, which are conducted with field officers and the community, seem incoherent and unnecessarily time consuming. It is mentioned that the results of these interviews are combined with secondary data in form of documents and reports such as the Environmental Impact Assessment report, in order to come up with a rating. However, the reviewing of reports, when combined with field data collection seems sufficient, and thus a considerable amount of time could be saved in this regard. In addition, much of the assessment is done on a qualitative rather than quantitative basis. In view of the mentioned lack of collection of primary data on plant an animal species, this research aims at collecting data on tree species, which will analysed for use in obtaining a score on the intensity scale of indicators for Sustainable Natural Production Forest Management, for indicator E 1.4.

1.6. Forest Management System in Indonesia

According to the (Indonesian Forestry Department, 1997), the Silvicultural System of Indonesian Selective Cutting and Planting (TPTI) known in Indonesian language as "*Sistem Silvikultur Tebang Pilih Tanaman Industri,"* comprises of logging practice with a diameter limit i.e. for harvesting. Provision is also made for forest regeneration. It began in 1972, and at the time, was regarded as the "Indonesian Selective Cutting (TPI)." Trees belonging to the family *dipterocarpaceae* generally dominate the natural production forests of Indonesia, which comprise of either permanent or limited forest. Several other tree species, sometimes dominate tropical rain forests, growing on certain sites, for example, agathis in forest with sandy soil, ebony in rocky and somewhat dry areas, and eucalypts in dry climate. The silvicultural system comprises of a series of activities carried out in managing the forest with the aim of ensuring sustainable production of timber and other forest products. These include logging, regeneration and tending operations.

The TPTI is based on the principles of sustainable forest management. Its objective is to regulate the utilization of natural tropical production forest as well as improve the value of such forest, in order to ensure that the next rotation of mixed forest stand can be formed. The formation of mixed forest stand is aimed at ensuring the sustainable flow or supply of raw materials for industry. In general, this system is based on a 35-year harvesting cycle under-which the production forest area is divided into 7 five-year work plan blocks or RKLs ("*Recana Karya Limatahun*) each of which is further subdivided into 5 annually felled compartments.

There are certain important regulations, which have to be followed by the concessionaires. For example, it is established by regulation, that 2 years before embarking on a 5 year plan, the concessionaire must make a logging plan, demarcate internal boundaries, and do a 100% inventory (stock mapping) of trees with a diameter at breast height (dbh) of at least 50cm. In addition, a 100% forest inventory must be carried out after 1 year of logging and this must be done before embarking on another annual harvesting compartment. These activities are important for determining post harvest impacts. The threshold dbh for felling an individual tree is 50cm within the fixed production area, whereas it is 60cm within the limited production area. A minimum of 25 nucleus trees (seed trees) per hectare should be maintained under the TPTI system. The nucleus trees should be of similar species to the ones logged, and with a minimum dbh of 20 cm. In cases where the number of trees per hectare is less than 25, other tree species are included.

In order to achieve the expected target(s) of the TPTI, the following series of activities and schedules are followed:

Table 1-3: Schedule of activities under the Indonesian Forest Management system

*T is the starting year of logging

Stage of activities	Time of implementation	Explanation
Organization of working area	*T - 3	Three years before logging commences boundary demarcation for logging sites is done.
Stand inventory before logging	T - 2	Two years before logging commences (100% inventory) is done
Opening up of forest area (Road construction)	T - 1	One year before logging commences road construction is done
Logging	T	Year of commencement of logging, actual felling of selected trees is carried out.
Liberation	T + 1	Enhancement of natural regeneration by creating more openings for light to reach the upcoming seedlings. This is achieved by climber cutting and other silvicultural operations.
Inventory of residual stand	T + 1	One year after logging, 100% inventory. This is done in order to establish the standing stock left behind after logging is completed in the particular compartment.
Procurement of planting stock	T + 2	Two years after logging planting material is procured
Enrichment planting	T + 2	In order to improve the stocking in the area initially logged over in year T

First stage tending	T + 3	Thinning is aimed at reducing competition between the future crop and unwanted species. The trees which compete with the future crop are killed by cambium cutting and poisoning
Advanced tending (liberation)	T + 4	
Advanced tending (thinning)	T + 9 T + 14 T + 19	
Forest protection and research	Continually	

1.7. Some challenges to Indonesian Forestry

There are several challenges to Indonesian forestry, which are likely to compromise sustainable forest management (Directorate General of Forest Inventory and Land use planning, 1996). These include among others:

- Deforestation of state forests due to exploitation and conversion of forest lands. This is enhanced more by the rising demand for forest products and forest area.

- Pressure exerted on the natural and plantation forests as a result of the increasing demand for wood by Indonesia's growing forest industries.

- Annual forest degradation of about 1 million hectares, as a result of illegal forest encroachment, forest fires, natural disasters etc. which tends to reduce normal forest function.

- Low achievement in the implementation of forest boundary demarcation and the gazetting of forests, despite the continued increase in forestland pressure.

- Incomplete assessment of forest resource conditions such as standing stock, forest resource distribution, location, area, forestland use change and other geographical information.

1.8. Problem statement

The interest in timber business at international scale is on the increase. This has caused increased investment in logging operations, which in turn poses a danger of enormously increasing forest-harvesting intensities. The continual increase in the volume of wood extracted from the forests, coupled with the activities associated with logging such as skidding (Figure 1-2), creates an enormous potential for forest degradation, which will eventually lead to the loss of biodiversity (Crook, 1998). Such a situation is in disharmony with the principle of sustainable forest management mentioned earlier (section 1.2). Since all concessionaires are interested in logging for increased profit, it is likely that they disregard the damage they may be causing to the long-term existence of the forest, in preference for their immediate and primary interest. Moreover large areas of forest still continue to be allocated as new concession areas. For example, in the Labanan concession, Indonesia, despite the fact that large areas of forest are already being logged, government still plans to subdivide the forest into three new concession areas (Fauzi, 2001). This presents a potential risk of increasing the intensity of logging which may eventually cause the decline, or even loss of biodiversity. This loss of biodiversity is likely to affect the highly fragile ecosystem causing an overall imbalance in its function. According to Rijksen (1998) the current protected area network in Kalimantan is hardly significant for the conservation of the unique biological diversity of the island. The most spectacular components of the endemic organisms occur outside the protected areas in state land allocated for production. (Rijksen, 1998) continues to add that the reduction of biological diversity is due to poor planning of timber extraction, and deficient control of the operations.

With the above argument in mind therefore, there is a strong need to determine the influence of any given management system on the sustainable existence of the forest. This can be done through assessment of forest status. Information obtained through this assessment should then be relayed to the relevant decision makers as an input to the development of appropriate management regimes, which fit within the framework of sustainable forest management. This prompts the necessity of having optimal and good quality certification procedures by which we can be confident that the impacts of the forest management system on the normal function of the forest have been subjected to precise judgement.

Figure 1-2: Logging and log skidding operations such as the one shown above, are contributory factors towards forest degradation and the decline of forest ecosystems

1.9. Objectives

The main objective of this research is to assess the status of tropical rain forest, under a given management system, from an ecological point of view, using the selected criterion, indicators and verifiers for Sustainable Natural Production Forest Management (SNPFM).

The specific objectives are:

1. To compare the tree species abundance and composition of an area of primary or undisturbed forest, with areas logged over at different periods of time within a particular felling cycle.
2. To assess patterns of tree species diversity change across areas harvested at different points in time within a given felling cycle.
3. To assess the extent of ecosystem damage at two different times within river protected area using remote sensing techniques.
4. To establish whether a relationship exists between radiance values and tree diversity indices for specific sample points within tropical forest.

1.10.Research questions

The following research questions are expected to meet the above-mentioned objectives:

Related to objective 1:

1. By how much do areas, which are closest to approaching the felling cycle, as well as those which have not been harvested, differ from the undisturbed forest in terms of tree species composition?
2. To what extent do the areas logged over at different periods of time differ from primary forest terms of the tree species abundance?

Related to objective 2:

3. What is the observed pattern of tree species diversity change with time within the given felling cycle and what are the underlying casual factors?

Related to objective 3:

4. To what extent can damage within the river-protected area be detected, using remote sensing techniques, when applied to Landsat TM images of the same area taken at two different times (years)?

Related to objective 4:

5. With regard to Landsat TM images, is there a considerable correlation between radiance values per band and tree diversity indices for specific sampled areas within the tropical forest?

1.11. Research approach

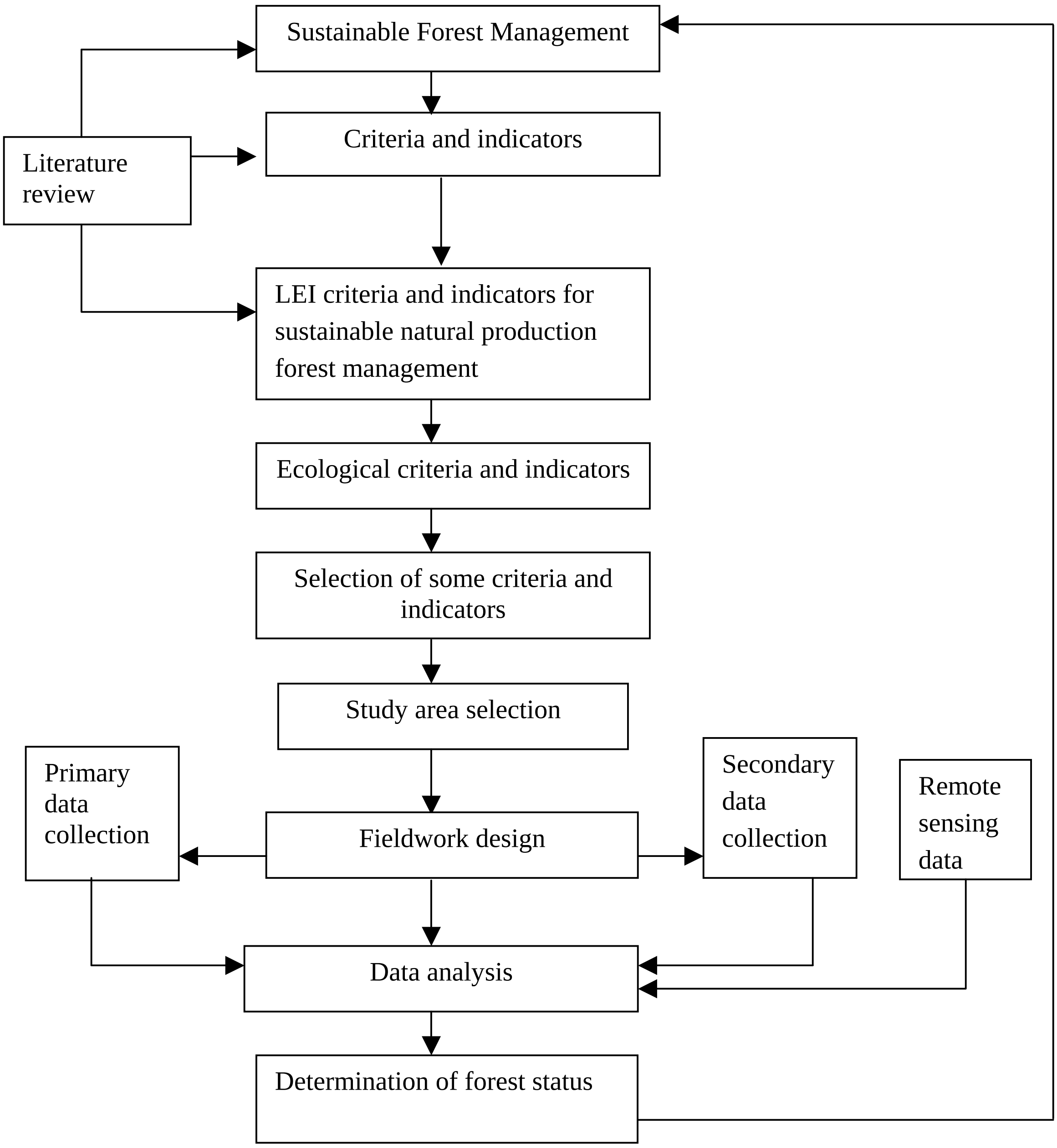


Figure 1-3: Flow chart of general research approach

2. LITERATURE REVIEW

2.1. Biodiversity Assessment

2.1.1. Selection of appropriate biodiversity index

Biodiversity can be defined as “a measure of species richness and/or their relative abundance within a sample or community” (Magurran, 1988). A community can be looked at as “an assemblage of species populations which occur together in space” (Begon, 1990).

Scores of biodiversity indices for use by ecologists in various fields exist. Some look at species richness, others at heterogeneity and some also at evenness of spread. Each of these indices when compared, reflect measures of different attributes of biodiversity. The determination of which index to use to measure what attribute, is therefore of great importance. Whereas there is an acute need to quantify biodiversity, its broad definition may itself be a limitation to its reliable quantification (Silbaugh and Betters, 1997) cited in Bouman, (1997). (McKenny, 1994) observes that as the definitions become broader, virtually everything in the forest becomes indicative of biodiversity and this makes it less practical for measurement by forest managers. (Silbaugh, 1997) emphasize the fact that successful measurement of biodiversity requires the selection of a few components to measure, and these should be viewed by society and science as the most important. (Magurran, 1988) points out a scientific method of selecting an appropriate diversity index. This is on the basis of whether it fulfils certain functions or criteria. The focus of this research is on the measurement of tree species diversity as a component of biodiversity.

2.1.2. Comparison of indices for measurement of Species Diversity

Various species diversity measures differ in their sensitivity to changes in the relative abundance of rare versus common species (Hill, 1973) and (Peet, 1974) cited in Bouman, (1997). (Silbaugh, 1997) identify and compare three measures of species diversity as species richness, heterogeneity and species diversity measures.

Species richness measures are a simple count of the number of species present in an area. They are very sensitive to the number of rare species present in that, as the size of a sampling area increases, species richness also increases (Magurran (1988) and (Wilson (1992). Heterogeneity measures, the most common of which are the Shannon and Simpson indices, measure diversity as the sum of the weighted proportional abundances of all species found in the sample. In these two, “diversity increases as rare species become less rare or as the most dominant species become less dominant” (Hulbert, 1971) cited in Bouman (1997). These are less sensitive to the number of rare species present as well as to the extent of the sampling area as compared to the species richness measures. The evenness measures determine the distribution of species’ proportional abundances regardless of the total number of species present.

2.1.3. Choice of index to be used in Tree diversity measurement

Since this study aims at looking at the level of abundance rather than the distribution of diversity, the Shannon and Simpson indices have been selected for use in tree diversity measurement. The Shannon Index is also referred to as the Shannon-Wiener Index since Shannon and Wiener separately came up with this function (Kent, 1996). It can be mathematically computed as shown below:

$$H' = -\sum_{i=1}^{s} pi \ln pi$$

Where: H' is the Shannon index

s, is the number of species

Pi is the proportion of individuals or the abundance of the ith species expressed as a fraction of the total and;

ln is the log base n. (Kent, 1996).

Negative values are generated when computing the natural logarithm (ln) of p_i , thus the equation has to be multiplied by a minus in order to transform the values into positives. In general, higher Shannon index values signify a better situation in terms of species richness although according to Peet (1974) cited in Magurran (1988), failure to include all species from the community is a substantial source of error. The error increases as the proportion of species represented in the sample decreases. Alimudoa (1999) also reported a slight initial increase in the Shannon index for the first 3 species counts and then a drop in the index as the number of species increased.

Shannon index values usually range from 1.5 to 3.5 and in rare cases may exceed 4.5 (Kent, 1996). According to May (1975), if the underlying species distribution is log normal, 10^5 species will be needed to produce a Shannon index value of greater than 5.

The Simpson index (D) will be used as a measure of abundance as well as a check during data analysis. It can be calculated according to the following formula:

$$D = \sum \left(\frac{n_i(n_i - 1)}{N(N-1)} \right)$$

Where D is the Simpson index

n_i is the number of individuals in the ith species and;

N *is* the total number of individuals (Magurran, 1988).

As D increases, diversity decreases and Simpson's index is therefore usually expressed as 1-D or 1/D. It is heavily weighted towards the most abundant species in the sample while being less sensitive to species richness. May (1975) cited in Magurran (1988) showed that once the number of species exceeds 10, the underlying species abundance distribution is important in determining whether the index has a high or low value.

2.2. Measurement of similarity

Many measures exist for the assessment of similarity or dissimilarity between vegetation samples or quadrants. Some are qualitative based on presence or absence data, while others are quantitative and will work on abundance data. Similarity indices measure the degree to which the species composition of quadrant or sample matches is alike (Kent and Coker, 1992). Dissimilarity coefficients assess the degree to which two quadrants or samples differ in composition. (Dissimilarity is the complement of similarity). For purposes of this study, the Sorensen coefficient will be used (Kent, 1996).

2.2.1. Measurement of similarity and dissimilarity

The assessment of similarity or dissimilarity between vegetation samples may be qualitative, based on the presence or absence data, while others are quantitative and will work on abundance data. Many measures exist by which this assessment can be done. In general, similarity indices measure the degree to which the species composition of quadrants or sample matches is alike, whereas dissimilarity coefficients assess the degree to which two quadrants or samples differ in composition. For purposes of this research, the Sorensen coefficient, which is generally applied to qualitative data, will be used.

It is expressed as:

$$S_s = \frac{2a}{2a+b+c}$$

(Kent and Coker, 1992)

a = Number of species common to both quadrants/samples

b = Number of species in quadrant/sample 1

c = Number of species in quadrant/sample 2

Often, the coefficient is multiplied by 100 to give a percentage similarity figure. Sorensen's coefficient gives weight to the species that are common to the quadrants or samples rather than to those that occur in either sample

Dissimilarity is then computed as below:

$$D_s = \frac{b+c}{2a+b+c} \quad \text{or} \quad 1-S_s$$

The figure can then be converted to percentage if required. The coefficient gives weight to the species that are common to the quadrants or samples (Kent and Coker, 1996)

A fictitious example of the calculation of similarity is shown below:
1 means the species is present

0 means the species is absent

Table 2-1: Fictitious example of Sorensen coefficient calculation

Species	Quadrant 1	Quadrant 2
A	1	1
B	0	1
C	1	0
D	1	0
E	1	1
Total occurrences	4	3

Number of joint occurrences (where the same species appears in both quadrants 1 and 2) = 2
b = total occurrences in quadrant 1
c = total occurrences in quadrant 2

$$S_S = \frac{2a}{2a+b+c} = \frac{2*2}{(2*2)+4+3} = \frac{4}{11} = 0.3636 = 36.4\%$$

Dissimilarity $D_s = \frac{b+c}{2a+b+c} = \frac{4+3}{(2*2)+4+3} = \frac{7}{11} = 0.6364 = 63.6\%$

2.3. Development of Sustainable Forest Management (SFM) Criteria and indicators by different organisations

The development of standards for the sustainable management of forests at national and international level has been proceeding for the past decade. Some of the key initiatives, at international level, which have been involved include; the International Tropical Timber Organisation (ITTO), the Forest Stewardship Council (FSC) and the International Standardization Organisation (ISO).

The very first attempt at the development of SFM standards was at an ITTO organised conference held in Bali in 1990. At the time, member nations agreed and committed themselves to implement SFM by the year 2000 (Agung, 2000). In 1992, ITTO took the first step in formulating criteria and indicators, with the aim of assisting member countries with relevant tools to observe the development of their forest management systems at the national and field level.

The Forest Stewardship Council (FSC) is an international non-profit organisation, which was formed in 1993. Prior to its formation, a group of timber users, traders and representatives of environmental and human-rights organizations met in California (USA) in 1990 to discuss how they could combine their interests in improving forest conservation and reducing deforestation. Their meeting confirmed the need for an honest and credible system for identifying well-managed forests as acceptable sources of forest products. It was from these beginnings that FSC developed. Its aims are to support environmentally appropriate, socially beneficial and economically viable management of the world's forests (Forest Stewardship Council, 1996). In 1993 in Toronto (Canada) 130 representatives from around the world held the Founding Assembly of the Forest Stewardship Council, which later led to an agreement to launch FSC. In 1994, 9 FSC principles were released consisting of SFM principles and related Criteria (Agung, 2000). FSC plays the role of an accreditation organisation for certification bodies. FSC accredited certification bodies are organizations accredited by the Forest Stewardship Council to certify forest management operations that comply with the FSC Principles and Criteria for Forest Stewardship. Accreditation covers plantation and natural forest certification.

The International Standards Organisation (ISO) has developed a certification framework called the Environmental Management System (EMS), which is oriented towards the management process within a Forest Management Unit. However, ISO standards do not yet cover all aspects of Sustainable Forest Management (Agung, 2000).

The Centre for International Forestry Research (CIFOR) is also involved in the development of Criteria and Indicators for SFM. The overall process was started in 1996 by (Prabhu, 1996). Over 1100 criteria and indicators selected from several different proposed systems of criteria and indicators were field tested by independent, international and multi-disciplinary teams. All aspects of forest management were covered, but concern was raised about the practicality of proposed indicators, or their relevance to forest management, especially with regard to biodiversity (Stock, 1997). From 1996 to date, CIFOR has been involved in the improvement of criteria and indicators. In all, CIFOR has generated a 10-toolbox series for testing criteria and indicators for sustainable forest management (CIFOR, 2001).

The Indonesian Ecolabeling Institute (LEI) was formed in 1994 in the form of an independent working group. In close coordination with the forestry sector, LEI prepared a set of national criteria and indicators for SFM certification. These criteria and indicators were developed by referring to standards set by ITTO and FSC as well as the environmental management system set by ISO. LEI has developed a complete certification system for natural forest management to be used as the national certification procedure. Up to the year 2000, LEI doubled as the national certification system developer and future accreditation organization as well as being a national certification body. Until recently, LEI works as a national system developer and accreditation organisation, the same role that FSC plays to its certification bodies (Agung, 2000). LEI's international position has increased especially after signing a Memorandum of Understanding to develop a Mutual Recognition Agreement (MRA) between LEI and FSC in 1998 in Rome. Following the MRA efforts, LEI has been improving its criteria and indicators and has also been performing periodic field trials. This finally resulted in an agreement to undertake joint certification between LEI and FSC within Indonesia, a process, which has received the support of GTZ and WWF. Under the joint certification agreement, the standards set by LEI criteria and indicators should be used in all certification activities in the natural production forest in Indonesia. Further joint certification agreements stipulate that an FMU, which successfully passes joint certification, will receive two certificates, one from LEI and another from FSC. The detailed process for joint certification between LEI and FSC certification bodies was worked out at a seminar held in Bogor, Indonesia, in 2000 (Agung, 2000)

2.4. LEI Forest certification Process

Under the LEI forest certification system a body accredited by LEI carries out the actual field assessment prior to certification. LEI develops the framework for certification within which the certification body works. At the start of the process, the management unit must first file its application for certification before the procedure begins (Lembaga Ekolabel Indonesia, 1998). Within the developed framework, the following activities are carried out:

- **Pre-field assessment stage**

The pre-field assessment is a series of activities designed to increase the efficiency of the evaluation process, in order to pave way for a more expeditious certification process. It enables an increased understanding of the underlying information, which serves as a basis for determining whether or not the management unit meets the qualifications to continue with the certification.

The activities involved within the pre-field assessment stage involve screening by an Expert Panel known as Expert Panel I. This panel deals with document evaluation, field scooping, decision-making and finally submission of recommendations. The second activity involves making a decision by a certification board, which consists of members of another expert Panel known as Expert Panel II. Both activities are carried out simultaneously.

- **Field assessment and community input stage**

Field assessment involves data collection and analytical processing by field assessors based on the Sustainable forest management criteria and indicators.

The community input stage provides the community with the opportunity to actively participate in the certification process. They provide data on both the positive and negative effects of the presence of the management unit being evaluated. The community input is submitted to the Certification Body as an input for the Expert Panel II to make a final decision on certification.

- **Performance evaluation and certification (decision making stage)**

Performance evaluation is the process of evaluating the management unit based on the actual and standard conditions in order to make a decision and rank of certification as well as recommendations to the management unit.

All the above i.e. the field assessment report, the community input and the results of the screening process are sources of information based upon which a final decision is made by the Expert Panel II of the Certification Body.

- **Certification decision stage**

After reviewing all the sources of information mentioned above, Expert Panel II makes the certification decision. To maintain the credibility of the certification decision, the Certification Body periodically monitors and assesses the already certified management units. A team of qualified individuals comparable to the Expert Panel carries out the surveillance activity.

2.5. The Remote sensing process

Remote sensing has been defined as the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand and Keifer, 2000). Electromagnetic sensors are currently being operated from airborne and spaceborne platforms to assist in inventorying, mapping and monitoring of earth resources. Electromagnetic remote sensing involves the two basic processes of data acquisition and data analysis.

In the data acquisition process, an energy source such as the sun or active sensor emits electromagnetic energy which is transmitted through the atmosphere, interacts with an earth surface feature, some of the energy is absorbed, while the other is reflected back through the atmosphere to the airborne or space borne sensors. The whole series of processes results in the generation of sensor data in pictorial and/or digital form. The sensors are used to record variations in the way earth surface features reflect and emit electromagnetic energy. The data analysis process involves examining the data using various viewing and interpretation devices to analyse the pictorial data and/or a computer to analyse digital sensor data. Reference data about the resources being studied (e.g. field-check data) are used when and where possible to assist in data analysis. The analyst extracts information about the type, extent, location and condition of the various resources over which the sensor data were collected. This can then be integrated with other layers in a Geographic Information System, after which the information is presented to users who apply to their decision making process.

2.5.1. Spectral reflectance of Vegetation, Soil and Water

Typical reflectance curves of the three basic types of earth features i.e. healthy green vegetation, dry bare soil and clear lake water, are distinctive (Figure 2-1). The configuration of these curves is an indicator of the type and condition of the features to which they apply (Lillesand and Keifer, 2000).

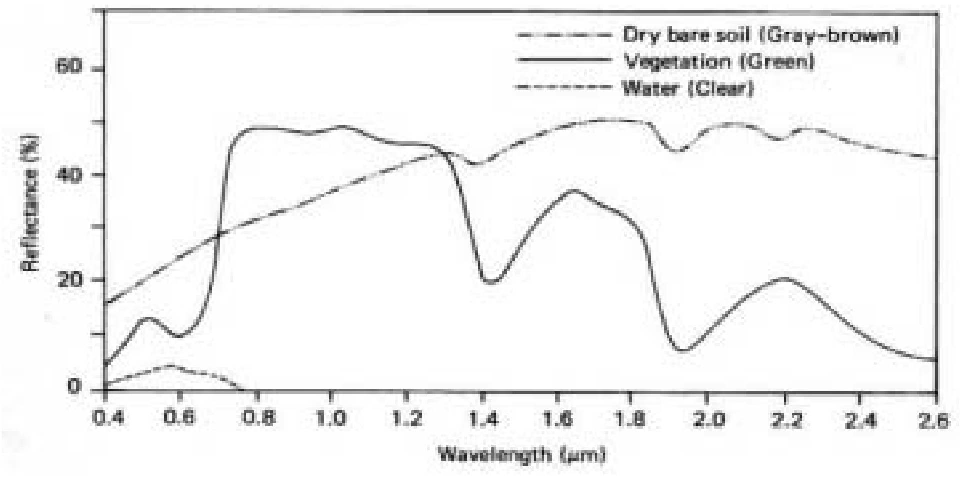


Figure 2-1: Spectral reflectance curves of vegetation, soil and water (Source Lillesand and Keifer, 2000)

2.5.2. Vegetation reflectance characteristics

The reflectance characteristics of vegetation depend on the properties of the leaves including the orientation and structure of the leaf canopy. The proportion of the radiation reflected in the different parts of the spectrum depends on the leaf pigmentation, leaf thickness and composition (cell structure) and the amount of water in the leaf tissue (Baker et al., 2000). In the visible portion of the spectrum (0.4-0.7µm), the reflection from the blue and red light is comparatively low since these portions are absorbed by the plant for photosynthesis and the vegetation reflects relatively more green light. Chlorophyll strongly absorbs energy in the wavelength bands from 0.45 to 0.67 (µm) (Lillesand and Keifer, 2000). From the visible to near-infrared portion of the spectrum at about 0.7µm, the reflectance of healthy vegetation increases dramatically. In the range from about 0.7 to 1.3µm, a plant leaf reflects 40 to 50 percent of the energy incident upon it. Most of the remaining energy is transmitted, since the absorption in this spectral region is minimal (less than 5 percent). Reflectance in the near infrared is highest but the amount depends on the leaf development and the cell structure of the leaves. In the middle infra red, the reflectance is mainly determined by free water in the leaf tissue, the more the free water, the less the reflectance. These bands are therefore termed “water absorption bands.” At 1.4, 1.9 and 2.7 µm, dips occur in reflectance because water in the leaves absorbs strongly at these wavelengths. Reflectance peaks occur at about 1.6 and 2.2 µm between the absorption bands. Dry leaves cause plants to reflect more in the red portion of the spectrum, less in the near infrared portion and higher in the middle infrared portion of the spectrum.

Plant reflection in the range 0.7 to 1µm results from the internal structure of plant leaves. This structure is highly variable between plant species, so reflectance measurements in this range permit us to discriminate between species (Lillesand and Kiefer, 2000).

2.5.3. Bare soil reflectance characteristics

The factors that influence soil reflectance act over less specific spectral bands. Some of the factors affecting soil reflectance are moisture content, soil texture, surface roughness, presence of iron oxide and organic matter content (Lillesand and Keifer, 2000). These factors are complex, variable and so interrelated. Surface reflectance from bare soil is dependent on so many factors that it is difficult to give one soil reflectance curve (Baker et al., 2000). In general, between 500 and 1300 nm the typical shape of most of the curves show a convex shape. Soils with relatively low moisture content well drained) exhibit a high reflectance, whereas poorly drained fine textured soils will have a lower reflectance (Lillesand and Keifer, 2000). In the absence of water, soils exhibit a reverse tendency with coarse textured soils appearing darker than fine textured soils. Thus, reflectance properties of soil are only consistent within particular ranges of conditions.

2.5.4. Water reflectance characteristics

Clear water absorbs relatively little energy having wavelengths less than about 0.6µm (Lillesand and Keifer, 2000). However, as the turbidity of water increases, transmittance and therefore reflectance changes dramatically. Water containing large quantities of suspended sediments normally has higher visible reflectance than other clear water. Water reflects electromagnetic energy in the visible up to the near infrared region of the electromagnetic spectrum. Beyond 1200nm, all the energy is absorbed (Lillesand and Keifer, 2000). In general, compared to vegetation and soils, water has a low reflectance.

Vegetation may reflect up to 50%, soils up to 30-40%, while water reflects at most 10% of the incoming radiation.

3. STUDY AREA

3.1. Location

Labanan concession area is found in Berau regency, East Kalimantan, Indonesia. This province is located in the (eastern Indonesian part of the island of Borneo. Its specific location is between latitude 2º10´ N and 1º45´N, and longitude 116º55´ E and 117º20´ E. It lies west of the Kelai river. The entire concession area covers about 83,240 ha of which 54, 567 ha is under fixed production, 26,997 ha under limited production and 1676 ha has been left for other uses such as transmigration, camping (by the logging and cruising crew), settlement and agriculture (Fakul tas Kehutanan, 2000). The concession area is managed by P.T. Inhutani I, which is a government owned concession company. The main town in the area is Tanjung Redeb, which is located on the levee of the Berau river. It has a harbour, which can accommodate seagoing ships.

3.2. Lithology, Landforms and soils

The area is situated inland of coastal swamps, consisting of undulating to rolling plains, interrupted by isolated masses of high hills with central cores of mountains. The characteristic topographic variation is as a result of folding and rock uplift, which is itself a result of tension occurring in the earth's crust (Mantel, 1998). Sedimentary rock provides the dominant parent material in the area.

The soils in the area are dominated by utisols (acrisols). They overlay acid, sedimentary parent materials. Less developed or eroded soils such as inceptisols or entisols (cambisols) are found on very steep slopes and in valley bottoms. Soils overlying basic parent material (limestone) are dominantly vertisols and inceptisols (cambisols). In the valley bottoms and the flood plain, hydromorphic soils are found, which have developed over alluvial material.

3.3. Climate,Vegetation and landuse

The annual rainfall ranges from 1500 to 4000 mm (Voss, 1983). It has neither wet (>200mm) months nor dry months (<100mm).

The natural vegetation of East Kalimantan is dominated by lowland mixed dipterocarp forest. Dipterocarps represent 50% of basal area and 60% of stand volume. The Berau area is characterized by high botanical diversity (KeBler, 1994) of the species found, 70% are represented by 1 or less individual stems per hectare, and 22 are recorded only once (Mantel, 1998).

Large parts of natural forest in East Kalimantan have been logged. Transmigration settlements can be found near Labanan and on the soils of the flood plains of the rivers. New transmigration settlements are planned in the eastern part of the Labanan area for which land is being cleared.

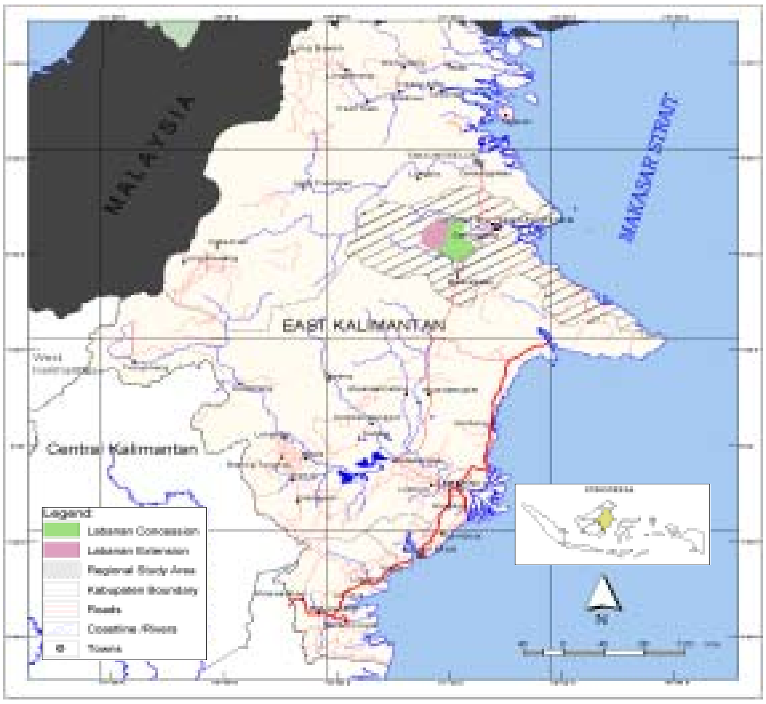


Figure 1-1: Location of Labanan concession area

Figure 3-1: Study area (Source: Steenis and Verhoeven, 2000, in (Fauzi, 2001).

3.4. Basis for selection of study area

The study area was chosen purposefully, because of the tropical forest management system in place, which allows for unbiased assessment. As mentioned earlier, section 1.4, the Indonesian forest management system is based on a 35-year harvesting cycle. In Labanan, selective logging activity by concessionaires began in 1974 with the demarcation of boundaries, stand inventorying and road construction. The actual tree felling began in 1976.

Based on this management system, the entire management unit has been divided into seven blocks (known as *Recana Karya Limatahun* (RKL's) in Indonesian language), each of which is further subdivided into five annually harvested compartments. In total, the proposed study area has up to 35 compartments demarcated for annual logging. The logging has been taking place progressively on an annual basis starting from the very first compartment in the first demarcated block. Currently, (2001) logging has just started taking place in the 6th block. The end of the felling cycle will be reached in 2011, when felling will be taking place in the last i.e. 35th compartment found within the 7th block. The cycle will repeat itself in the following year (2012). Part of the 6th as well as the entire 7th block still remain untouched in this particular forest management unit. Within the harvesting area, are zones purposefully demarcated for protection purposes.

4. METHODS AND MATERIALS

This chapter deals with the activities relating to the design of research and the methods involved in its implementation. These are broadly divided into pre –fieldwork, fieldwork and post fieldwork stages. The pre fieldwork stage involves work undertaken prior to going to the field, the fieldwork stage includes the actual fieldwork, and the post fieldwork stage includes the processing, analysis and interpretation of data.

4.1. Pre–fieldwork stage

4.1.1. Preparation of image data

A georeferenced Landsat ETM image of 26th August 2000 covering part of the study area was acquired prior to going to the field. This was used in making some false colour composites, which gave a clue about the existing field conditions. The image had already been georeferenced with reference to a base topographic map, which had itself been generated from an aerial photo of the study area. A professional consultant, P.T. Mapindo Parama, made the base map.

4.1.2. Review of literature and group discussions

Review of literature regarding forest certification in general, and the LEI certification system in particular, was done prior to the actual fieldwork (see section 2.3). This was done in order to get a broad view of forest certification, since this study is based on assessment of selected ecological criteria and indicators for sustainable forest management. The overall context in which the criteria and indicators were developed had to be understood before looking specifically at those related with ecological aspects. From the list of ecological criteria and indicators, 2 criteria and 5 verifiers were selected as explained in section 1.4. The methods of measurement of the selected criteria and indicators were also studied. In addition, review of literature regarding the Indonesian forest management system, and how it is applied in the study area was also done (section 4.2.1).

4.1.3. Materials and instruments used

The following materials and instruments were used; Landsat 7 ETM+ acquired on 26th August 2000, Landsat 5 TM acquired on 12th April 1996, measuring tape, diameter tape, compass, handheld GPS receiver, mouse horn densitometer, sunto clinometer, and a forest work plan map (showing the harvesting blocks or RKLs).

4.2. Fieldwork stage

The fieldwork stage involved collection of both primary and secondary data. First, a meeting was held at the central office of P.T.Inhutani I, the state owned company in charge of Labanan concession. During this meeting, discussions were held with the director and some other officials. Permission to access the study area was then granted.

Other meetings were held with various stakeholders in the field of forest certification within Indonesia. These meetings were held in the capital city of Indonesia, Jakarta as well as the city of Bogor. Those visited included; The Natural Resources Management Project, which is USAID funded, Mutu Agung Lestari, a certifying body, accredited by LEI, Smartwood, a certifying body accredited by FSC and CIFOR (Centre for International Forestry Research). LEI and FSC were both involved in certification of Labanan concession. At the time the fieldwork was conducted, LEI had already certified the forest, whereas FSC had not.

Prior to the field data collection, a meeting was held with both the manager and chief of planning of Labanan concession, during which they elaborated issues pertaining to their activities. The availability of secondary data, which could be incorporated into the research design, was mentioned. A brief introductory tour of the concession was also organised in order to gain familiarity of the study area.

4.2.1. Indonesian Forest Management System as applied in the study area

The implementation of the Indonesian forest management system within the study area was based on the five-year work plan system explained in section 1.6. The entire forest management unit had been divided into blocks (RKLs) at the start of the harvesting cycle (1974). Under normal circumstances, the harvesting cycle would have been as shown in the second column of table 4-1. However, according to the head of the planning division of Labanan concession, the location of RKLs was later redesigned as shown in the third column of Table 4-1.

Table 4-1: Showing the initially planned and the redesigned logging plan

Table 4-2: RKL/Harvesting block number	Initially planned years of harvesting	Redesigned years of harvesting	Current area of RKL (Ha)
1	1976-1980	1976-1980	6748.80
2	1981-1985	1981-1985	7501.46
3	1986-1990	1976-1980	7719.46
4	1991-1995	1991-1995	7596.91
5	1996-2000	1996-2000	8181.5
6	2001-2005	2001-2005 (Current logging)	7578.65
7	2006-2010	2006-2010 (Still unlogged)	7609.53

From the table, RKL 3 is not an exact reflection of the initially planned RKL but is rather more representative of RKL 1.

4.2.2. Sampling

4.2.2.a Permanent Inventory Plots

Within the study area, secondary data on trees from rectangular Permanent Inventory Plots (PIPs) was available. Permanent inventory plots are defined as sample plots established in the forest and measured at several points in time for purposes of assessing tree yields and changes in tree yields over time (Berau Forest Management Project, 1999). They provide estimates of changes in forest stocking and volume over time (Alder, 1992). In order to meet their intended purpose, the following

data are collected from the PIPs; tree girth at breast height, tree bole height, and tree species identification, data on mortality and ingrowth (i.e. new individuals from a lower age class entering

into a new age class). According to the Planning manager of Labanan concession, these data are collected over a two-year period.

The PIPs were distributed within most of the logged RKLs (five year felling plans) and were of two sizes, either 2500m² or 10000m². The existence of the PIPs formed the basis for the sampling design. In total 12 PIPs were available. The distribution of the PIPs within the RKLs varied from one RKL to another and as such, where more than 2 PIPs existed, 2 were selected for sampling. The PIPs were distributed as shown in Table 4-2 below:

Table 4-2: Distribution and sizes of PIPs for tree data collection within the RKLs

RKL Number	Total number of PIPs within the RKL	Number of PIPs selected	Respective sizes of each PIP sampled (m²)
1	4	2	2,500 and 10,000
2	1	1	2,500
3	3	2	2500 and 2500
4	3	2	2,500 and 2500
5	1	1	10,000

RKLs 2 and 5 had only one PIP, whereas RKL 6 (in which logging had just began) and 7, which is still unlogged, did not have any PIP. As a result, some Temporary Inventory Plots (TIPs) were established within them as shown in Table 4-3.

Table 4-3: RKLs and corresponding Temporary Inventory Plots (TIPs) used for tree data collection

RKL number	Number of (TIPs)
2	1
5	1
6	2
7	2

4.2.2.b Biodiversity conservation area

One of the protected area types in Indonesia is the biodiversity conservation area (Appendix 6). Within the study area, such a plot had been established, of 100 ha size. It lies within the area allocated for logging, and no logging at all has taken place within this area. It therefore provided an important benchmark for comparison.

4.2.2.c Sampling design

A sample is a part from which we draw conclusions about the whole. The design of a sample refers to the method used to choose the sample from the population (Moore, 1999). Substantial savings in resources, time, money and qualified personnel can be made through sampling (De Gier, 2000). The choice of a particular sampling design used in any particular study is dependent upon the objective(s) of the study. In

general, this study aims at assessing forest status using selected ecological criteria and indicators. It specifically looks at comparing the tree species composition and abundance of the biodiversity conservation area with selected RKLs, looking at the trends of change of tree diversity with time (based

on RKLs), as well as relating image reflectance values with tree diversity for specific sample points. With these objectives in mind, as well as the limitations of resources in terms of money and time, sampling was done based on the existing secondary data in form of PIPs of known location. Thus, a combination of stratified and purposive sampling was used. Five forest strata were identified for data collection, four of which were further subdivided into substrata. The identified strata were; Biodiversity conservation area, Virgin forest, area logged more than 20 years ago, area logged from 11 to 20 years ago and areas logged from 1 to 10 years ago. Besides the biodiversity conservation area, the four other strata are each further divided into sub-strata (5- year felling blocks or RKLs), which were further subdivided into annual felling compartments (Figure 4-1). Sampling was done within two-selected Permanent Inventory Plots (PIPs), which were located within most of the 5 year felling blocks. (Kent and Coker, 1996) pointed out that stratification should be carried out on the basis of major and obvious variations within the study area, and hence stratified, purposive sampling was chosen. In addition, (Mawdsley, 1999) recognized the RKLs as appropriate strata for carrying out diversity related studies.

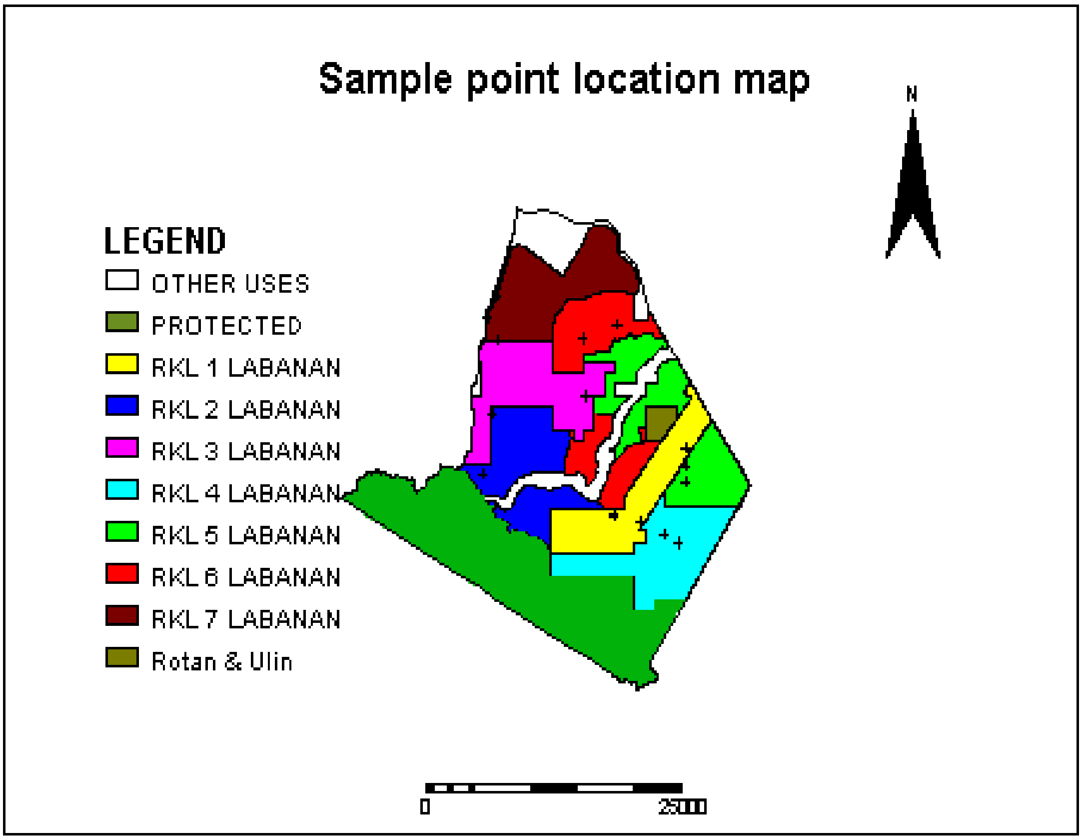


Figure 4-1: Map showing sample point locations within the study area. The white arrow and grey circle indicate the location of the biodiversity conservation area.

4.3. Primary data collection

The collection of primary tree data was done based on the already existent PIP secondary data. Some RKLs had secondary data on trees (from PIPs), whereas others did not. Thus, primary tree data were not collected from the RKLs, which already had PIPs. For the RKLs, which did not have secondary data,

Temporary Inventory Plots were established from which primary tree data were collected from plots of size 500m². The particular RKLs from which such data were collected are shown in Table 4-3 above. Primary tree data were also collected from the biodiversity conservation area.

4.2.3.a Plot size and shape for primary data collection

For collection of primary tree data, plots of any size and shape can be used but some sizes and shapes are more appropriate than others for studying trees in forests. The size and shape of plots is often determined by balancing three factors, the ability to determine plot boundaries with minimum effort, reducing edge effects and expected scale of pattern in the vegetation (White, 2000). The use of plots demands that, edge effects should be reduced as much as possible since they are a potential source of error in the data. In this case, the optimal plot shape chosen was circular, since this minimizes the edge: surface area ratio.

Three concentric circular plots were used in this study. This is because whereas circular plots of 500 m^2 area and radius 12.62 m can be used in sampling of big trees, this area is practically impossible to be used in sampling of the smaller ones like seedlings. In line with this, the following concentric plot sizes for the assessment of different tree classes were used:

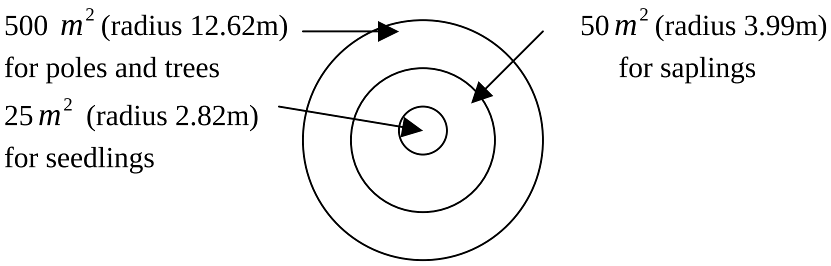


Figure 4-2: Sample plot layout

The outer circular plot radius is generally used in forest inventorying, whereas the two inner radii conform to those used in similar studies. The 25m² was also used by (Reed and Clokie, 2001) whereas the 50m² was used by (Lejju, 2001) in similar studies.

4.2.3.b Primary data collected

Species identification was done for different tree classes within each of the different concentric sample plots. Within the 2.82m radius sample plot, all seedlings were identified, counted and recorded, while the same was done for all saplings within the 3.99m radius sample plot. The bigger plot of radius 12.62m was used for sampling the poles and bigger trees. For purposes of this study, the criteria for judging seedlings, saplings and poles and trees in the field was done according to the system used by the Indonesian Department of Forestry (Indonesian Forestry Department, 1997).
The criteria are as follows:

Table 4-4: Criteria for judging seedlings saplings and poles and trees (Indonesian Department of Forestry)

Tree category	Criterion
-Seedling	-Height up to 1.5m
-Sapling	-Height>1.5m and diameter <10cm
-Poles and trees	-Diameter > 10cm

In addition to the tree data specified above, data on crown cover, slope and aspect, were also collected from each primary data plot.

4.2.3.d Location of plot centres within the PIPs and TIPs

The location of sample plot centres was preceded by identification of the specific PIPs. PIPs were identified on maps produced by the concession, and with the assistance of field helpers, they were located in the field. On the other hand, TIPs were located based on random identification of positions within the RKLs, which did not have PIPs. The TIPs had to be located at safe distances away from settlement, in order to avoid possible influences of human disturbance, since it was the same condition followed in locating positions during the establishment of PIPs. Within the PIP's and/or TIP's, two sample plot centres were located along the diagonal originating from the southwestern corner at a bearing of 45º. The first plot centre was located at a distance of 17.84m from this point of origin, while the second was located 35m away from first plot centre along the same bearing (52.84m metres from the southwestern corner) (Figure 4-3). The southwestern corners of the PIPs were located by aid if a compass. Only data on seedlings and saplings were collected from the PIPs, whereas data on seedlings, saplings, poles and trees were collected from the TIPs. The plot sizes shown in Figure 4-2 above were used.

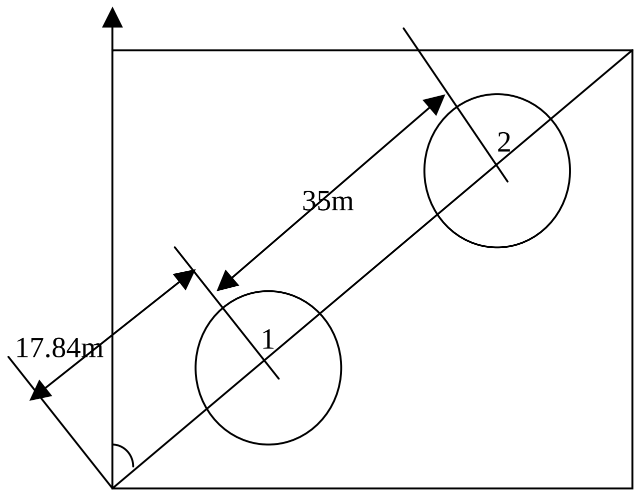


Figure 4-3: Layout of sample plots within PIPs and/or TIPs (1 and 2 are the first and second plot centres respectively).

4.2.3e Location of plot centres within the biodiversity conservation area

Within the biodiversity conservation area, data were collected from four plot locations. The Northeastern corner was identified and at a bearing of 202.5º, and a distance of 25 metres, the first plot was located. The second plot was located 30 metres from the first plot centre, at the same bearing. Using the same corner point, the third plot was located at a bearing of 247.5º and distance of 25 m. Similarly, the fourth plot was located at a distance of 30 metres from the third plot centre at the same bearing i.e. 55 metres from the corner point.

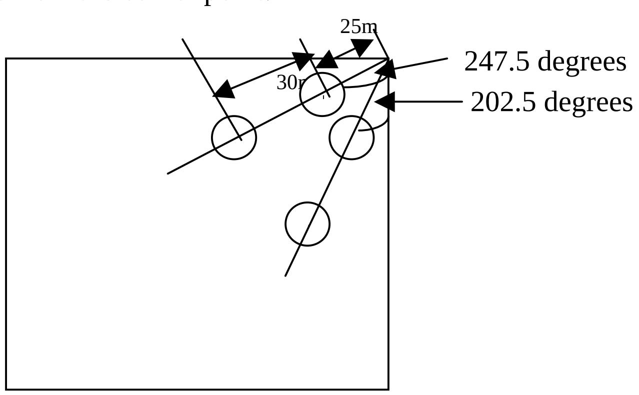


Figure 4-4: Layout of sample plots within the biodiversity conservation area (1, 2, 3 and 4) are the first, second, third and fourth plot centres respectively).

4.2.3.c Field data recording and tallying

Data were entered into an initially prepared field form shown in Appendix 7. In order to speed up the data collection process, a trained taxonomist was used to help in tree identification and tallying. The researcher determined the boundaries of the plots from which the data were collected and also took measurements such as slope, crown cover and aspect. These data were also entered into the same data form shown in Appendix 7.

Figure 4-5: Seedling identification in the field. The upright stick in the left foreground is the position of the plot centre.

4.3.1. Secondary data collection

Secondary data from PIPs earlier mentioned in section 4.2.2.a was collected from the Labanan concession database. A wide range of other data including georeferenced Landsat TM image data and maps showing the location of the PIPs as well as literature were available.

4.4. Post-fieldwork stage

This stage deals with the processing and subsequent analysis of all primary and secondary data. Here, the data collected were entered into a database using the Microsoft excel program. The data entry was done for the three different tree categories of seedlings, saplings and poles and trees per plot. XY coordinates for each of the different plots were also entered. This was followed by first preliminary, and then further data analysis.

4.4.1. Data processing and analysis

The data processing stage involved the computation of all Shannon and Simpson seedling, sapling and pole and tree indices per plot, using the formulae specified in section 2.1.3. Total tree counts, and number of species per plot were also computed. The Sorensen similarity coefficient was also computed. The formular used in computing the Sorensen coefficient is specified in section 2.2.1.

Analysis regarding research question 1 which is **“By how much do areas, which are closest to approaching the felling cycle, as well as those which have not been harvested, differ from the undisturbed forest in terms of tree species composition?”** was done by comparing the Sorensen similarity coefficient of the areas logged more than 20 years ago (closest to approaching the felling cycle) as well as areas that have not been logged at all (Virgin or unlogged forest) with that of the biodiversity conservation area. The number of seedling, sapling and pole and tree species similar to all the three areas was also examined as a means of judging the distribution of species within the forest.

The values of similarity where then interpreted in terms of the intensity scale of indicators for Sustainable Natural Production Forest Management given in Appendix 5. LEI developed this intensity scale for the purpose of categorizing a particular verifier of an indicator of sustainable forest management. The criterion under study here is E 1.4, which is; "the condition of tree species diversity in protected areas in various forest formations or types within management units" as, mentioned in Chapter 1, section 1.4. The results of the intensity scale were then compared to the rating given by Mutu Agung Lestari, the Certification Body accredited by LEI.

Analysis regarding research question 2, which is **"To what extent do the areas logged over at different periods of time differ from primary forest terms of the tree species abundance?"** was done by comparing the Simpson indices of the seedling and sapling plots within the strata mentioned in section 4.2.2.c, with the Simpson index of the biodiversity conservation area. The Simpson indices of poles and trees could not be compared because some of the strata had pole and tree data from circular plots of size 500m², whereas others had this data from Permanent Inventory Plots of size 2500m². The strata are; area logged more than 20 years ago, area logged from 11 to 20 years ago, the area logged from 1 to 10 years ago and the unlogged area. The Simpson index was used as a measure of species abundance, since according to (Magurran, 1988) it is heavily weighted towards the most abundant species in the sample. Using the MINITAB software, Simpson indices for each of the strata were categorized and then analysed for normality. Whereas some of the Simpson indices were normally distributed, others were not. For this reason, comparison of the Simpson indices for the different strata was done using the Mann-Whitney non-parametric test. In addition, the Mann-Whitney test was chosen since it can be performed with two samples of different sizes (Kent, 1992). The sample size within the biodiversity conservation area was 4, while that within the other strata was 8.

Analysis regarding research question 3, which is **"What is the observed pattern of tree species diversity change with time within the given felling cycle, and what are the underlying casual factors?"** was done by plotting of graphs of change of the Shannon and Simpson indices with the 5-year periods of logging for the categories of seedlings, saplings and poles and trees.

Analyses with regard to research questions 4 and 5 were based on remote sensing and are covered in sections 4.4.2 and 4.4.3 below.

4.4.2. Visual interpretation of images and map on screen digitizing

With regard to research question 4, which is **"To what extent can damage within the river protected area be detected, using remote sensing techniques, when applied to Landsat TM images of the same area taken at two different times (years)?",** the following was done:

Colour composites were made in ILWIS (Integrated Land and Water Information System), with the band combinations of 5, 4, 2 and 4, 5, 2 in the Red, Green and Blue channels respectively. This was done in order to distinguish areas of encroachment around the river as much as possible in the Landsat TM 1996 and ETM+ 2000 images. According to the Indonesian regulations, for rivers of up to 4 metres wide, buffer zones of up to 50 metres wide on both sides are designated as protected, whereas for rivers wider than 4 metres, buffer zones of up to 100 metres are considered protected. In the study area, the river was wider than 4 metres and so 100 metres from the river sides were taken as the buffer zone area. Boundaries of the observable encroachment areas on both sides of the river were then delineated by on-screen digitizing and polygonized. The polygons formed were then converted to raster format. Since this is some form of mapping, a minimum mapping unit had to be determined. This was set at 11 pixels (each 30 x 30 m), which approximates about 1 hectare. The principle employed in the delineation exercise was that of land cover mapping, by which, the type of features present on the surface of land were judged using the spectral reflectance properties exhibited. Land cover refers to the type of feature present on the surface of the land (Baker et al., 2000). The type of land use activity existent in the delineated areas was deduced from the land cover. Land use here relates to the human activity or economic function for a specific piece of land (Baker et al., 2000). The River pixels were distinguished using the 4, 3, 2 colour composite, and their centers digitized to create a river segment map. Using the distance function in ILWIS, the river-protected area was then designated taking 116 metres on both sides of the river segment map. The 116-metre distance was chosen based on observation in the field that the river width is about 30 metres wide in most areas. Thus a maximum distance of 15 metres from the river segment was considered on both sides as the river width, allowing for about 100 metres of protected area on both sides of the riverbanks. Using the cross function in ILWIS, the river protected map was then crossed with the encroachment areas, and from the cross table, the sizes of areas of encroachment within the protected area were determined. These encroachment areas were then summed up and taken as a proportion of the total river protected area, which provided a basis for determining the position in terms of rating, on the intensity scale of indicators for Sustainable Natural Production Forest Management (Appendix 5). The result of rating obtained on the intensity scale of indicators for SNPFM, with regard to indicator E 1.3 was then compared with that obtained by Mutuagung Lestari, the assessors accredited by LEI.

4.4.3. Correlation of index values and reflectance

Analysis with regard to research question 5, which is **“With regard to Landsat TM images, is there a considerable correlation between radiance values per band and biodiversity indices for specific sampled areas within the tropical forest?”** was done as follows:

Reflectance values of the Landsat ETM+ 2000 image, for each pole and tree plot were obtained through creation of a sample set in ILWIS. From the file menu in the ILWIS main window, the create sample set

option was chosen, then the map list containing all the 7 bands of the study area image was selected. The sample point map was then overlaid on the map list so that their exact locations could be identified. The RKL polygon map was also overlaid in order to ascertain that the points being selected were the right ones. The sample statistics for particular sample pixels were then obtained using the overlaid sample point map as a reference. The sample statistics indicated the mean reflectance value of pixels per band, the standard deviation and the total number of pixels sampled. 9 pixels were sampled for each of the entire pole and tree plots. These included the self-established plots of size 500m², the PIPs of size 2500m², and PIPs of size 10,000m². The pole and tree plots were selected, based on the assumption that reflectance within the natural forest is mainly affected by trees in the upper storey.

The reflectance values obtained as explained above, were then entered into an excel spreadsheet, for each sample plot and categorized according to Table 4-5 below. From the whole set of reflectance values, four bands were chosen namely; Band 5 (Middle Infra red), Band 4 (Near Infra Red), Band 3 (Red) and Band 2 (Green), from which correlation coefficients with the Shannon diversity indices were obtained. The correlation factors between tree species diversity and reflectance values were computed in the Microsoft excel program. The flowcharts of methods are shown in figures 4-6 and 4-7.

Table 4-5: Forest stratification used in categorizing reflectance values

Stratum	Logged (Years ago)	RKLs
I	1 to 10	5 and 4
II	11 to 20	3 and 2
III	More than 20	RKL 1
IV	Unlogged	RKL 7
V	Biodiversity Conservation area	-

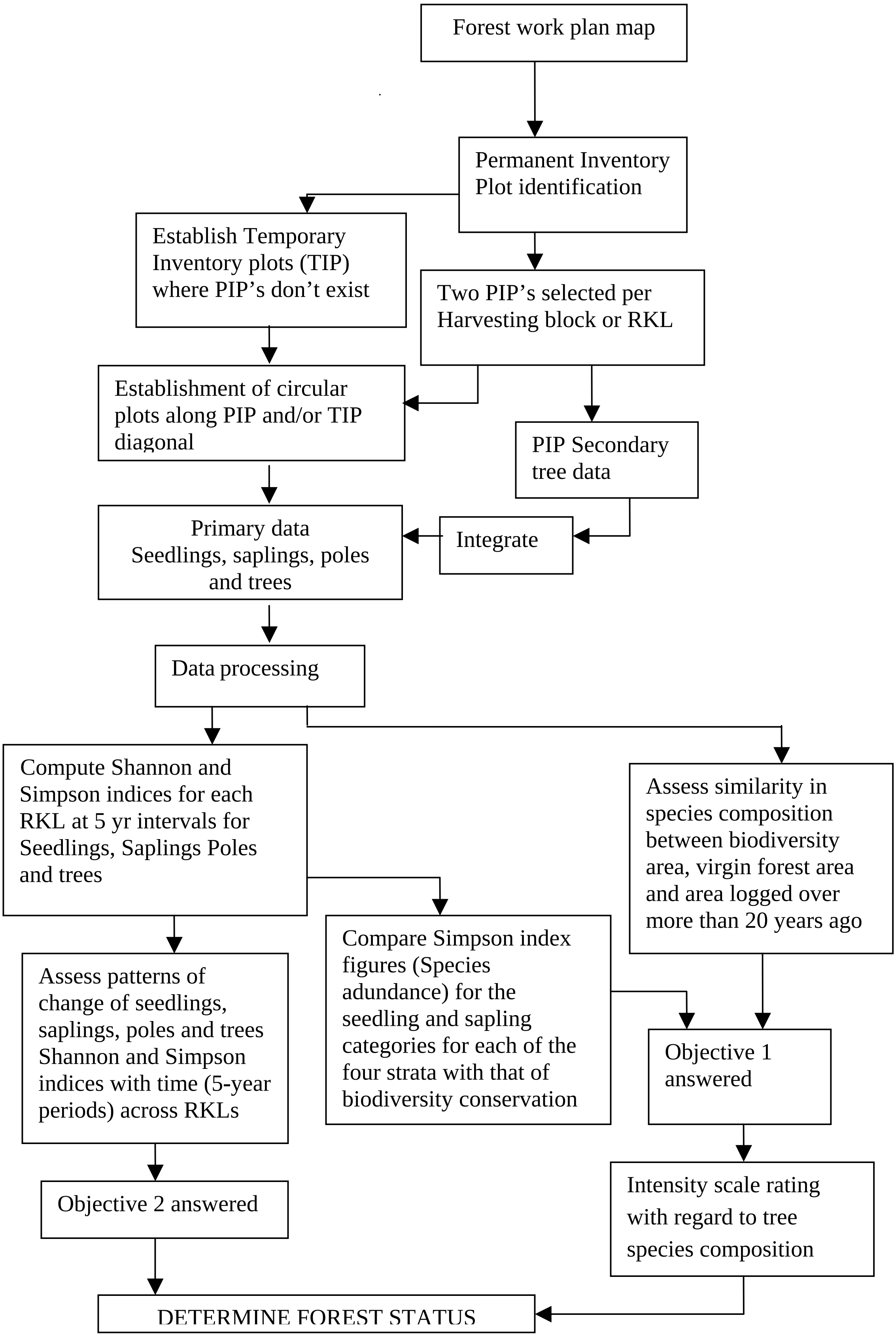


Figure 4-6: Flowchart of the seedling, sapling, pole and tree data analysis

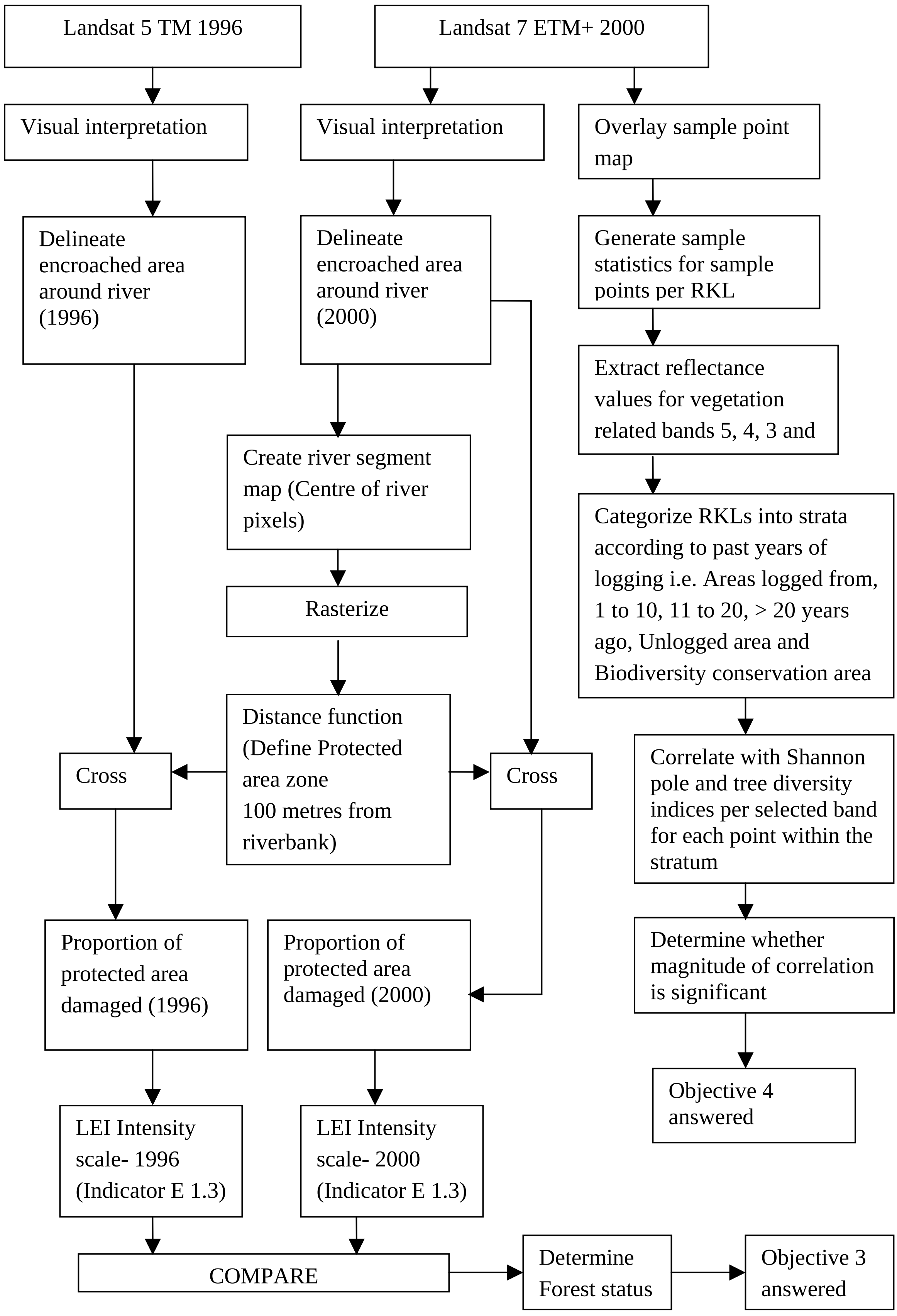


Figure 4-7: Flowchart of remote sensing approach

5. RESULTS AND DISCUSSIONS

This chapter presents the results of this study and discusses the various findings. It attempts to answer the various research questions raised in chapter 1, and thus answers the objectives of the research. It deals with:

- Comparison of species composition of the biodiversity conservation area with a stratum, which was logged more than 20 years ago, as well as with a stratum, which has not been logged at all. This is then related to the intensity scale of indicators for Sustainable Natural Production Forest Management in the LEI certification process.
- Comparison of species abundance of biodiversity conservation area with other strata.
- Patterns of change of tree species diversity across different RKLs (Five year felling plans) and the possible causes of trends.
- Assessment of damage within the river protected area, and its relationship with intensity scale of indicators for Sustainable Natural Production Forest Management in the LEI certification process.
- Relationship between radiance values and tree diversity indices for specific areas sampled in the tropical forest.

5.1. Comparison of species composition between the biodiversity conservation area and areas logged more than 20 years ago

Analysis with regard to this section is done according to the Sorensen coefficient of similarity as given by (Kent and Coker, 1992). Similarity indices were computed for the seedling, sapling and poles and trees categories of RKL 7, which represented the virgin or unlogged forest, as well as for RKL 1, which represented the forest area logged more than 20 years ago. Their species compositions were compared with the species composition of the biodiversity conservation area. As an example, the computation of the Sorensen similarity coefficient for the seedlings category in RKL 7 (unlogged forest) as shown in Table 5-1, is given below:

Using the formula for the Sorensen coefficient of similarity (S_s)

i.e. $S_s = \dfrac{2a}{2a + b + c}$

Where;

a = Number of species common to both quadrants/samples

b = Number of species in quadrant/sample 1

c = Number of species in quadrant/sample 2 (Kent and Coker, 1992)

From Table 5-1 below, a = 19, b = 57 and c = 39

Thus,

$$S_s = \frac{(2*19)}{(2*19)+57+39} = \frac{38}{38+57+39} = \frac{38}{134} = 28.36\%$$

The results of the similarity computations ranged from 7.21% for trees in RKL 1 (Table 5-2), to 28.36% for seedlings in RKL 7 (Table 5-1), meaning that there is very little similarity in the composition of species present both in the logged as well as unlogged forest areas. The results of the other similarity values are given in Tables 5-1 and 5-2.

Table 5-1: Similarity analysis between RKL 7 (Unlogged forest) and Biodiversity conservation area

Tree category	Number of species in RKL 7 (Unlogged forest)	Number of species in Biodiversity conservation area	Number of species common to both areas	Percentage Similarity (Sorensen coefficient)
Seedlings	57	39	19	28.36%
Saplings	63	38	18	26.28%
Poles and trees	66	41	11	17.05%

As shown in Table 5-1, of the 57 seedling species sampled in RKL 7 and 39 sampled in the biodiversity conservation area, 19 of them were similar, giving a percentage similarity of 28.36%, whereas of the 63 sapling species sampled in RKL 7, and 38 in the biodiversity conservation area, 18 of them were similar, giving a percentage similarity figure of 26.28% (Table 5-1). In the case of trees, of the 66 species sampled in RKL 7, and 41 sampled in the biodiversity conservation area, 11 of them were similar to both areas, giving a percentage similarity of 17.05%.

Table 5-2: Similarity analysis between RKL 1 (Logged more than 20 years ago) and Biodiversity conservation area.

Tree category	Number of species in RKL 1 (Logged more than 20 years ago)	Number of species in Biodiversity conservation area	Number of species common to both areas	Percentage similarity (Sorensen coefficient)
Seedlings	28	39	10	22.98 %
Saplings	61	38	18	26.67 %
Poles and trees	165	41	8	7.21 %

As shown in Table 5-2, of the 28 seedling species sampled in RKL 1, and 39 in the biodiversity conservation area, 10 of them were similar; giving a percentage similarity of 22.98%, whereas, of the 61 sapling species sampled in RKL 1, and 38 in the biodiversity conservation area, 18 of them were similar, giving a percentage similarity figure of 26.67% (Table 5-2). In the case of trees, of the 165 species sampled in RKL 1, and 41 sampled in the biodiversity conservation area 8 of them were similar to both areas, giving a percentage similarity of 7.21%. The low similarity figure of the poles and trees category may be attributed to the size of area sampled in RKL 1, which was 1.25 hectares, whereas that of RKL 7 was 0.2 hectares i.e. 1 permanent inventory plot of size 1 hectare and another of 0.2 hectares in RKL 1, and 4 circular plots of size 500m² each in RKL 7. The plot sizes for the seedlings and saplings categories were all 0.2 hectares in RKLs 1 and 7.

5.1.1. Comparison of the similarity figures for seedlings, saplings, poles and trees within RKL 1, RKL 7 and biodiversity conservation area

The similarity percentage value for the seedling category is higher (by 5.38%) in the unlogged area (RKL 7), when compared with the area logged more than 20 years ago (RKL 1). Thus, in terms of seedling species composition, the unlogged area (RKL 7) is more similar to the biodiversity conservation area than the area logged more than 20 years ago.

The similarity percentage values of the sapling category, of unlogged forest (RKL 7) and forest logged more than 20 years ago (RKL 1) are very close (with a difference of 0.39%). This implies that, in terms of sapling species composition, neither of the areas RKL 1 nor RKL 7 is more similar to the biodiversity conservation area than the other. The similarity percentage figure for trees is higher in RKL 7 than it is in RKL 1 by 9.84 %. This implies that RKL 7 is more similar to the biodiversity conservation area than RKL 1 in terms of tree species composition, despite the larger area sampled in RKL 1. The dissimilarity between RKL 7 and RKL 1 in terms of the tree species composition may be attributed to the intense logging activity that took place in RKL 1 as evidenced by (Van Gardingen, 1999). Thus, the unlogged area (RKL 7) is more similar to the biodiversity area in terms of seedling and tree species, as compared to the area logged more than 20 years ago.

5.1.2. Analysis of seedling species common to RKL 1, RKL 7 and biodiversity conservation area

Analysis of similarity between the seedling species common to RKL 1 and biodiversity conservation area, as well as RKL 7 and biodiversity conservation area was done. The results are as shown in Table 5-3. Further analysis of the species common to both these categories generated the species common to all the three areas.

Table 5-3:Analysis of the seedling species common to RKL 1, RKL 7 and the biodiversity conservation area

Seedling species common to both RKL 1 and Biodiversity conservation area	Seedling species common to both RKL 7 and Biodiversity conservation area	Common seedling species RKL 1, RKL 7 and Biodiversity conservation area
Diospyros borneensis	*Antidesma leucopodium*	*Diospyros bornensis*
Diospyros curanii	*Cleistanthus beccarianus*	*Diospyros curanii*
Gluta renghas	*Croton griffithii*	*Gluta renghas*
Knema laurina	*Dacryodes rugosa*	*Knema Laurina*
Koilodepas pectinatus	*Dialiunm indum*	*Koilodepas pectinatus*
Lepisanthes amoena	*Diospyros boornensis*	*Litsea firma*
Litsea firma	*Diospyros curanii*	*Shorea atrinervosa*
Shorea atrinervosa	*Eurycoma longifolia*	*Syzigium species*
Shorea pationensis	*Fordia splendidisma*	
Syzigium species	*Gluta renghas*	
	Knema elmeri	
	Knema laurina	
	Koilodepas pectinatus	
	Litsea firma	
	Polyalthia sumatrana	
	Shorea atrinervosa	
	Shorea smithiana	
	Syzighium secies	
	Vatica rassak	

From Table 5-3, a bigger number of seedling species were common to both RKL 7 (Unlogged forest) and the biodiversity conservation area, as compared to RKL 1 (the area logged more than 20 years ago) and the biodiversity conservation area. The reason for this could be attributed to logging activity, which was conducted more than 20 years ago in RKL 1, by contractors, who applied the TPI logging system, as opposed to the TPTI system currently in use today (section 1.6). The TPI system involves selective cutting only, whereas the TPTI system involves selective cutting with planting. It is probable that under the TPI system, so many mother trees were felled causing a decline in the potential for regeneration of a variety of seedling species. This is evidenced by (Van Gardingen, 1999) who reports that the basal area in a part of RKL 1, where thinning plots were established, was found to be low and was similar to that of RKL 4 immediately after logging. Yet, this particular plot in RKL 1 had been harvested earlier (between 1979 to 1980) and so would have been expected to have a bigger basal area than that of RKL 4. This finding is in agreement with that of Cannon (1998) who reported that logging reduced the number of tree species.

Of the entire seedling species, only 8 were common to the biodiversity conservation area, area logged more than 20 years ago (RKL 1) and the unlogged area (RKL 7) as shown in the analysis above (Table 5-3). This gives an indication of the distribution of species i.e. only 8 species out of a total of 124 (Table 5-4), are found distributed across the three areas within the sample plots. In terms of percentage, this represents a value of 6.45%.

Table 5-4: Total number of seedling species sampled in RKL 1, biodiversity conservation area and RKL 7 (Bolded value in fourth column)

Number of seedling species present within RKL 1	Number of seedling species present within Biodiversity conservation area	Number of seedling species present within RKL 7	Total number of seedling species sampled in the three areas
28	39	57	**124**

5.1.3. Analysis of sapling species common to RKL 1, RKL 7 and Biodiversity conservation area

Analysis similar to that of seedlings species in section 5.1.2 was also done for sapling species. Sapling species common to RKL 1 and biodiversity conservation area, as well as RKL 7 and biodiversity conservation area were determined. The results are as shown in Table 5-5. By finding out the species common to these two categories, the species common to all the three areas were determined i.e. RKL 1, RKL 7 and the biodiversity conservation area.

Table 5-5: Analysis of the sapling species common to RKL 1, RKL 7 and biodiversity conservation area

Sapling species common to both RKL 1 and Biodiversity conservation area	Sapling species common to both RKL 7 and Biodiversity conservation area	Common sapling species RKL 1, RKL 7 and Biodiversity area
Aglaia tomentosa *Chionanthus pluriflorus* *Dialium indum* *Diospyros curanii* *Garcinia parvifolia* *Gardenia species* *Gluta renghas* *Hydnocarpus polypetala* *Ixora species* *Koilodepas pectinatus* *Lepisanthes amoena* *Lophopetalum beccarianum* *Madhuca maganifica* *Madhuca malacensis* *Mallotus penangensis* *Neoscortechinia kingii* *Shorea pationensis* *Syzigium species*	*Aglaia tomentosa* *Chionanthus pluriflorus* *Cleistanthus beccarianus* *Diospyros borneensis* *Diospyros curanii* *Dipterocarpus confertus* *Garcinia parvifolia* *Gluta renghas* *Hydnocarpus polypetala* *Ixora species* *Koilodepas pectinatus* *Macaranga lowii* *Madhuca magnifica* *Polyalthea sumatrana* *Shorea patoenensis* *Syzigium species* *Vatica rassak* *Xanthophyllum affine*	*Aglaia tomentosa* *Chionanthus pluriflorus* *Diospyros curanii* *Garcinia parvifolia* *Gluta renghas* *Hydnocarpus polypetala* *Ixora species* *Koilodepas pectinatus* *Madhuca magnifica* *Shorea patoenensis*

From Table 5-5, the same number of sapling species is common to RKL 7 and the biodiversity conservation area, as is common to RKL 1 and the biodiversity conservation area i.e. 18 species (Table 5-5). Of these, only 10 are found distributed within all the three areas i.e. RKL 1, 7 and the biodiversity conservation area as shown in the analysis above (Table 5-5). When expressed as a proportion of the total of 162 species (Table 5-6), this gives a percentage of 6.17%.

Table 5-6: Total number of sapling species sampled in RKL 1, biodiversity conservation area and RKL 7 (Bolded value in fourth column)

Number of saplings species present within RKL 1	Number of sapling species present within Biodiversity conservation area	Number of sapling species present within RKL 7	Total number of sapling species in the three areas
61	38	63	**162**

5.1.4. Analysis of pole and tree species common to RKL 1, RKL 7 and Biodiversity conservation area

Analysis similar to that of sapling species in section 5.1.2 was also done for the pole and tree species. The pole and tree species common to RKL 1, the biodiversity conservation area and RKL 7 were determined. The results are as shown in Table 5-7. This analysis generated the species common to all three areas.

Table 5-7: Analysis of the pole and tree species common to RKL 1, RKL 7 and biodiversity conservation area

Pole and tree species common to both RKL 1 and Biodiversity conservation area	Pole and tree species common to both RKL 7 and Biodiversity conservation area	Common Pole and tree species in RKL 1, RKL 7 and Biodiversity conservation area
Baringtonia pendula *Dipterocapus confertus* *Dipterocarpus verrcosus* *Drypetes kikir* *Gluta walichii* *Syzigium species* *Vatica umbonata* *Xanthophyllum species*	*Cleistanthus beccarianus* *Dacryodes rugosa* *Dialium indum* *Madhuca malacensis* *Polyalthia glauca* *Shorea atrinervosa* *Shorea laevis* *Shorea smithiana* *Syzigium species* *Vatica umbonata* *Xanthophyllum affine*	*Syzigium species* *Vatica umbonata*

From Table 5-7, 11 pole and tree species are common to RKL 7 (unlogged forest area) and the biodiversity conservation area, as compared to 8 species common to RKL 1 (logged more than 20 years ago) and the biodiversity conservation area. Of these only 2 out of the 272 species (Table 5-8), or 0.735% are found in all the three areas.

Table 5-8: Total number of pole and tree species sampled in RKL 1, biodiversity conservation area and RKL 7 (Bolded value in fourth column)

Number of pole and tree species present within RKL 1	Number of pole and tree species present within Biodiversity conservation area	Number of pole and tree species present within RKL 7	Number of pole and tree species in the three areas
165	41	66	**272**

5.1.5. Tropical forest heterogeneity

The above analyses for the distribution of seedling, sapling and pole and tree species show that the distribution of species over the forest is uneven, meaning that the forest is heterogeneous and diverse.

Turner (2001) pointed out that tropical forests are the most diverse of terrestrial ecosystems. Topographic and edaphic factors lead to landscapes of patches of different forest communities that further add to the diversity of a lowland tropical region. Turner (2001) continues to add that the high diversity of a particular forest frequently involves the coexistence of species in the same genus.

5.1.6. Intensity scale rating with regard to comparison of species composition between the biodiversity plot and area logged more than 20 years ago

The analyses of species composition for the seedling, sapling and pole and tree species that was done in the preceding sections was translated into the intensity scale of indicators for Sustainable Natural Production Forest Management with regard to indicator E 1.4, in order to determine the status of the forest concession. The LEI system of intensity scale of indicators for the Sustainable Natural Production Forest Management, with regard to indicator E 1.4 can be seen in Appendix 5. According to the intensity scale, the diversity of flora in the protected area is taken as a percentage of that of virgin forest as well as forest that was logged over more than 20 years ago. The measure of diversity used here is the number of species.

5.1.5a Intensity scale rating with regard to seedling species

From Table 5-1, the number of seedling species in the protected area (in this case the biodiversity conservation area) is 39, while the number of species in RKL 7 (unlogged forest) is 57. In this case, the number of seedling species in each of the areas is taken as a measure of diversity. Thus, taking the number of seedling species in the biodiversity conservation area as a percentage of the number of seedling species in the unlogged or virgin forest, gives 68.42% (Table 5-9). On the other hand, taking the number of seedling species in the biodiversity conservation area, which is 39, as a percentage of the number of seedling species in the RKL 1 (area logged more than 20 years ago), which is 28, gives a percentage of over 139.3% (Table, 5-9). This percentage figure may be attributed to the high logging intensity, which took place in RKL 1 leading to possible extraction of many species of potential mother trees, which in turn affected the regeneration of a variety of seedling species. This consequently gives a lower value of diversity. Evidence of this high logging intensity is given by (Van Gardingen, 1999). Taking the percentage value derived from comparing the seedling species diversity of the biodiversity conservation area and RKL 1 (area logged more than 20 years ago), as well as that obtained from comparing the seedling species diversity of the biodiversity conservation area and RKL 7 (unlogged area), gives a mean percentage figure of 103.81% (Table 5-9). For indicator E 1.4, with regard to seedling species, this gives a position on the intensity scale of indicators for Sustainable Natural Production Forest Management of “EXCELLENT” (Appendix 5) i.e “The diversity of flora and fauna in the protected area is greater than or equal to the diversity of the flora in the virgin forest and greater than or equal to the diversity of flora and fauna in the area logged more than 20 years ago”. The assessment in this case, was done basing only on the diversity of flora. This means that the efforts of Labanan concession towards keeping a well-managed and protected area are commendable. However, these results show that the harvesting techniques employed in RKL 1 were destructive to the existing species as indicated by the over 100% difference between the flora diversity in the biodiversity conservation area and RKL 1.

Table 5-9: Showing the percentages of number of seedling species in Biodiversity conservation area to number in unlogged area, as well as to the area logged more than 20 years ago, and the mean of both percentages

Number of seedling species in biodiversity conservation area	Number of seedling species in unlogged area	Number of seedling species in area logged more than 20 years ago (RKL1)	Percentage of number of seedling species in biodiversity conservation area, to number of seedling species in unlogged area	Percentage of number of seedling species in biodiversity conservation area, to number of seedling species in area logged > 20 years ago	Mean percentage value
39	57	28	68.42%	139.3%	103.81%

5.1.5.b Intensity scale rating with regard to sapling species

From Table 5-1, with regard to the sapling species, taking the number of species in the biodiversity conservation area, which is 38, and expressing it as a percentage of sapling species present in RKL 7 or unlogged forest, which is 63, gives a percentage of 60.3%. On the other hand, taking the number of sapling species in the biodiversity conservation area, which is 38, as a percentage of the number of sapling species in the RKL 1 (area logged more than 20 years ago), which is 61, gives a percentage of 62.3% (Table, 5-10). Taking the mean percentage value derived from comparing the sapling species diversity of the biodiversity conservation area and RKL 1, as well as that derived from comparing the sapling species diversity of the biodiversity conservation area and RKL 7, and obtaining the mean percentage value, gives a mean percentage figure of 61.15% (Table 5-10). With regard to sapling species, this gives a position on the intensity scale of indicators for Sustainable Natural Production Forest Management, of “POOR” i.e. “the diversity of flora in the protected area is 60 to 70% of the diversity in the virgin forest and area logged over more than 20 years ago.”

Table 5-10: Showing the percentages of number of sapling species in Biodiversity conservation area to number in unlogged area, as well as to the area logged more than 20 years ago, and the mean of both percentages

Number of sapling species in biodiversity conservation area	Number of sapling species in unlogged area	Number of sapling species in area logged more than 20 years ago (RKL1)	Percentage of number of sapling species in biodiversity conservation area, to number of sapling species in unlogged area	Percentage of number of sapling species in biodiversity conservation area, to number of sapling species in area logged > 20 years ago	Mean percentage value
38	63	61	60.3%	62.3%	61.15%

5.1.5.c Intensity scale rating with regard to pole and tree species

From Table 5-1 (section 5.1) the number of pole and tree species in the biodiversity conservation area, which is 41 and expressing it as a percentage of the number of pole and tree species in RKL 7 (Virgin forest), which is 66, gives an intensity scale percentage of 62.12%, while the percentage intensity scale rating with regard to poles and trees in RKL 1, given the number of tree species sampled in RKL 1 as 165 (Table 5-11), is 24.84%. Taking the percentage value derived from comparing the pole and tree species diversity of the biodiversity conservation area and RKL 1, as well as comparing the pole and tree species diversity of the biodiversity conservation area and RKL 7, gives a mean percentage figure of 43.48% (Table 5-11). With regard to pole and tree species, this gives a position on the intensity scale of indicators of sustainable Natural Production Forest Management of “BAD” i.e. “the diversity of flora in the protected area is less than 60% of the diversity of flora in the virgin forest and area logged over more than 20 years ago.” However, the size of area sampled in RKL 1 (area logged more than 20 years ago) is 1.25 hectares and that sampled in biodiversity area is 0.2 hectares. Thus, the result obtained from comparing the number of pole and tree species of the biodiversity conservation area with RKL 1, may have been greatly influenced by area sampled.

Table 5-11: Showing the number of pole and tree species in Biodiversity conservation area expressed as a percentage of the number in unlogged area, as well as the area logged more than 20 years ago, and the mean of both percentages

Number of pole and tree species in biodiversity conservation area	Number of pole and tree species in unlogged area	Number of pole and tree species in area logged more than 20 years ago (RKL1)	Percentage of number of pole and tree species in biodiversity conservation area, to number of pole and tree species in unlogged area	Percentage of number of pole and tree species in biodiversity conservation area, to number of pole and tree species in area logged > 20 years ago	Mean percentage value
41	66	165	62.12	24.84	43.48

5.1.7. Overall rating of tree species diversity with regard to indicator E1.4

With regard to tree species diversity, the overall rating may be computed as an average of all the values obtained above. i.e. from section 5.1.5.a to section 5.1.5.c. Table 5-12 gives the mean value of the percentage intensity values obtained for seedlings, saplings and poles and trees categories. These are used in determining the overall intensity scale value with regard to species composition.

Table 5-12: Mean percentage intensity values for the seedling, sapling and pole and tree categories, as well as overall mean percentage intensity

Plant category	Seedlings	Saplings	Poles and trees	Overall mean percentage intensity
Mean percentage intensity value	103.81	61.15	43.48	**69.48**

From table 5-12, the overall mean percentage intensity value is 69.48. The position on the intensity scale of rating for this figure is “POOR” i.e. “The diversity of flora in the protected area is 60 to 70% of the diversity in the virgin forest and the area logged more than 20 years ago”.

5.1.8. Similarity percentage and its relation to intensity scale of rating

The similarity percentage was also interpreted in terms of the intensity scale of indicators for Sustainable Natural Production Forest Management.

From Table 5-1, the similarity coefficient between the biodiversity conservation area, and the unlogged area (RKL 7) for saplings is 26.28%, which gives a percentage dissimilarity of 73.72%, whereas for seedlings it is 28.36%, which gives a percentage dissimilarity figure of 71.64% and for poles and trees it is 17.05%, which gives a percentage dissimilarity figure of 82.95% (Table 5-1).

Similarly, the similarity coefficient for the biodiversity conservation area and area logged more than 20 years ago for saplings is 26.67% which gives a percentage dissimilarity of 73.33% (Table 5-2), whereas the percentage similarity coefficient for seedlings in this same area is 22.98% which gives a percentage dissimilarity of 77.02%, and the percentage similarity coefficient for poles and trees is 7.21% which gives a percentage dissimilarity of 92.79% (Table 5-2). According to Kent and Coker (1992) dissimilarity measures the extent to which two quadrants or samples being compared are dissimilar in terms of species composition. The interpretation of dissimilarity as a measure could be taken as an indication of how diverse a particular community is in terms of species i.e. the more similar it is, the less diverse the community. Thus, taking the mean of all the six above mentioned dissimilarity figures as a measure of diversity of the samples would give a value of 78.58%. According to the intensity scale, this would give a ranking of “FAIR” (Appendix 6) i.e. “The diversity of flora in the protected area is 70 to 90% of the diversity of flora in the virgin forest and old logged over area”.

5.1.9. Comparison of methods used for assessing indicator E 1.4 in this research, with methods used by the Certification body accredited by LEI

In principle, certain methods of assessment have to be used to assess indicator E 1.4 (Appendix 5). However, despite the existence of these methods, which specify the quantitative means of comparing the diversities of the protected area and the area logged more than 20 years ago, as well as the unlogged area, the assessors use mainly visual observation to decide upon the levels of diversity in the different forest areas mentioned. According to the assessors, they look generally at the condition of vegetation, which they compare with previous reports on biodiversity. For example, in the recent assessment of diversity within the protected areas on slopes greater than 40%, three arbitrarily selected points were used to estimate the diversity levels. The assessors also state that information on tree species diversity is limited, which further jeopardises the reliable judgement of the tree diversity status. Using the means and resources available to them, the assessors established that the biodiversity area was richer than the logged over area in terms of species diversity. In the actual assessment of indicator E 1.4, with regard to the intensity scale of criteria for Sustainable Natural Production Forest Management, there was no data to show that the condition of the protected area was better than either the area logged more than 20 years ago, or the unlogged area (P.T.Mutuagung Lestari, 2001). According to P.T.Mutuagung Lestari (2001) visual observation showed that the protected areas especially along steep slopes were in a good condition, which concurred with findings according to Mawdsely (1999). This finding compelled the assessors to rate indicator E 1.4 according to the intensity scale of indicators for Sustainable Natural production Forest Management as “FAIR”.

The method of assessment of indicator E 1.4 employed in this research, was based on actual data on seedling, sapling and pole and tree species collected from the field. These data were then used to calculate the number of species in the protected area (Biodiversity conservation area), as well as the area logged more than 20 years ago and the unlogged forest area. The percentage of number of species in biodiversity conservation area relative to the two other areas was then calculated. Based on the computed percentages, the rating of indicator E 1.4, based on the intensity scale of indicators for Sustainable Natural production Forest Management was determined (Appendix 5). Based on this approach the rating of “POOR” was arrived at.

Another method employed in this study was that of using the dissimilarity measure as an estimate of tree species diversity between the biodiversity area and areas logged more than 20 years ago as well as the unlogged areas. This was done for all categories of seedlings, saplings and poles and trees. This dissimilarity percentage was then directly interpreted in terms of the intensity scale of indicators for Sustainable Natural production Forest Management (Appendix 5). Based on this approach the rating of "FAIR" was arrived at.

In general, since the methods used in this study are based on actual field data collected, rather than on mere field observation and previous reports, they are considered an improvement to the methods currently being used by the assessors.

5.2. Comparison of species abundance of biodiversity conservation area with that of other strata

In comparing the species abundances of the biodiversity conservation area with the abundances of other strata, species were not directly measured, but Simpson indices were used as a measure to reflect the relative abundances between plots. (Magurran, 1988) explains that the Simpson index is more weighted towards the abundances of the most common species rather than providing a measure of species richness, and so it was considered appropriate for this purpose. Thus, the abundance of the biodiversity conservation area was compared to that of the other strata mentioned in section 4.2.2.a. These are; Virgin or Unlogged forest (Stratum IV), area logged more than 20 years ago (stratum III), area logged from 11 to 20 years ago (Stratum II) and areas logged from 1 to 10 years ago (Stratum I). The Mann-Whitney non-parametric test was used for comparison of the abundances of the different strata. The Mann-Whitney test was preferred since it can be performed with two samples of differing sizes. It tests for differences in population medians. The null hypothesis being tested here was that there was no difference between the abundance of species in the biodiversity conservation area and that of the other mentioned strata. The alternative hypothesis was that the abundance of species in the biodiversity conservation area was higher than it was in the other strata. The results of the tests for each stratum are shown in Tables 5-13 to 5-20. The tests were significant at ($\alpha = 0.05$) for all strata when compared to the biodiversity conservation area. Details of the tests are shown in Appendix 8. From this analysis, it can be deduced that no differences exist between the abundances of each of the strata and that of the biodiversity conservation area. This indicates that the most common species were present in equal proportions throughout the sampled areas.

- **Seedling abundance comparisons**

Tables 5-13: Comparison between seedling abundance in stratum I and biodiversity conservation area using the Mann-Whitney significance test.

Stratum	Number of sample plots	Median abundance value
I (logged 1 to 10 years ago)	8	0.1712
Biodiversity conservation area	4	0.1404

P value = 0.7989, Cannot reject Ho at alpha = 0.05

Table 5-14: Comparison between seedling abundance in stratum II and biodiversity conservation area using the Mann-Whitney significance test

Stratum	Number of sample plots	Median abundance value
II (logged 11 to 20 years ago)	8	0.1476

Biodiversity conservation area	4	0.1404

P value = 1.0000, Cannot reject Ho at alpha = 0.05

Table 5-15: Comparison between seedling abundance in stratum III and biodiversity conservation area using the Mann-Whitney significance test

Stratum	Number of sample plots	Median abundance value
III (logged > 20 years ago)	8	0.1712
Biodiversity conservation area	4	0.1404

P value = 0.6650, Cannot reject Ho at alpha = 0.05

Table 5-16: Comparison between seedling abundance in stratum IV (unlogged forest) and biodiversity conservation area using the Mann-Whitney significance test

Stratum	Number of sample plots	Median abundance value
IV (Unlogged forest)	8	0.1062
Biodiversity conservation area	4	0.1404

P value = 0.2027, Cannot reject Ho at alpha = 0.05

- **Sapling abundance comparisons**

Table 5-17: Comparison between sapling abundance in stratum I (forest logged 1 to 10 years ago) and biodiversity conservation area using the Mann-Whitney significance test

Stratum	Number of sample plots	Median abundance value
I (logged 1 to 10 years ago)	8	0.0461
Biodiversity conservation area	4	0.1157

P value = 0.1066, Cannot reject Ho at alpha = 0.05

Table 5-18: Comparison between sapling abundance in stratum II (forest logged 11 to 20 years ago) and biodiversity conservation area using the Mann-Whitney significance test

Stratum	Number of sample plots	Median abundance value
II (logged 11 to 20 years ago)	8	0.0555
Biodiversity conservation area	4	0.1157

P value = 0.7986, Cannot reject Ho at alpha = 0.05

Table 5-19: Comparison between sapling abundance in stratum III (forest area logged more than 20 years ago) and biodiversity conservation area using the Mann-Whitney significance test

Stratum	Number of sample plots	Median abundance value
III (logged > 20 years ago)	8	0.0.0897
Biodiversity conservation area	4	0.1157

P value = 0.8852, Cannot reject Ho at alpha = 0.05

Table 5-20: Comparison between sapling abundance in stratum IV (unlogged forest area) and biodiversity conservation area using the Mann-Whitney significance test

Stratum	Number of sample plots	Median abundance value
IV (Unlogged forest)	8	0.0548
Biodiversity conservation area	4	0.1157

P value = 0.3502, Cannot reject Ho at alpha = 0.05

5.3. Patterns of change of tree species diversity across different RKLs and possible causes of trends

Analysis under this subchapter is aimed at finding out whether there is any significant change in tree species diversity across the different RKLs as estimated from the Simpson and Shannon diversity indices. The observed trends are then related to the logging or management history of the specific RKLs in which they occur. An attempt is then made at trying to interprete the diversity indices in terms of the LEI intensity scale of indicators for Sustainable Natural Production Forest Management.

5.3.1. Analysis of patterns of change for the poles and trees category

This subsection analyses the patterns of change of the Simpson and Shannon indices for poles and trees at five year felling intervals.

Table 5-21: Table of values of mean Shannon and Simpson indices for poles and trees per RKL

RKL	**Mean Simpson's Index (1-D)**	**Mean Shannon Index (H')**
1	**0.979**	**4.055**
2	**0.944**	**2.833**
3	**0.963**	**3.472**
4	**0.957**	**3.411**
5	**0.910**	**2.610**
6	**0.962**	**2.729**
7	**0.975**	**2.978**

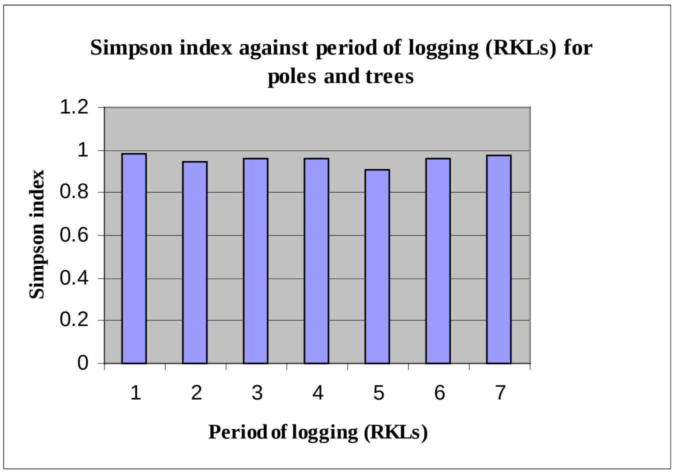


Figure 5-1: Simpson index against period of logging for poles and trees

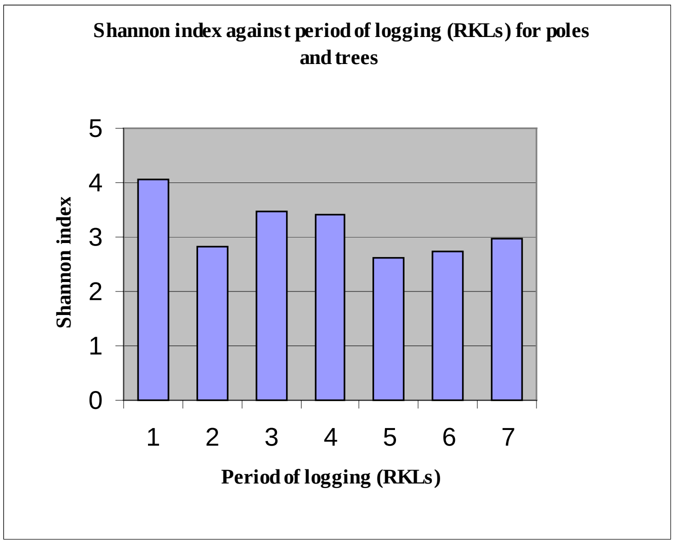


Figure 5-2: Shannon index against 5-year period of logging for poles and trees

The Simpson index for poles and trees shows a slight fluctuation with time (across the RKLs), as compared to the Shannon index for the same category (Figures 5-1 and 5-2) and Table 5-21. Since the Simpson index is bent more towards the abundance of the most common species within the sample or community (Magguran, 1988), it indicates that there is no significant difference in the abundance of the most common pole and tree species across the RKLs. However, there is a slight drop at RKL 2, and a more significant one at RKL 5. The drop at RKL 5 can be explained by the recent logging activity that has just taken place in this particular RKL. Even then, the drop at RKL 5 is not as severe as would have been expected. This is probably due to the reduced impact logging, which was conducted here (Matikainen, 1998). This finding concurs with that of (Cannon, 1998) who in a related study, revealed that selectively logged tropical rainforest in Indonesia contained high tree species richness, despite undergoing severe structural damage.

In the case of the Shannon index for the poles and trees category, RKL 1 has the highest index value of about 4.055 (Table 5-21). It then reduces through RKL 2, which is the expected trend for a sustainably managed forest. However, in RKL 3 where, the index would have been expected to decline, it instead rises. This may be due to the changes that have taken place within Labanan concession with regard to the harvesting areas. According to the Head of the Planning Division of Labanan concession, the compartments were redesigned during which process; part of RKL 1 became RKL 3. The area represented as RKL 3 is actually representative of RKL 1 and as can be seen from the graph, the index value is tending more towards that of RKL 1.

From RKL 5 onwards, the trend of change of Shannon index with time (five year period) follows an expected trend gradually rising from RKL 5 through 6 to RKL 7.

5.3.2. Analysis of patterns of change for the saplings category

This subsection analyses the patterns of change of the Simpson and Shannon indices for saplings at five year felling intervals. The values used in plotting the graphs are shown in Table 5-22.

Table 5-22: Table of values of mean Shannon and Simpson indices for saplings per RKL

RKL	Mean Shannon index H'	Mean Simpson index 1-D
1	2.640	0.914
2	2.502	0.944
3	1.967	0.770
4	2.560	0.942
5	2.958	0.945
6	2.973	0.943
7	2.778	0.942

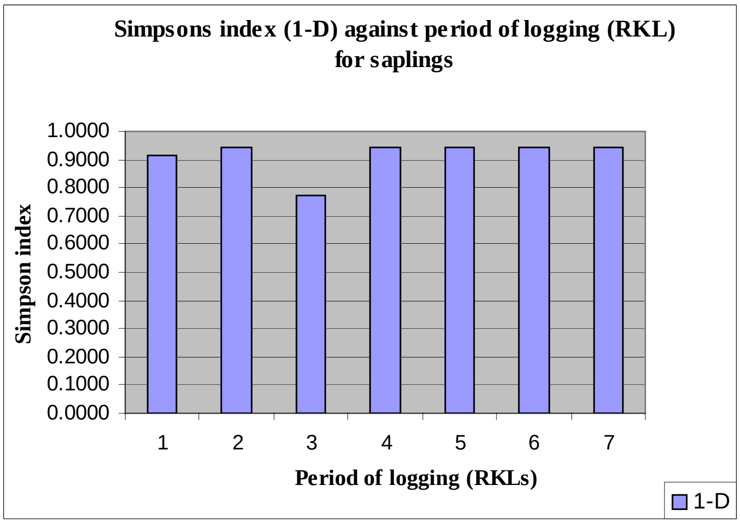


Figure 5-3: Simpson index against 5-year period of logging for saplings

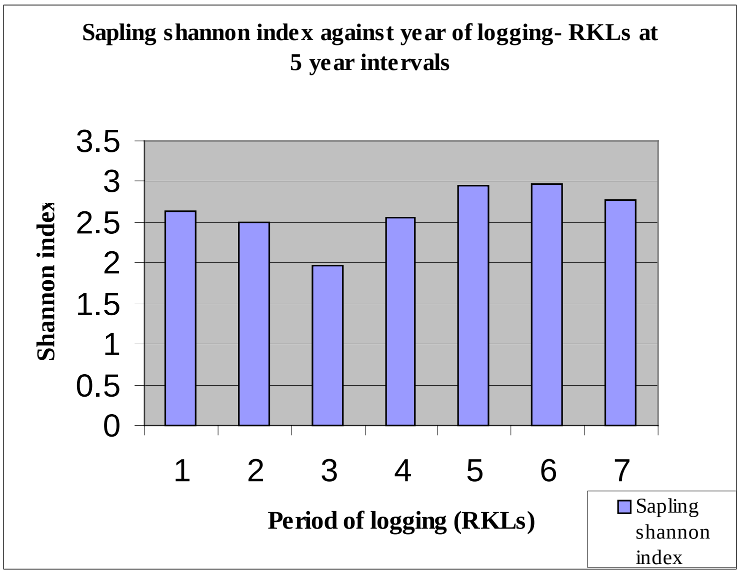


Figure 5-4: Shannon index against period of logging for saplings

The Simpson index for saplings shows a small fluctuation with time (across the RKLs) as compared to the Shannon index for the same category (Figures 5-3 and 5-4). The only difference occurs at RKL 3, where there is a drop from the Simpson index of RKL 2. Since the Simpson index is bent more towards the abundance of the most common species within the sample or community (Magguran, 1988) it indicates that there is no difference in the abundance of the most common pole and tree species across the RKLs. The drop in RKL 3 cannot be attributed to the heavy logging which took place in RKL 1 as explained by the redesign process, but may be due to other factors such as crown cover percentage and slope. This is so since RKL 1 shows a higher Simpson index than RKL 3, and yet according to the redesigned plan of Labanan, these two areas are similar.

5.3.3. Analysis of patterns of change for the seedlings category

Table 5-23: Table of values of mean Shannon and Simpson indices for seedlings per RKL

RKL	Shannon index H'	Mean Simpson index 1-D
1	1.967	0.836
2	2.307	0.877
3	2.061	0.798
4	1.977	0.864
5	2.304	0.841
6	2.552	0.888
7	2.540	0.904

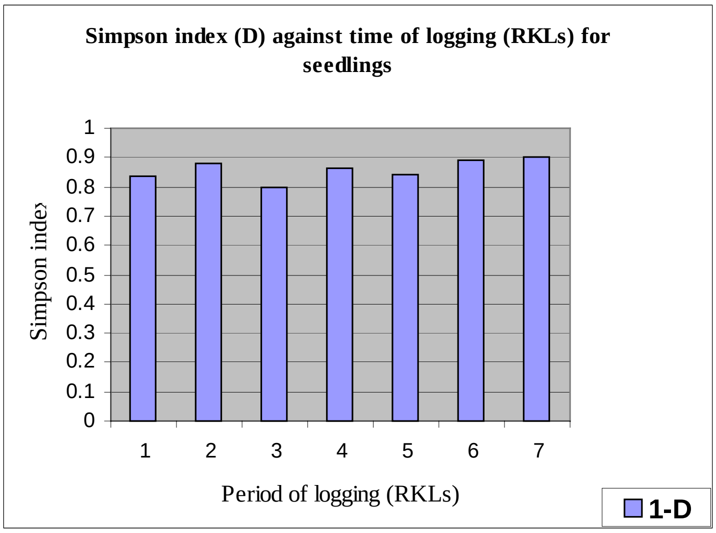


Figure 5-5: Simpson index against period of logging for seedlings

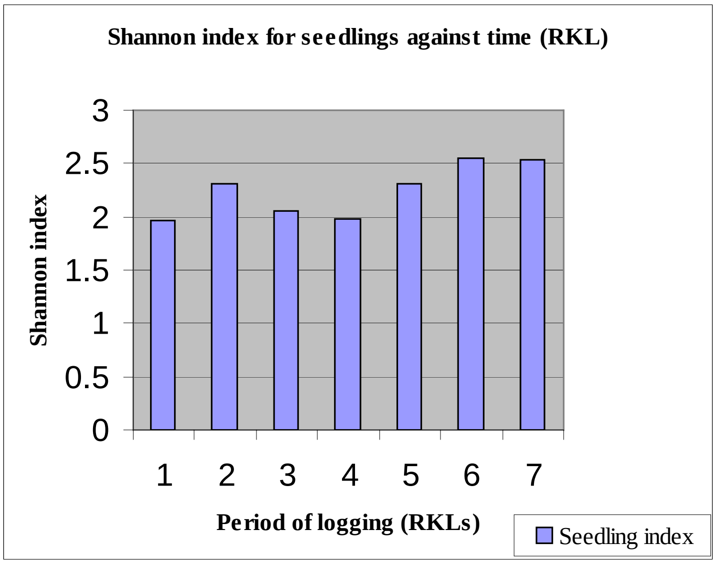


Figure 5-6: Shannon index against period of logging for seedlings

From Figures 5-5 and 5-6, the trends of change of the Shannon and Simpson indices are in agreement for RKLs 1, 2 and 3.

However, the Simpson index in RKL 4 is slightly higher than it is in RKL 3 and RKL 5 (Figure 5-5), whereas the Shannon index in RKL 4 is lower than it is in RKL 3 and RKL 5 (Figure 5-6). The trend is the same, for both the Shannon and Simpson indices, from RKL 5 to 6 with both indices increasing. For RKLs 6 and 7, the Shannon indices are the same, whereas the Simpson index is slightly higher in RKL 7 than it is in RKL 6.

These differences could be attributed to the aspects each of the indices is measuring. The Simpson index is weighted towards the abundance of the commonest species, whereas the Shannon index is more biased towards species richness (Magurran, 1988). Thus, the species richness of RKL 4 must be lower than that of RKL 3 and 5, whereas the abundance of the most common species may be higher in RKL 4 as compared to RKLs 3 and 5. This observation is in agreement with what (Mawdsley, 1999) reported that the forest areas logged 8 years ago (RKL 4) were less diverse in several groups and distinct from older logged forest in terms of species composition. (Mawdsley, 1999) continues to report a decrease in the number of species in logged forest.

The index value for RKL 1 would have been expected to be higher than all RKLs up to RKL 5. However, the value is low here probably because of the enormous logging that took place in RKL 1.

5.3.4. Interpretation of the diversity indices in terms of the LEI intensity scale of Sustainable Natural Production Forest

The patterns of change of the diversity indices with time, did not yield any observable pattern that could be used to assess the whether Labanan forest is sustainable or not, in terms of seedlings, saplings and pole and tree species. In addition, the LEI intensity scale of Sustainable Natural Production Forest Management does not cater for such analysis. In this regard, analyses using the mean Shannon and Simpson indices for the area logged over more than 20 years ago, the unlogged areas, as well as the biodiversity conservation area were done. Using the intensity scale of indicator E 1.4 (Appendix 5), the respective indices were used to give ratings. This was done by taking the Simpson and Shannon indices, respectively, for the biodiversity conservation area, as separate fractions of the area logged over more than 20 years ago and the unlogged forest. The analyses done are shown in Tables 5-24 and 5-25 for the Shannon and Simpson indices respectively.

Table 5-24: Showing mean values of Simpson indices for seedlings, saplings, poles and trees in RKL1, RKL7 and the Biodiversity conservation area.

Category	RKL1	RKL7	Biodiversity conservation area
Seedlings	0.836	0.904	0.183
Saplings	0.914	0.942	0.116
Poles and trees	0.979	0.975	0.079
Mean values	**0.909**	**0.940**	**0.126**

From Table 5-24 above, taking the mean value of the Simpson index for the biodiversity conservation area, and expressing it as a fraction of the mean value of the Simpson index for RKL 7 (Unlogged forest), gives a percentage value of 13.4%, whereas taking the mean Simpson index value of the biodiversity conservation area, and expressing it as a percentage of the mean Simpson value for RKL 1 (area logged more than 20 years ago), gives a percentage value of 13.9%. Relating these percentage values to the intensity scale of indicators for the sustainable Natural Production Forest Management, gives a rating of “BAD” i.e. “The diversity of flora in the protected area is less than 60% of the diversity of flora in the virgin forest and area logged over more than 20 years ago”.

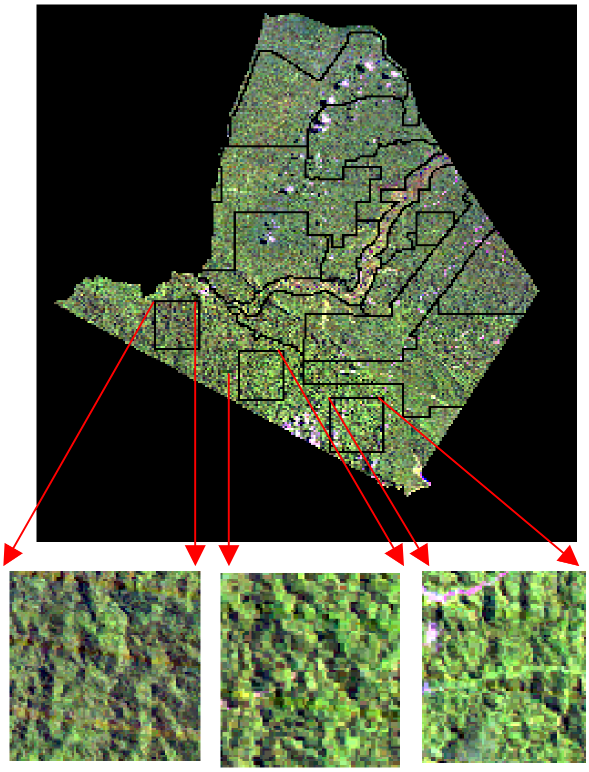
Table 5-25: Showing mean values of Shannon indices for seedlings, saplings, poles and trees in RKL1, RKL7 and the biodiversity conservation area.

Category	RKL1	RKL7	Biodiversity conservation area
Seedlings	1.97	2.54	2.13
Saplings	2.64	2.778	2.237
Poles and trees	4.055	2.78	2.467
Mean values	2.88	2.699	2.278

From Table 5-25 above, taking the mean value of the Shannon index for the biodiversity conservation area, and expressing it as a fraction of the mean value of the Shannon index for RKL 7 (unlogged forest), gives a percentage value of 84.4%, whereas taking the mean Shannon index value of the biodiversity conservation area, and expressing it as a percentage of the mean Shannon value for RKL 1 (area logged more than 20 years ago), gives a percentage value of 79.1%. Relating these percentage values to the intensity scale of indicators for the sustainable Natural Production Forest Management, gives a rating of "FAIR" i.e. "The diversity of flora in the protected area is 70 to 90% of the diversity of flora in the virgin forest and area logged over more than 20 years ago".

5.4. Assessment of damage within the river protected area, and its relationship with the intensity scale of indicators for Sustainable Natural Production Forest Management

This sub-chapter demonstrates the possibility of using remote sensing techniques, to assess damage within the river-protected area, and then relates this assessment with the intensity scale of indicators for Sustainable Natural Production Forest Management given in Appendix 5. Damage within the river-protected area was considered because the rest of the protected area to the south of the concession has not suffered any degradation, deforestation or observable change, which means it is still intact. This can be evidenced by the colour composites of Landsat TM 1996 and 2000, with the Middle Infrared, Near Infrared and Green bands in the Red, Green and Blue channels respectively (Figure 5-7). This colour composite gives a clear picture of the terrain properties of the southern protected area, which is rugged. Mutuagung Lestari, the certification body accredited by LEI, also reported no evidence of severe damage within the southern protected area (P.T.Mutuagung Lestari, 2001).



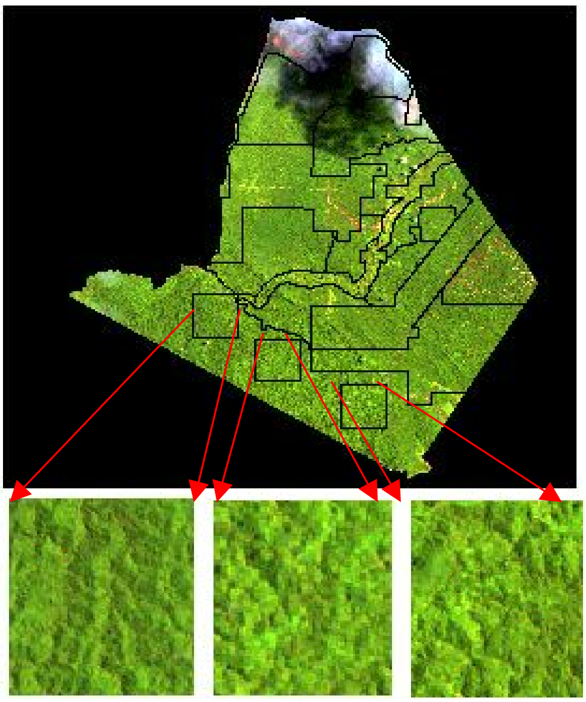


Figure 5-7: (a) and (b) Showing three zoomed in portions of the protected area to the south, using the 542 Colour composites of Landsat TM bands (a) 1996 and (b) 2000. The southern most boundary running from west to east in both images (above the three boxes) is the demarcation of the protected area. All the other boundaries are demarcations of RKLs.

5.4.1. Determination of river protected area

As stated in the Indonesian regulations, the river-protected area is defined as a buffer zone of 100 metres along both sides of the riverbanks. Figure 5-8 shows the river-protected area, which was produced from a rasterized river segment map, using the Geographical Information System (GIS) distance function in ILWIS. The distance range was set at 0 to 116 metres in order to create a buffer area, which represented the river-protected area. The width of the river was taken as 1 pixel wide (30 metres) based on field observation. Taking one side of the river from its middle, gives 15 metres from the river (half the pixel width), leaving 101 metres out of the 116 metres, as the extra buffer zone area. This area represents the river-protected area. The extra 1 metre was included in order to allow for an error range of ± 0.5 metres on both sides of the river. During the production this map, a histogram was generated, from which the areas of the different distance zones from the river edge could be derived. These areas were then summed up to generate the total river protected area (Table 5-26). All the pixels with a distance value of zero (Table 5-26) were omitted from the summation of area since they signified actual river pixels and not forest area pixels. The estimated total river protected area derived from summing up the buffer zone areas is 1144 hectares.

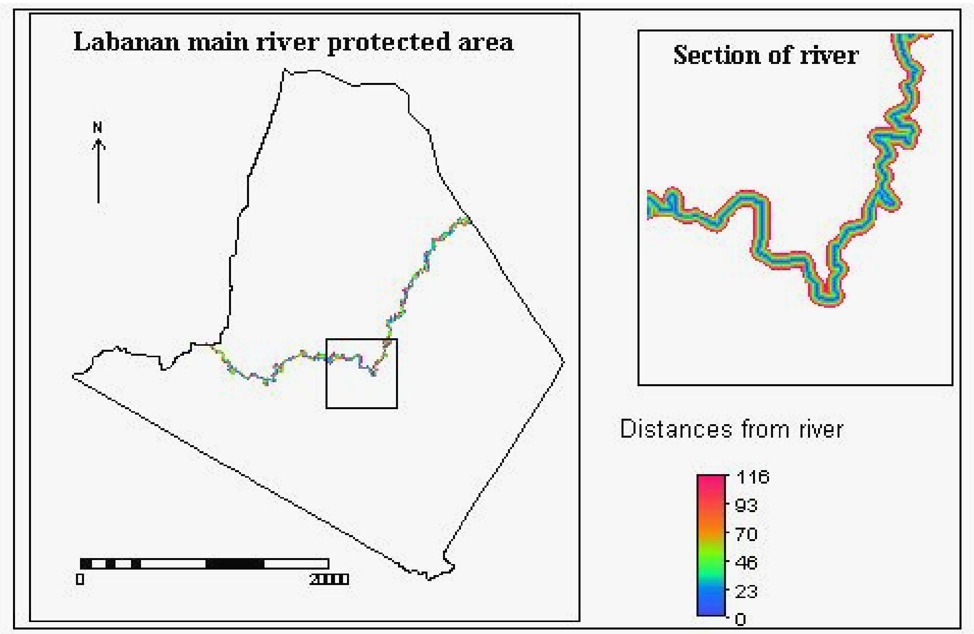


Figure 5-8: Map showing the river-protected area in Labanan produced using the distance function in ILWIIS

Table 5-26: Showing the distance classes expressed on the river protected area map, the number of pixels and the areas of each distance class

Distances from the river bank (m)	Number of pixels	Area (m^2)	Area (Ha)
0*	1979*	1783119*	178.3*
29	3515	3167086	316.7
41	1173	1056897	105.7
58	1949	1756089	175.6
70	1208	1088433	108.8
81	921	829840	83.0
87	1224	1102849	110.3
99	698	628912	62.9
110	992	893812	89.4
116	1017	916338	91.6
Totals	12697	11440256	1144

5.4.2. Delineation of areas of damage

Two Landsat TM images acquired in 1996 and 2000 were used in damage assessment, by which areas of encroachment around the river-protected area were delineated in each image (Section 4.4.2). An example of such delineated area from Landsat TM 2000 using the 542-colour composite is shown in Figure 5-9. These areas were later polygonized and then and rasterized in order to be able to cross each of them separately, with the river protected area map, which was generated as explained in section 5.4.1 above. The encroached areas were derived from summing up the areas of all the pixels, which were a result of the cross between the encroachment areas, and the previously created river protected area. The resulting sizes of encroached areas (within the protected area) for the years 1996 and 2000 are shown in Table 5-27. The proportion of protected area encroached in each of the years 1996 and 2000, was computed by expressing each of the encroached areas in hectares for 1996 and 2000, as a percentage of the total protected area given in Table 5-27.

* This distance class was omitted from the total since these are river pixels.

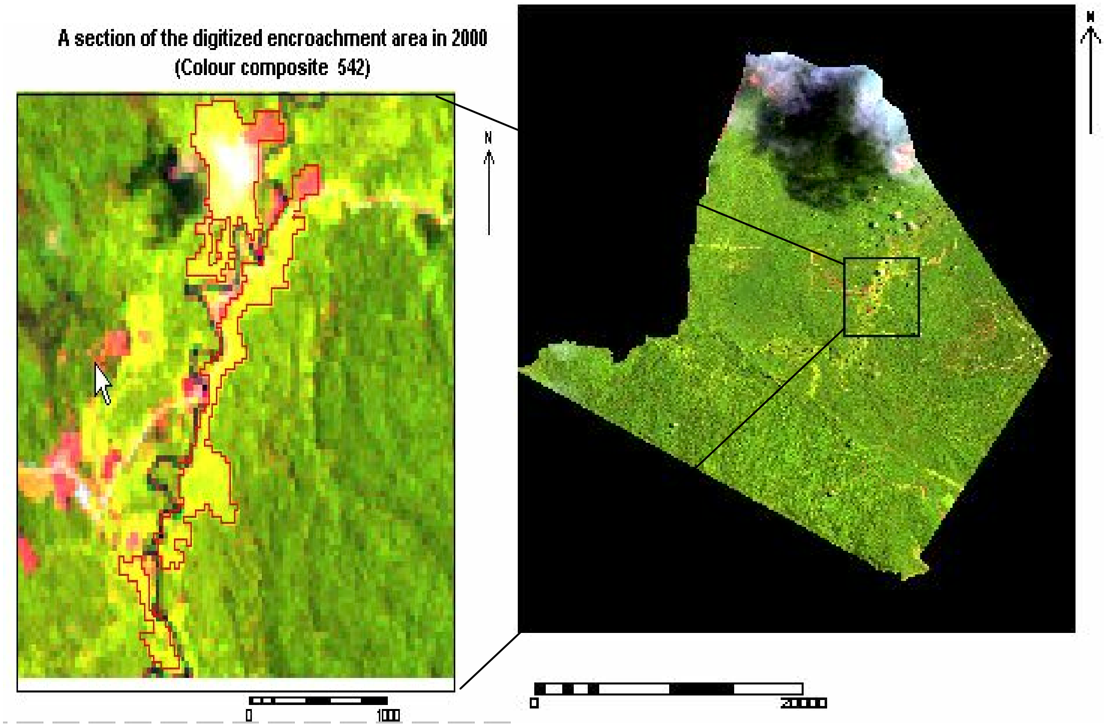


Figure 5-9: An example of digitised encroachment area around the river (In the year 2000)

Table 5-27: Showing the size of encroached area in 1996 and 2000 within the river protected area

Year	Encroached area (Ha)	Total river protected area	Area encroached expressed as a percentage of total protected area
1996	22	1144	1.92%
2000	86	1144	7.52%

5.4.3. Encroached area damage and its relationship with intensity scale rating

According to the intensity scale rating associated with indicator E 1.3 i.e. “the intensity of damage in the protected areas which includes the danger of forest fires”, the ranking for this particular indicator, with regard to encroachment within the river-protected area, is “GOOD” (Appendix 5). This is because as specified in the scale, the area size of the damaged protected area is small (<25%) and there is a low degree of damage. Alternatively it could be stated that; the damaged protected area is very small (<10%); there is a moderate degree of damage and control efforts are adequate. However, based on qualitative rating by Mutuagung Lestari, the certifying body accredited by Lembaga Ekolabel Indonesia (LEI), the rating given according to the intensity scale was “FAIR” (P.T.Mutuagung Lestari, 2001). P.T.Mutuagung Lestari (2001) continues to add that the most critical areas are the ones bordering rivers since they have valuable timber species, coupled with their proximity to the river, which is used for transporting logs to the market. In addition, skidding tracks are constructed around the rivers an activity which leads to further degradation.

Table 5-28: Encroachment areas such as the one shown above can be found within the river protected area. This particular one was opened using fire for rice growing. Planting of rice is taking place in the background.

5.4.4. Comparison of methods used for assessing indicator E 1.3 in this research with methods used by the Certification body accredited by LEI

The methods of assessment of indicator E1.3 used by the assessors are based on visual observation of damage within the protected area, rather than on quantification of the damage. This is so even if the intensity scale of indicators for Sustainable Natural Production Forest with regard to indicator 1.3 requires quantification of actual damage (Appendix 5). In their most recent assessment of indicator E1.3 carried out in 2000, the assessors looked at the general physical condition of the protected area, which they said was “good” except for the riverbanks. Records concerning the protected area were also reviewed. The assessors found that no records existed regarding disturbance and conditions within the protected area. For instance, an area in compartment 23 of about 10 hectares was found burnt by fire, which was reportedly caused by hunters, having been caused in 1997. However, no official record of this fire was available with the forest management unit.

The methods of assessment of damage within the river-protected area used in this research are quantitative, based on the actual areas damaged as seen from the Landsat TM images of 1996 and 2000. This was however done without ground truth data and so the most obvious areas of damage were selected based on visual observation as explained in section 5.4.2 above. The aim of this analysis was to demonstrate that it is possible for the certifiers to assess the extent of damage caused within the protected area. If combined with ground truth data, this method is likely to yield more accurate and dependable results.

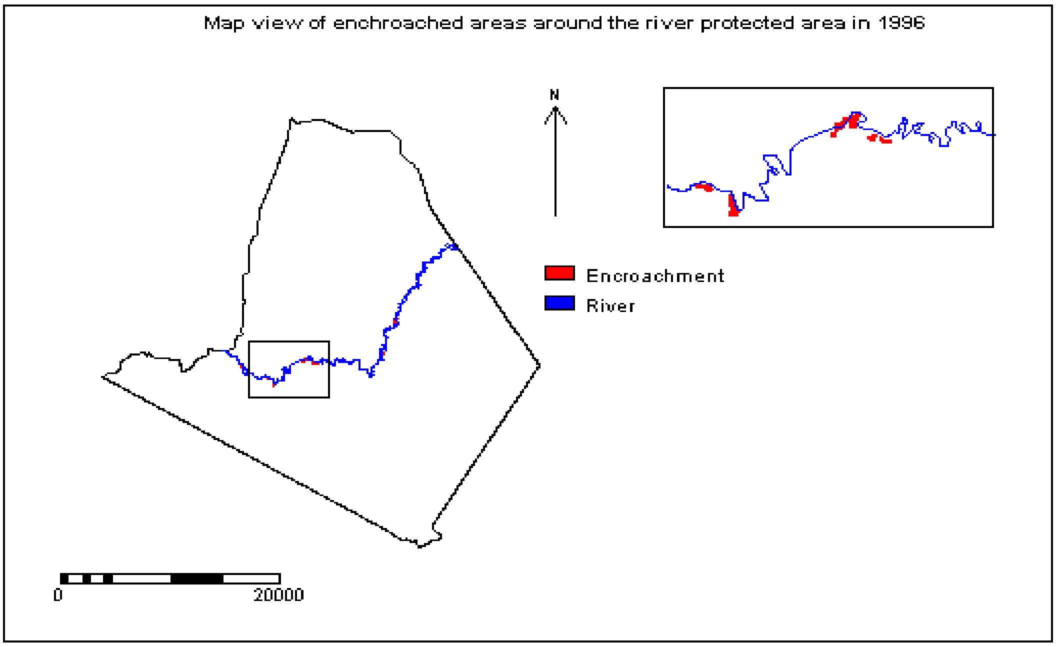


Figure 5-10: Map showing encroachment areas around the river-protected area in Labanan concession in the year 1996

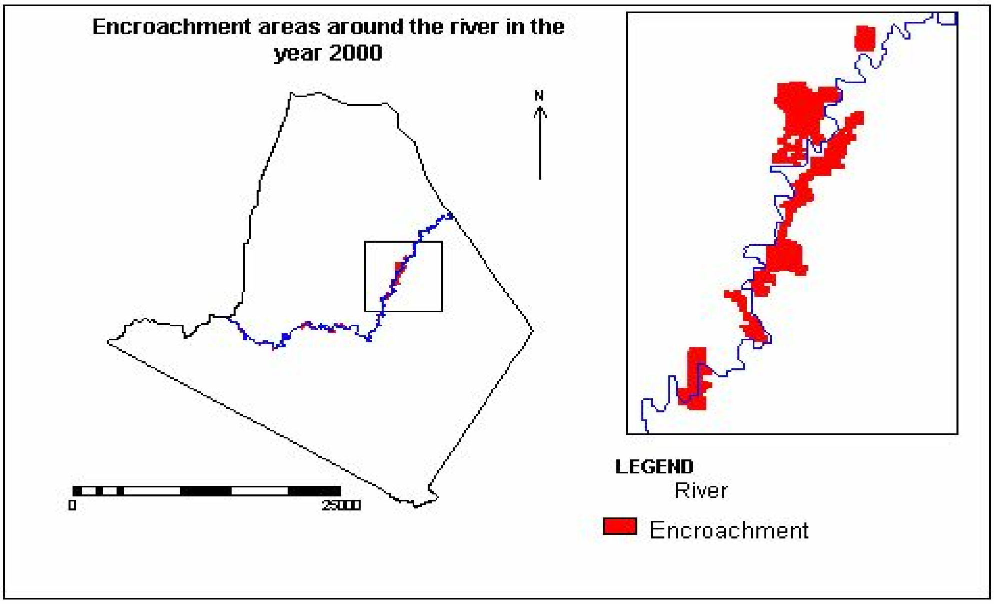


Figure 5-11: Map showing encroachment areas around the river-protected areas in Labanan concession in the year 2000

5.5. Spectral reflectance properties of the different RKLs with selected bands

This sub-chapter analyses the spectral reflectance characteristics of the different RKLs within Labanan concession. It attempts to indicate whether there is any observable difference in the spectral reflectance properties of the RKLs, with the aim of finding out whether the spectral characteristics of a particular RKL can be used to deduce its characteristics and hence, its management history. Hopefully, this will go a long way towards contributing to the determination of overall forest status, by using the spectral reflectances derived from imagery, to ascertain the performance of the particular forest management unit in question. Figure 5-12 shows the spectral reflectance curves derived from the four selected Landsat TM bands 2 (Green), 3 (Red), 4 (Near Infrared), and 5 (Middle Infrared). These bands were selected, since they are closely related with vegetation characteristics.

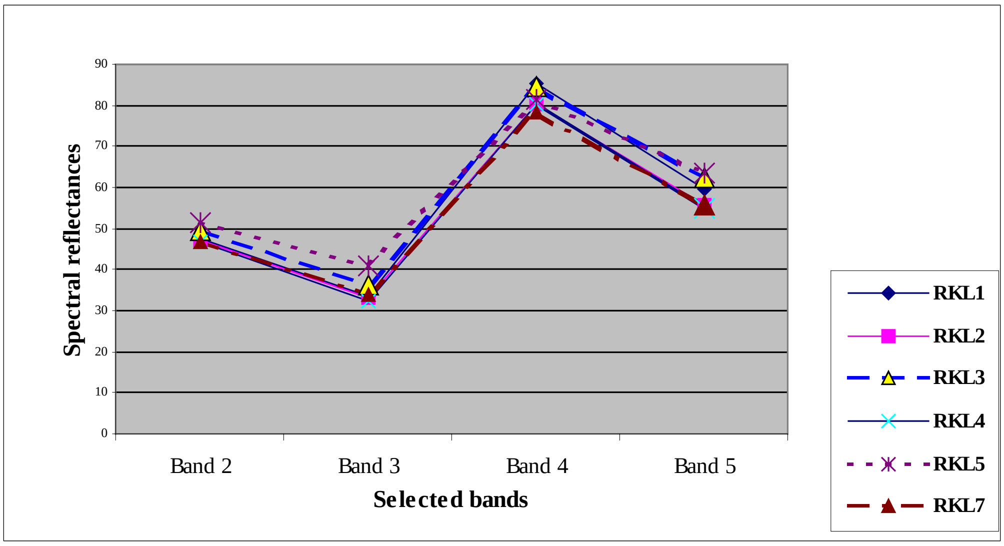


Figure 5-12: Spectral reflectance curves of the different RKLs with selected bands of Landsat TM

The spectral reflectances for different bands generally follow the same trend with the different RKLs 1 to 7 (Figure 5-12). RKL 6 is not indicated because it was under cloud in the image. From the Figure 5-12, RKL 5 has higher spectral reflectance than the other RKLs in the Green, Red and Middle Infra-red bands. The differences in the spectral reflectances of the mentioned bands can be attributed to the fact that RKL5 has just been logged, as compared to the other RKLs which were logged earlier. The spectral reflectance in the green band (Band 2) is high probably because of the upcoming vegetation in RKL 5, since its canopy has just been opened. Opening of the canopy allows light to reach the forest floor, which enhances the regeneration of tree species. The young and growing trees being active will tend to reflect more green light. According to (Belward, 1990) chlorophyll strongly absorbs red light, while the energy of the green light tends to be reflected and transmitted, rather than being absorbed. The maximum reflectance of light in the visible wavelengths occurs in the green part of the spectrum (Band 2). Comparison of the general trends in Figure 5-12 with the ideal spectral curve for vegetation (Figure 2-1) depicts a similar trend. The spectral reflectance in Band 4 (Near Infra Red) for RKL 5 is intermediate since having been harvested recently; the soil is exposed, which might influence the high reflectance that is expected from the fresh upcoming vegetation. According to (Lillesand and Keifer, 2000) plant reflectance in the range 0.7 to 1.3 µm (Near Infra Red) increases with the number of layers of leaves in a plant canopy. This means that areas with a few leaf layers (open canopy) have low plant reflectance when compared with those with more leaf layers such as RKLs 1, 2 and 3.

5.6. Relationship between radiance values and Shannon pole and tree diversity indices

This sub-chapter analyses the correlation between the Shannon indices for trees and the reflectances for particular areas sampled within the natural forest. It is aimed at finding out whether a considerable correlation can be obtained between reflectance values and biodiversity indices of pole and tree species located in different areas (strata) of the natural forest. It follows from the assertion that the difference between species can be considerable and sufficient to permit their discrimination (Mather, 1998).

Nagendra (2001) reports that establishment of direct relationships between spectral radiance values recorded from remote sensors and species distribution patterns recorded from field observations may assist in assessing species diversity. With regard to this study, if it was anticipated that if spectral reflectance values can be used to more or less predict tree species diversity, then it would be a valuable input towards the determination of forest status on the one hand and forest certification on the other.

In examining the relationship between tree diversity indices and reflectance values, four bands of Landsat TM, known to be relevant to vegetation were selected, with which to correlate the Shannon indices: namely; Band 4 (Near Infra red), Band 2 (Green), Band 3 (Red) and Bands 5 (Middle Infrared). The reflectance values were obtained from the five strata mentioned in Table 4-5 (section 4.4.3.) i.e. The Biodiversity conservation plot, Virgin (Unlogged) forest, area logged more than 20 years ago, area logged from 11 to 20 years ago and areas logged from 1 to 10 years ago. Nine pixels within which, the pole and tree sample plots were located were identified and selected in the sample set option of ILWIS (Integrated Land and Water Information System), in order to generate sample statistics which gave the mean reflectance values for all the landsat TM bands. These were later input into Microsoft excel, from where correlation values were computed. Figure 5.13 (a) to (d) show the results of the correlation values obtained per selected band for each stratum. However, due to data limitations, correlation values between reflectances of the area logged more than 20 years ago and the tree diversity indices are not included in the analysis. This area had only two values of the Shannon index, as well as the corresponding two-reflectance values, which gave an obvious correlation of one.

Within the biodiversity conservation area (Figure 5-13 (a)), bands 4 (Near Infrared) and 2 (Green) were negatively correlated with the Shannon index, whereas bands 3 (Red) and 5 (Middle Infrared) were positively correlated. Within the unlogged area, a negative correlation was obtained for all the selected bands. In the case of the area logged from 1 to 10 years ago, Band 4 (Near Infrared) was positively correlated whereas the Green, Red and Middle Infra-red bands (2, 3 and 5, respectively) were negatively correlated. In the case of the area logged from 11 to 20 years ago, there was a positive correlation between the Shannon index and all the selected bands. There was no observed trend or explainable pattern in the directions of the correlations for the different strata. This may be attributed to the design of the research. Most of the research conducted in the area of attempting to establish correlation values with biodiversity indices, is conducted at landscape level, where different vegetation types consisting of species of apparent structural characteristic differences are selected for study. In most cases, where differences in vegetation characteristics occur, the vegetation types are clustered, with each cluster assuming homogeneous characteristics. In the case of this study, the heterogeneity of the study area might have had a great impact on the result that was obtained. Even so, the amount of data that was used to establish the correlation factors was considerably small. Except for the area logged from 1 to 10 years ago, in which five Landsat band reflectance values were correlated with five tree diversity index values, for all the other strata, four reflectance values were correlated with four index values (Appendix 9).

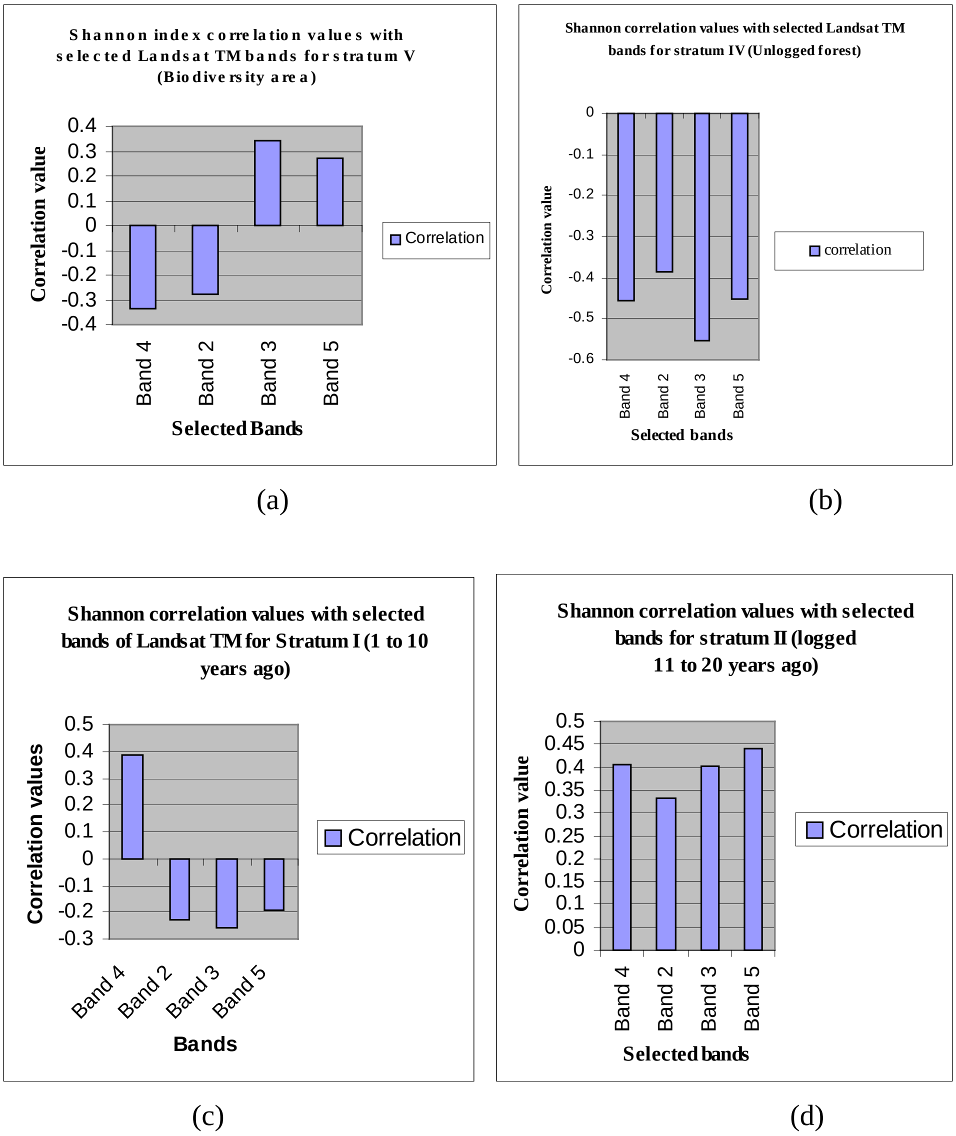


Figure 5-13 (a) to (d): Correlation values between Shannon index and reflectance values for; (a) the biodiversity conservation area and (b) the unlogged area (c) area logged from 1 to 10 years ago and (d) area logged from 11 to 20 years ago.

5.6.1. Correlation values and tree diversity estimation

The correlation values for each of the selected bands were not high enough to enable reflectance values to be used as an estimator of tree diversity. The highest correlation value is about 0.55 with band 3 (Figure, 5-13b) in the unlogged forest (Stratum IV) i.e. (r = - 0.55), which even gives a lower R^2 value of about 0.3025. The Shannon index is a measure, which reflects the number of species occurring within the community. According to the mentioned results, it means that there is no correlation between species richness and the reflectance values of Landsat TM. The reasons for the low correlation between the Shannon index and the Landsat TM selected bands are explained by the variation of the Shannon index with the different RKLs as shown in section 5.3. The Shannon index showed no particular observable pattern for the poles and trees category with time. Being an indicator of species richness, and aware that differences between species may cause their discrimination through remotely sensed data, the low correlation was expected since there were no sharp differences in the Shannon index values across the

RKLs (Section 5.3.1; Figure 5-2). Another limitation could be the differing plot sizes from which the reflectance values were obtained. This could have created errors in the estimation of both the Shannon indices and reflectance values. However, the limitations not withstanding, Jakubauskas and Price (1997), cited in Nagendra (2001) arrived at similar results when they attempted to relate Landsat TM data and species composition in 70 stands, using data normalized to units of one hectare per stand, with only 31% of the overstorey species explained.

5.6.2. Possible reasons for correlation of Landsat TM reflectance and tree diversity

The low correlation values can also be attributed to the low spatial and spectral resolution of the Landsat TM image. The low spatial resolution of the landsat TM image (30m) is in relation to the size of the tree crowns. (Mather (1998) reports that the spatial resolution of an imaging system is not an easy concept to define. It can be measured in a number of different ways, depending on the user's purpose. Townsend (1980) cited in Mather (1998) uses four separate criteria on which to base the definition of spatial resolution. These criteria are:

- Geometrical properties of the imaging system
- The ability to distinguish between point targets
- The ability to measure periodicity of repetitive targets and;
- The ability to measure spectral properties of small targets.

In the case of distinguishing between tree species, the first, second and fourth criteria are of importance. Based on the geometric properties of the imaging system, the commonly used measure of spatial resolution is the instantaneous field of view (IFOV) of a sensor. It is defined as the area on the ground that is viewed by the instrument from a given altitude at any given instant in time (Mather, 1998). At any instant in time, a sensor is able to measure the reflected energy within the system's instantaneous field of view (Alimudoa, 1999). All the energy reflected towards the instrument within the IFOV contributes to the reflectance measured at a particular instant. A small IFOV is desirable to record a high spatial detail. The smaller the IFOV, the smaller the minimum resolvable scan element. The resolvable scan element of Landsat is 30m, which exceeds the crown size of a tree and thus a single species may not be resolved in order to have an impact on the reflectance of a pixel individually. The observed reflectance may be an average of the individual trees in the plot or pixel. The ability of an imaging device to distinguish between specific targets is a measure of its spatial resolving power (Mather, 1998) and this could also influence species identification. Remote sensing involves the detection and recording of the radiance of targets, the radiance being measured at a number of discrete points, so it is necessary to define spatial resolution taking into account the way in which radiance is generated. This is the effective resolution element. The effective resolution element is defined as the size of an area for which a single radiance value can be assigned with reasonable assurance that the response is within 5 percent of the value representing the actual relative radiance. The spatial resolving power is an important attribute of remote sensing systems because different resolutions are relevant to different problems. A hierarchy of spatial problems exist that can use remotely sensed data with a spatial resolution appropriate to each problem. In the case of trees, an image with a spatial resolution of 1m and pixel size of 1m x 1m, for instance, can represent individual crowns. This would be useful for analysing species variations, abundance and distributions in an area (Alimudoa, 1999). The spatial resolution of Landsat TM being 30m, cannot distinguish individual trees, and the spectral information of the individual pixel is an averaged reflectance of all the trees in the pixel, which does not depend on a particular species. According to Nagendra (2001) the ideal spatial resolution required for mapping tree species is fairly high, but typically depends on the size of tree crowns, which can vary widely within and between species. The low spectral resolution is related to the width of the spectral bands. The position in the spectrum and width, and number of spectral bands can determine the degree to which individual targets such as tree species can be discriminated on the multispectral image. The use of a multispectral image can lead to a higher degree of discriminating power than any single band taken on its own (Mather, 1998). The difference between a given target such as tree species might be very subtle and therefore the target may be separable only if the recording device is capable of detecting the spectral reflectance of the target in a narrow waveband. Landsat TM, being a wide band instrument, simply averages out the differences. Mather, (1998) continues to add that for more reliable identification of particular targets on a remotely sensed image, the spectral resolution of the sensor must be close to the spectral reflectance curve of the intended target. To ensure this, it would require an increase in the spectral resolution of the sensor. However, this would necessitate incurring huge costs, making it unfeasible.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

This chapter points out the conclusions arrived at as an output of the data analysis. For each research question, a corresponding conclusion is given. Other conclusions are also given concerning the rating on the intensity scale of indicators for Sustainable Production Forest Management.

Conclusion based on research question 1: "**By how much do areas, which are closest to approaching the felling cycle, as well as those which have not been harvested, differ from the undisturbed forest in terms of tree species composition?"**

- The unlogged forest area was found to be more similar to the biodiversity conservation area, in terms of seedling and tree species composition than the area logged more than 20 years ago. However, in terms of similarity of sapling species, both the unlogged area and area logged more than 20 years ago were found to be the same.

Conclusion based on research question 2: **"To what extent do the areas logged over at different periods of time differ from primary forest terms of the tree species abundance?"**

- Using the Mann Whitney non parametric test, no difference was found between the biodiversity conservation area, and the area logged more than 20 years ago, the area logged from 11 to 20 years ago, the area logged from 1 to 10 years ago as well as the unlogged area, in terms of species abundance which was measured by the Simpson index.

Conclusion based on research question 3: **"What is the observed pattern of tree species diversity change with time within the given felling cycle and what are the underlying casual factors?"**

- The Simpson diversity index did not fluctuate as much as the Shannon index when plotted against time (at five year logging intervals) for all the categories i.e. seedlings, saplings, poles and trees. The possible factors causing the observed trends in the fluctuation of the Shannon or Simpson indices with time are natural and human induced (through logging). It was not possible to draw a clear distinction between the two casual factors.

Conclusion based on research question 4: **"To what extent can damage within the protected area be detected, using remote sensing techniques, when applied to Landsat TM images of the same area taken at two different times (years)?"**

- Damage within the river-protected area could easily be delineated by visual means, for the Landsat TM images of 1996 and 2000. The delineated areas were then summed up to give an overall estimate of the encroachments around the river-protected area. These areas were then each expressed as a proportion of the total river protected area. The proportion of damage in 1996 was estimated as 22 hectares out of 1144 hectares or 1.92%, whereas that in 2000 was estimated at 86 hectares out of the same 1144 hectares or 7.52%. In both cases, this gave a rating of "GOOD" according to the intensity scale of indicators for Sustainable Natural Production Forest Management. The assessors on the other hand rated indicator E 1.3 as being "FAIR" on the intensity scale of indicators for Sustainable Natural Production Forest Management.

***Conclusion based on research question 5:* "With regard to Landsat TM images, is there a considerable correlation between radiance values per band and tree diversity indices for specific sampled areas within the tropical forest?"**

- No observed correlation was found between the radiance values per band, and the Shannon biodiversity indices for all strata i.e. areas logged 1 to 10 years ago, 11to 20 years ago, the biodiversity conservation area and the unlogged area, except for stratum III (area logged more than 20 years ago), which was not included in the analysis.

Conclusions regarding the intensity scale of indicators for Sustainable Natural Production Forest Management (Appendix 6)

- According to the intensity scale of indicators for Sustainable Natural Production Forest Management, the rating given to indicator E1.4 was "POOR" using the seedling, sapling and pole and tree data, while it was "FAIR" in using the Sorensen dissimilarity coefficient.

- With regard to the use of the Shannon index as a measure of species diversity, the rating given to indicator E1.4 was "FAIR". Based on visual observation, the assessors rated the forest as being "FAIR" with regard to tree species diversity.

- The level of encroachment within the river-protected area was found to be "GOOD" as compared to the rating given by, the assessors, which was "BAD".

Conclusion in regard to comparison between the assessment of criteria E1.3 and E 1.4 done by the assessors (certification body) and the assessment done in this study:

In regard to comparison between the methods used in this research, with the current methods being used by the assessors to rate indicator E 1.3 and E 1.4, it was found out that the assessors use qualitative means to estimate forest tree diversity, as well as the extent of damage within the river protected area. Methods used in this research are based on a scientific, standard and repeatable methodology.

6.2. Recommendations

1. Rather than using visual means to estimate tree species diversity, the assessors of the forest concession should collect some primary data, which can be analysed, to provide information about indicator E1.4. In addition, there is no systematic method of biodiversity assessment used by the assessors. Developing of a systematic methodology for this purpose should be given priority.

2. Assessment of damage within the river-protected area should be determined with the ground truth data in order to ascertain the exact areas of encroachment being delineated on the image, and so come up with a true rating on the intensity scale of indicators for Sustainable Natural Production Forest Management.

Study limitations

1. Tropical rain thunderstorms while in the field necessitated the use of secondary data on poles and trees from (Permanent Inventory Plots) PIPs.
2. Some of the analyses were affected by the different sizes of the PIPs some of which were 0.25 hectares and others 1 hectare. Statistical analysis for the abundance of poles and trees was particularly affected.
3. The cloud cover in the Landsat- 7 ETM+ 2000 image and Landsat 5 TM image of 1996 also affected some of the analyses especially where reflectance values had to be obtained (particularly for RKL 6 which was under cloud). Therefore, high, spatial resolution and longer wavelength radar images nay be the solution to this problem.
4. There was limited information on tree diversity assessment with regard to Labanan concession, which made comparison of findings in this research with previous findings in Labanan difficult. However, whatever information was available was quoted.

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APPENDIX 1

Some processes involved in forest certification

Process	No. of criteria	No. of indicators	Applicability	Place of adoption	Date of adoption	No. of countries
ITTO	7	68	Tropical Forest National & FMU level	Yokohama, Japan	1992	12
Dry zone Africa Process	7	47	National level	Nairobi, Kenya	1995	28
Pan-European Forest Process	6	128	Boreal, Temperate and Mediterranean forests (Regional & National)	Helsinki, Finland Lisbon, Portugal	1993 & 1998	37
Montreal process	7	67	Temperate & Boreal Forests (Outside Europe)	Santiago Chile	1995	8
Near East Process	7	65	Regional and national levels (Arabic countries)	Cairo, Egypt	1996	30
African Timber Organisation	28	60	ATO member countries (Regional & National level)	Libreville, Gabon	1993	13
Regional Initiative for Dry Forests in Asia	8	49	Dry forests in Asia (National level)	Bhopal, India	1999	9
LEI	10	57	Tropical Forest Indonesia	Indonesia	1994	1

Source: Modified from Geleens (2000).

APPENDIX 2

Relative weights of Principles derived through voting by a selected Panel of Experts involved in Multi Criteria Decision Making aimed at prioritising principles to be used.

Principle	P1	P2	P3	P4	P5	P6
Ranking	18	18	16	13	14	20
Rating	20	20	14	12	11	22
Combined	19	19	15	13	13	21

Source: (Mendoza and Prabhu, 1999)

-P1 is "Policy, management and forest management systems are conducive to sustainable forest management"
-P2 is "Maintenance of ecosystem integrity"
-P3 is "Forest management maintains or enhances fair access to resources and economic benefit"
-P4 is "Local communities and other affected parties have an acknowledged right and means to participate in forest management to the extent necessary to maintain or enhance equitable access to resources and economic benefits
-P5 is "The health, welfare and rights of the forest workforce and their families are maintained or enhanced"
-P6 is "Management plan to ensure sustainable yield and quality of forest goods and services is documented and implemented.

Relative weights of Criteria under Principle P2 based on estimations of the Panel of experts in Kalimantan

Criteria	Ranking	Rating	Combined
C2.1	24	20	22
C2.2	32	35	33
C2.3	26	32	29
C2.4	19	13	16

Source: (Mendoza and Prabhu, 1999)

-C2.1 is "The Forest Management Unit has identified its main impacts on the environment through an environmental impact assessment (or equivalent process) and has determined actions in response to potential impacts"
-C2.2 is "The processes that maintain biodiversity in management forests are conserved"
-C2.3 is "Soil and water processes are maintained"
-C2.4 is "Chemical contamination of forest resources is eliminated or, at a maximum, reduced to the minimum possible"

APPENDIX 3

LEI document –01: Verifier and verification toolbox for the assessment of criteria and indicators of Sustainable Natural Production Forest Management certification system (Showing the selected Principle, Criteria, Indicators and Verifiers)

Principle (Ecological sustainability)
Definition:
Ecological sustainability refers to the assurance of forest functions as a support system to a variety of indigenous species and their ecosystems

Indicator E 1.3 (Intensity of damage in the protected areas, including from fire hazards)
Definition
The damage intensity, of specifically activities caused by man or forest fire, towards protected area varies according to the location and area size, and the frequency, type and level of damage that factually occurs. In addition, the damage intensity towards the protected area is also influenced by damage prevention and control performed by the management unit. No damage occurrence in protected areas, including those caused by forest fires, reflects the optimum role of the area in maintaining stability in the production forest ecosystem. The compatibility between damage handling intensity in the protected area towards the factual damage occurrence is a significant factor that needs to be taken into consideration.
Verifiers
-Size and type of damage protected area
-Condition of damaged protected area
-Number and frequency of damage listed
-Number of damage cases that are settled
-Frequency and form of protected area security activity
-Number and location of warning signs in relation to protected area security
-Forest fire prevention and control
-Early warning signs for fire hazards monitoring
-Facilities and infrastructure for forest fire hazard prevention and control
Primary data
-Results of interview with forest rangers.
-Result of interviews with the local community.
-Result of field observation/measurement.
Secondary data
-Management unit annual report.
-Protected area security official report.
-Records on number and frequency of damage.
-Damage case settlement official report.
-Aerial photograph.
-Landsat imaging or other imaging.
-Other relevant resources.
Appendix 3…. Continued

Appendix 3 continued:

Verification/Sampling method

Interviews with forest rangers/local community, study forest security documents, followed by investigation on size and condition of protected area and forest security facilities and infrastructure. Analysis is intended to obtain an indicator score based on size and intensity of damage to protected area, and effective efforts by the management unit. In practice, field investigation can be combined with other relevant criteria/indicators.

- **Indicator E 1.4 (Condition of flora and/or fauna species diversity in protected area in various forest formations/types within management units**

Definition

The relative condition of diverse flora and fauna species in protected areas towards the condition of virgin forest and old logged over area (>20 years) within the same forest formation or type can be used as a benchmark to find whether the aforementioned protected area is functioning well in maintaining forest ecosystem stability.

Verifiers

-Flora and fauna diversity in protected area
-Flora and fauna diversity in virgin forest
-Flora and fauna diversity in logged over area

Secondary data

-AMDAL document (Environmental Impact Assessment Report)
-Environmental observation result
-Relevant reports
-Relevant research findings

Primary data

-Result of interview with forest officers
-Results of interview with the community
-Result of field observation measurement

Verification/Sampling method

Secondary data analysis followed by interview with officers and local community who regularly enter forests, and field observation \or measurement. Analysis is directed at obtaining an indicator score based on flora and fauna level of diversity as a comparative study result between protected area, virgin forest and old logged over areas (>20 years). In practice field observation/measurement can be combined with other relevant criteria/indicators.

APPENDIX 4

LEI CRITERIA AND INDICATORS OF ECOLOGICAL FUNCTION

Criteria - 1: The Stability of Ecosystem
E1.1 The proportion of well-functioned protected area from its total size that should be protected, and confirmed and/or recognized by the parties concerned.
E1.2 The proportion of well designed protected area to the total size that should be protected and has already been delineated in the field
E1.3 The intensity of damage in the protected areas
E1.4 The condition of flora and/or fauna species diversity in protected areas in various forest formations/types within management units
E1.5 The damage intensity of forest structure and plant species composition
E1.6 The damage intensity of production management activities on soil
E1.7 The damage intensity of production management activities on water
E1.8 The effectiveness of damage management on stand/forest structure and compositions
E1.9 The effectiveness of controlling techniques on the impact of production management activities on soil
E1.10 The effectiveness of controlling techniques on the impact of production management activities on water
E1.11 The effectiveness of counselling regarding the importance of sustainability of forest ecosystem as support system and the impact of over harvesting activities to forest ecosystem
Criteria 2: Survival of Endangered/Endemic/Protected Species
E2.1 The proportion of protected area as stipulated based on consideration of endangered/ endemic/protected species or unique ecosystem (special area) existence of which has been confirmed and/or recognized by involved parties
E2.2 The proportion of well designed protected area, which is specially designed for the survival of endangered/endemic/protected species or protected unique ecosystem, and has already been delineated in the field
E2.3 The damage intensity to endangered/endemic/protected species in the special areas
E2.4 The condition of endangered/endemic/protected species in the special areas
E2.5 The impact intensity of production management activities towards endangered/endemic/ protected plant species and their habitat
E2.6 The impact intensity of production management activities towards endangered/endemic/ protected wildlife species and their habitat
E2.7 The security of endangered/endemic/protected plant species and their habitat
E2.8 The security of endangered/endemic/protected wildlife species and their habitat

Source: LEI DOCUMENT-02

APPENDIX 5

INTENSITY SCALE OF INDICATORS FOR SUSTAINABLE NATURAL PRODUCTION FOREST MANAGEMENT

RATING INTENSITY SCALE FOR INDICATOR E1.3

- Excellent

No damage in the protected area

- Good

The area size of the damaged protected area is small (<25%); there is a low degree of damage and its control efforts are adequate OR

The damaged area in the protected area is very small (<10%); there is a moderate degree of damage and control efforts are adequate

- Fair

The damaged protected area is small (<25%); there is a low degree of damage and control efforts are inadequate.

The damaged protected area is small (25%); there is a moderate degree of damage and control efforts are adequate

The damaged protected area is very small (<10%), there is a high degree of damage and control effects are adequate

- Poor

The damaged protected area is small (<25%), and there is a high degree of damage OR

The damaged protected area is moderate (<50%); there is a low to moderate level of damage and control efforts are adequate

- Bad

The damaged protected area is large (>50%)

RATING INTENSITY SCALE FOR INDICATOR E1.4

- Excellent

The diversity of flora in the protected area* is greater than or equal to the diversity of the flora in the virgin forest and greater than the diversity of the flora in the old logged over area (> 20 years)

- Good

The diversity of flora in the protected area is 90 – 100% of the diversity of flora in the virgin forest and old logged over area (>20 years)

- Fair

The diversity of flora in the protected area is 70 – 90% of the diversity of flora in the virgin forest and logged over area.

- Poor

The diversity of flora in the protected area is 60 – 70% of the diversity in the virgin forest and old logged over area (>20 years).

- Bad

The diversity of flora in the protected area is < 60% of the diversity in the virgin forest and old logged over area (>20 years).

Source: LEI DOCUMENT-02

* Note: Reference is made to the protected area but for purposes of this research, the biodiversity conservation area will be used. This due to the fact that field findings revealed that the protected area was partly harvested.

APPENDIX 6

Some types of protected area in Indonesia

Riverbanks (100m on each side for big rivers, 50m on each side for small rivers)
Beach banks
Lagoon/Dyke bank
Mangrove forest
Peat swamp forest (>3m deep)
Spring banks
Highland area (>2000m asl)
Steep slopes area (>40m asl)
Animal corridor
Biodiversity conservation area
Animal protection area
Nature conservation area
Heath Forest
Forest with slope 15% with erodible soil (e.g. regosol, Lithosols, organosols, renzina)
Nature preservation area
Wildlife conservation area
National park
Special cultural area
Area of high archeological value
Nature recreation park

APPENDIX 7

Sample Field data collection form

Stratum No………… Name of recorder……………… Date……………..

Sampling plot no.	Map scale	Grid reference Land mark X	Y	Distance to plot centre (m)	Bearing to plot centre	Co-ordinates of plot centre X	Y	Slope (%)	Aspect

Forest use type		Stand composition		Type of stand origin		Crown cover %	Encroachment/ Fire damage	Undergrowth		
Prod[n]	Prot[n]	Pure	Mixed	Plant[n]	Natural			Full	med	Low

Data on poles and trees (DBH=or > 10cm) Sample plot radius = 12.62m

Tree no.	Species	DBH (cm)

Data on saplings (Height > 1.5m and DBH < 10cm) Plot radius = 3.99m

Serial number	Tally	Number of saplings

Data on seedlings (Height < = 1.5m) Plot radius = 2.82m

Serial number	Species	Number of seedlings

APPENDIX 8

SIGNIFICANT TESTS OF ABUNDANCE FOR SEEDLINGS

Mann-Whitney Test (Seedlings):
Comparison of Stratum I (Forest area logged from 1 to 10 years ago) and Biodiversity conservation area.

- Number of samples in stratum I (Forest area logged from 1 to 10 years ago), N = 8
- Median abundance value for stratum I (Forest area logged from 1 to 10 years ago) = 0.1712
- Number of samples in Biodiversity conservation area, N = 4
- Median abundance value for in Biodiversity conservation area = 0.1404
- Point estimate for ETA1-ETA2 (i.e the median of all the pair wise differences between observations in stratum I and the Biodiversity conservation area) is 0.0206.
96.6 Percent Confidence Interval for ETA1-ETA2 is (-0.2082,0.1267)
-Test statistic, W = 54.0
Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at 0.7989

Cannot reject at alpha = 0.05

Mann-Whitney Test (Seedlings):
Comparison of Stratum II (Forest area logged from 11 to 20 years ago) and Biodiversity conservation area.
- Number of samples in stratum II (Forest area logged from 11 to 20 years ago), N = 8
- Median abundance value for stratum II (Forest area logged from 11 to 20 years ago) = 0.1476
- Number of samples in Biodiversity conservation area, N = 4
- Median abundance value for Biodiversity conservation area = 0.1404
- Point estimate for ETA1-ETA2 (i.e the median of all the pair wise differences between observations in the stratum II and the Biodiversity conservation area) is -0.0054.
96.6 Percent Confidence Interval for ETA1-ETA2 is (-0.2562,0.1295)
- Test statistic, W = 52.0
Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at 1.0000

Cannot reject at alpha = 0.05

Mann-Whitney Test (Seedlings)**:**
Comparison of Stratum III (Forest area logged more than 20 years ago) and Biodiversity conservation area.
- Number of samples in stratum III (Forest area logged more than 20 years ago**),** N = 4
- Median abundance value for stratum III (Forest area logged more than 20 years ago**)** = 0.1712
- Number of samples in biodiversity conservation area**,** N = 4
- Median abundance value for biodiversity conservation area = 0.1404

Appendix 8… ***continued***

Appendix 8 continued:

- Point estimate for ETA1-ETA2 is 0.0233 (i.e the median of all the pair wise differences between observations in the stratum III and the Biodiversity conservation area).
97.0 Percent Confidence Interval for ETA1-ETA2 is (-0.2830,0.1458)
-Test statistic, W = 20.0
Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at 0.6650

Cannot reject at alpha = 0.05

Mann-Whitney Test (Seedlings):
Comparison of Stratum IV (Unlogged forest area) and Biodiversity conservation area.
- Number of samples in stratum IV (Unlogged forest area), N = 8
- Median abundance value for stratum IV = 0.1062
- Number of samples in Biodiversity conservation area, N = 4
- Median abundance value for biodiversity conservation area = 0.1404
- Point estimate for ETA1-ETA2 (i.e the median of all the pair wise differences between observations in the stratum III and the Biodiversity conservation area) is -0.0357

96.6 Percent CI for ETA1-ETA2 is (-0.2726,0.0355)
-Test statistic, W = 44.0
Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at 0.2027

Cannot reject at alpha = 0.05

SIGNIFICANT TESTS OF ABUNDANCE FOR SAPLINGS

Mann-Whitney Test (Saplings):
Comparison of Stratum I (Forest area logged from 1 to 10 years ago) and biodiversity conservation area
- Number of samples in stratum I (Forest area logged from 1 to 10 years ago), N = 8
- Median abundance value for stratum I (Forest area logged from 1 to 10 years ago) = 0.0461
- Number of samples in Biodiversity conservation area, N = 4
- Median abundance value for biodiversity conservation area = 0.1157
- Point estimate for ETA1-ETA2 is -0.0468

96.6 Percent Confidence Interval for ETA1-ETA2 is (-0.1509,0.0389)
Test statistic, W = 42.0
Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at 0.1066

Cannot reject at alpha = 0.05
Comparison of Stratum II and (Forest area logged from 11 to 20 years ago) and biodiversity conservation area

Mann-Whitney Test (Saplings):
- Number of samples in stratum II (Forest area logged from 11 to 20 years ago) N = 8
- Median abundance value of stratum II (Forest area logged from 11 to 20 years ago) = 0.0555

- Number of samples in Biodiversity conservation area, N = 4
- Median abundance value of Biodiversity conservation area = 0.1157
- Point estimate for ETA1-ETA2 (i.e the median of all the pair wise differences between observations in stratum II and the Biodiversity conservation area) is -0.0125

96.6 Percent CI for ETA1-ETA2 is (-0.1379,0.4746)
- Test statistic, W = 50.0

Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.7989
- The test is significant at 0.7986 (adjusted for ties)

Cannot reject at alpha = 0.05

Mann-Whitney Test (Saplings):
Comparison of Stratum III (Forest area logged more than 20 years ago) and biodiversity conservation area

STRATUM III (>20), BIOD
- Number of samples in stratum III (Forest area logged more than 20 years ago), N = 4
- Median abundance value of stratum III (Forest area logged more than 20 years ago) = 0.0897
- Number of samples in Biodiversity conservation area, N = 4
- Median abunbance value of Biodiversity conservation area = 0.1157
- Point estimate for ETA1-ETA2 (i.e the median of all the pair wise differences between observations in stratum III and the Biodiversity conservation area) is -0.0335

97.0 Percent Confidence interval for ETA1-ETA2 is (-0.1401,0.0711)
-Test statistic, W = 17.0

Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at 0.8852

Cannot reject at alpha = 0.05

Mann-Whitney Test (Saplings):
Comparison of Stratum IV (Unlogged forest area) and biodiversity conservation area
- Number of samples in stratum IV (Unlogged forest area**),** N = 8
- Median abundance value of stratum IV (Unlogged forest area**)** = 0.0548
- Number of samples in Biodiversity conservation area N = 4
- Median abundance value of the Biodiversity conservation area = 0.1157
- Point estimate for ETA1-ETA2 (i.e the median of all the pair wise differences between observations in stratum IV and the Biodiversity conservation area) is -0.0566

96.6 Percent Confidence interval for ETA1-ETA2 (is (-0.1357,0.0154)
- Test statistic, W = 46.0

Test of ETA1 = ETA2 vs. ETA1 not = ETA2 is significant at 0.3502

Cannot reject at alpha = 0.05

APPENDIX 9

Showing the Shannon indices and reflectances for the strata I to V (Excluding III) which were used to obtain the correlation coefficients with each of the bands; Band 4 (Near Infrared), Band 2 (Green), Band 3 (Red) and Band 5 (Middle Infra red)

Correlation for Stratum I (RKL 4 and 5)

Sample plots	RKL	Plot type	Size (Ha)	Shannon index	Band 4 reflectance	Band 2 reflectance	Band 3 reflectance	Band 5 reflectance
1 & 2	4	PIP	0.25	3.283	79.4	46.8	32.8	54.8
5 & 6	4	PIP	0.25	3.538	81.3	46.6	32.2	54.8
9 & 10	5	PIP	0.25	2.096	78.2	47.2	33.8	55.3
19	5	Circular	0.25	3.042	87.3	51.4	40.6	64.6
32	5	Circular	0.25	2.692	78.7	55.2	48.2	71

Correlation for Stratum II (RKL 2 and 3)

Sample plots	RKL	Plot type	Size (Ha)	Shannon index	Band 4 reflectance	Band 2 reflectance	Band 3 reflectance	Band 5 reflectance
20 & 21	3	PIP	0.25	3.483	81.6	49.3	36.9	63.6
24 & 25	3	PIP	0.25	3.461	87.3	49.8	35.2	60.8
29	2	Circular	0.05	3.283	77.3	46.7	32.4	53.4
30	2	Circular	0.05	3.538	79.4	46.8	32.8	54.8

Correlation for stratum IV (RKL 6 and 7 but RKL 6 is under cloud so not included) **unclogged (RKL 7)**

Sample plots	RKL	Plot type	Size (Ha)	Shannon index	Band 4 reflectance	Band 2 reflectance	Band 3 reflectance	Band 5 reflectance
28	7	Circular	0.05	3.045	68.7	49.4	36.6	47.7
31	7	Circular	0.05	2.979	70	48.2	35.8	47.8
26	7	Circular	0.05	3.034	87.1	55.1	40.2	62.2
27	7	Circular	0.05	2.853	86.8	54.9	41.4	62.2

Correlation for stratum V (Biodiversity plot)

Sample plots	RKL	Plot type	Size (Ha)	Shannon index	Band 4 reflectance	Band 2 reflectance	Band 3 reflectance	Band 5 reflectance
15	Biod	Circular	0.05	2.581	76.9	46	34	54.2
16	Biod	Circular	0.05	2.384	79.8	47.6	34.4	56.8
17	Biod	Circular	0.05	2.293	74.9	46.4	32.9	54.7
18	Biod	Circular	0.05	2.611	73	46.8	33.6	57.8