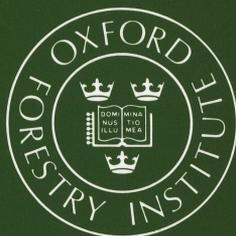


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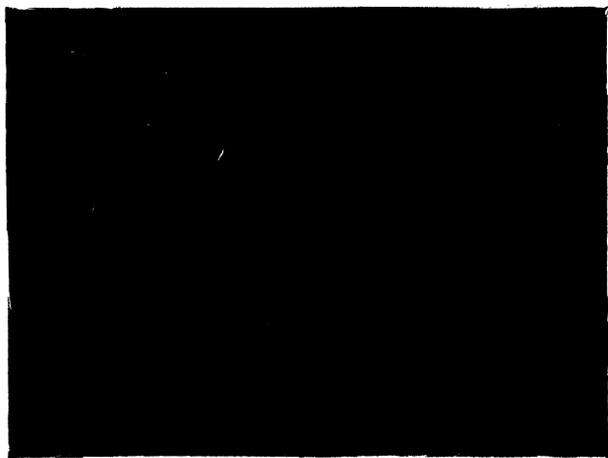
O.F.I. Occasional Papers

52

Proceedings of a workshop
on
**Humid and semi-humid
tropical forest yield regulation
with minimal data**

H.L. Wright and D.Alder
2000

OXFORD FORESTRY INSTITUTE
Department of Plant Sciences
UNIVERSITY OF OXFORD



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Held at CATIE, Costa Rica, 5-9 July 1999

Edited by

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Acknowledgements

Annex 1 List of participants

INTRODUCTION

Howard L Wright

Oxford Forestry Institute, South Parks Road, Oxford.

This workshop was organised as part of project "R7278 Humid and semi-humid tropical forest yield regulation with minimal data" that is being carried out at the Oxford Forestry Institute with funds provided by the UK Department for International Development, Forestry Research Programme.

The project aims to develop a simple methodology for estimating and regulating the potential yield from a tropical moist forest when there are only data available from one point in time and to present this in the form of a manual.

There is a rapidly increasing need to demonstrate that rates of exploitation of tropical moist forest (TMF) are sustainable over time and do not lead to degradation of the forest either rapid or gradual. Current conventional methods of yield regulation and determination of an allowable cut tend to rely on extensive data on rates of growth, mortality and recruitment at one end of the spectrum or they may be by almost rule of thumb methods at the other. Cut may also be determined by other factors such as the requirements of the logging company to make a profit - a dangerous method on its own. Extensive and well validated data on growth are obtained over time by recurrent measurement and are frequently not available, even in situations with a relatively long history of forest management. In many cases where there may be data available, the expertise to make use of the information is not present and they may not be used in an efficient way. After a considerable amount of work on the Ghana PSP data, for example, it was concluded in a recent report that "*Further work is required before a detailed yield regulation system can be devised*" (Wong 1997). Vanclay said in 1993 that "*Most forest services have insufficient or inadequate growth data from the natural forest, thus growth models and simulation studies cannot be made, and we can only guess the sustainable timber yield*". There is very little written work on the regulation of yield in TMF either in textbooks or in research publications; what there is usually presumes a knowledge of growth.

With the rapid extension of participatory management to communities, the presence of dynamic information becomes even less likely. What always tends to be available, however, is static information, *i.e.* data from forest inventory (increasingly participatory by forest communities) and volume studies. The problem is thus to try and develop methods which can use this type of information supplemented perhaps by other variables that can be measured at the same single point in time. At the same time it should be an approach that can be easily refined as more data become available enabling more confident predictions to be made.

There will be essentially three main outputs from this project:

1. A review of the available methods for yield regulation and a compilation of information on growth, recruitment, mortality and logging damage for TMF.

2. Development of a simple pan-tropical yield regulation system which can be used with minimal data.
3. Preparation of a manual/workbook for use with the yield regulation system.

The project falls into three stages corresponding to the three main outputs given above. For the first and last stage it was proposed that a workshop would be organised: the first workshop will be geared to defining the exact objectives of the system - what is required and for what purpose and situation. This will be relatively broad-based covering all the potential end users of the system. The second workshop will be an opportunity for these end users to try out the system. This approach should ensure that the final product is what is wanted and can be used by relatively inexperienced people.

This publication contains the papers presented at the first workshop that was held at CATIE in Costa Rica. A list of the participants is given in Annex 1.

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YIELD DETERMINATION IN TROPICAL MOIST FOREST

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Summary

This paper highlights the importance of yield regulation in the management of tropical forests. It emphasises that one of the most important aspects of yield regulation is the determination of the Annual Allowable Cut (AAC) or prescribed yield. It sets out to describe a selection of the classical methods for the estimation of the AAC developed primarily for the even and uneven-aged forests of Europe from the beginning of the last century. In all but the simplest of systems some estimate of the rate of growth of the forest is needed.

Introduction

In writing about tropical forest management, Palmer said in 1975 "*The principle managerial difficulty is in setting the allowable yield*". This is even truer today than it was then as the whole process of setting, justifying and controlling a sustainable yield for a forest comes under greater and greater scrutiny. There is a rapidly increasing need to demonstrate that rates of exploitation of tropical moist forest (TMF) are sustainable over time and do not lead to degradation of the forest, either rapid or gradual. Current conventional methods of yield regulation and determination of an allowable cut tend to rely on extensive data on rates of growth, mortality and recruitment at one end of the spectrum or, at the other end of the spectrum, they may be over simplistic rule of thumb methods. Cut may also be determined by the requirements of the logging company to make a profit - a dangerous method on its own. Extensive data utilised in the more rigorous methods, are obtained over time by recurrent measurement and are often not available, even in situations with a relatively long history of forest management. In many cases where there may be data available, the expertise to make use of the information is not present and they may not be used in an efficient way. After a considerable amount of work on the Ghana permanent sample plot (PSP) data, for example, it was concluded in a recent report that further work was required before a detailed yield regulation system could be devised (Wong 1997). Vanclay said in 1993 that "*Most forest services have insufficient or inadequate growth data from the natural forest, thus growth models and simulation studies cannot be made, and we can only guess the sustainable timber yield*". There is very little written work on the regulation of yield in TMF either in textbooks or in research publications; what there is usually presumes a knowledge of growth.

With the rapid extension of participatory management with communities, the presence of dynamic information becomes even less likely. What always tends to be available, however, is static information, *i.e.* data from forest inventory (increasingly undertaken by or with forest communities) and volume studies. The problem is thus to try and develop methods that can use this type of information, supplemented perhaps by other variables that can be measured at the same single point in time. The approach developed should be one that can be easily refined as more data become available, enabling more confident predictions to be made.

Yield regulation techniques

Yield has recently been defined as "the amount of wood that may be harvested from a particular type of forest stand by species, site, stocking and management regime at

various ages" (Helms, 1998). Yield regulation is the determination of this yield and its expression in a management plan prescription, including where, when and how the yield should be extracted (FAO, 1998). A number of other definitions are associated with yield regulation and are given in Table 1.

Table 1 Some terms and criteria used in yield regulation. (modified from FAO, 1998)

| Term | Definition |
|--|--|
| Allowable Cut Prescribed Cut Prescribed Yield Permissible Yield | A clearly expressed specification of the average quantity of wood (or other product), usually in an approved management plan, that may be harvested from a forest management unit, annually or periodically over a specified period. Usually expressed as quantity per unit area. |
| Annual Allowable Cut (AAC) | The Allowable Cut expressed on an annual basis. |
| Felling Cycle Cutting Cycle | The interval, in years, between successive fellings in a polycyclic silvicultural system. |
| Rotation | The planned number of years between the establishment of a crop (by planting or regeneration) and final felling. The term is applied where forest is managed on a monocyclic silvicultural system where the Rotation is equal to the Felling Cycle. |
| Sustainable Yield | The equilibrium level of production from the growth rate of trees comprising a forest, annually or periodically, in perpetuity. It means the continuous production with the aim of achieving an approximate balance between the net growth of a forest and harvest. |
| Sustainable Forest Management | Is achieved if the accumulated mean annual increment for uneven-aged forest having a balanced diameter class distribution is equal to or marginally greater than the total harvest during a planning period of not less than 15 years. In the case of a heavily exploited forest where the diameter class distribution is not balanced the accumulated MAI should always be less than the total harvest. ??? |
| Time of Passage Transition Time. | The time, in years, for a tree to grow through one or more diameter classes; often the time taken for a tree to reach merchantable size. |

Early yield regulation methods used in tropical forest tended to follow the classic techniques developed and employed in Europe during the nineteenth century for both even-aged and uneven-aged forests. Recknagle (1917), for example, describes eighteen distinct methods. For most of this time foresters were concerned with attempting to achieve the so-called 'normal' forest and this had a major influence on the development of methods of yield regulation. For this review, it is assumed that the tropical forest will be managed on a selection or uniform system, implying felling, harvesting and regeneration of large timber at set intervals on a polycyclic or monocyclic system. The felling operation may or may not be followed by some form of silvicultural improvement treatment such as liberation thinning.

Methods of calculating the yield depend on a number of factors such as the constitution of the growing stock, especially its silvicultural characteristics, and on the extent of knowledge on diameter distributions, volumes and increment. The many methods of calculating the yield have been classified according to the variables used. Osmaston (1968) gives the following classification:

1. Area
 - a) Control by silvicultural and other felling rules.
 - b) Control by rotation and age-classes or periodic blocks.
 - c) Control by development or treatment classes.
2. Volume
 - a) Control by rotation or exploitable age.
3. Volume and Increment
 - a) Control by rotation or exploitable age.
4. Numbers of Trees
 - a) Control by stem size and increment (time of passage).

Control by area

Control by area is the simplest of all methods and has been used in tropical forests that are in an early phase of management. The prescribed yield is that found on a specified area which is removed over a limited time. The stand is then left for a period until it is again ready for exploitation. If some estimate of the rotation or felling cycle is made the forest can be divided into an equivalent number of equal-sized blocks and one block exploited each year. The number of trees felled each year is controlled by felling rules that may be based on minimum size limits for utilisation, favoured species, silvicultural considerations and an assessment of potential logging damage. Tropical forests that are coming under management may vary considerably, ranging from primary forest that has not been logged previously to forest that has had a history of exploitation. The former is often characterised by an abundance of mature and overmature trees whilst the latter may not contain many trees in the exploitable size classes. This will affect choice of cutting cycle and minimum girth limits. In practice, the forest is likely to be divided into blocks such that one block may be exploited over a period of years rather than annually. There is little or no control of the number of trees felled and hence yields can fluctuate from year to year or period to period depending on the variation within the forest. An extension of this method is to alter the areas so that they become equi-productive, basing this on the results of the forest inventory. This however, is moving towards control by volume. The choice of the felling cycle length is not of vital concern as it can be changed as more information is acquired. As Dawkins (1958) wrote "*The first felling cycle is no more than an introduction of planned management into natural forest. Even if it marks the birth of sustained yield it is highly unlikely to be the birth of a sustained system*".

Control by volume

Control by volume has a long history and can be traced back to an Austrian government decree of 1788. The timber industry generally prefers a guarantee of yearly volume to one of yearly area. One of the most well known of yield regulation formulae is that of Von Mantel in which

$$AAC = \frac{2V_a}{R}$$

Where R = the rotation (cutting cycle) for the major species.

V_a = the actual volume obtained from inventory.

This formula does not consider increment, forest structure or variability in growth. However, some estimate of rotation length has to be made. The Von Mantel formula

is, in effect, making use of an exploitation percent; for example, given a rotation of 100 years the rate of exploitation is 2%, irrespective of species, site or the state of the growing stock. This method of calculating the allowable cut as a percentage of actual volume was first introduced by Hundeshagen in 1821 who used the ratio of 'normal yield' to 'normal volume' as the percentage. Von Mantel's formula is a modification of this. He based his method on the concept of a normal forest in which the growing stock is equal to the mean annual increment multiplied by half the rotation. One of the advantages of the Von Mantel formula is that it is easier to estimate a suitable rotation for a forest rather than a certain cutting percent. The use of a constant exploitation percentage observes the guiding principle that more should be cut when the actual volume is in excess and *vice versa*.

The formula given above is theoretically correct only if V represents the whole crop from seedlings to mature trees; by measuring down to a merchantable diameter a serious error is introduced. There was considerable discussion of this in the pages of the Indian Forester between 1920 and 1926 involving Howard, Blanford, Smythies, Simmons and Chaturvedi working in India and Burma. A modification was worked out to calculate the yield where the volume was measured above a specified diameter. This is attributed to Blanford and Simmons in Trevor and Smythies (1923).

$$AAC = \frac{2V}{(1 - m^2)R}$$

where V = volume above a specified diameter limit,

m = the ratio of age of lowest diameter enumerated to the rotation R .

Use of this formula assumes that the condition of the stand below the diameter limit is not abnormal.

Dawkins (1958) points out that the assumption that there is a limit to the basal area of healthy trees that a site can develop leads to a further assumption that old primary tropical forest has reached its limit. The significance of this is that such forests, yet to be exploited, are likely to have a steady or slightly fluctuating total volume. He suggested that yield calculation should therefore be based on a 'half-Mantel' formula of V/R , at least during the first felling cycle.

Use of this formula for forests that have not been exploited and thus may have a large number of over-mature trees will result in an AAC that cannot be sustained unless there is a long cutting cycle to grow more over-mature trees. In Papua New Guinea this realization led to a modification of the formula (Louman, 1994) where

$$AAC = \frac{(V_p - V_f)}{R}$$

Where V_p = present merchantable volume,

V_f = future merchantable volume,

R = the length of two cutting cycles where each is $0.5R$.

The problem in practice, of course, is the estimation of future merchantable volume.

Dawkins (1958) in his classical book on the management of tropical high forest said that *“the only sound method of measuring increment – the foundation of yield – is by periodic measurements of a sample of the stand, extending over at least ten and preferably twenty years, and eventually through the rotation”*. In the meantime he proposed methods for initial yield calculation. Given the following figures:

V_m = volume greater than a merchantable diameter, D_m

V_o = volume of over-mature timber greater than diameter of D_o

V_p = merchantable volume below which harvesting is not economic (D_p)

R_m = estimation of rotation for merchantable diameter

R_o = estimation of rotation for overmature diameter, i.e. the age at which trees become overmature

R_p = estimation of rotation for economic diameter limit

He distinguishes three types of stand structure:

- a) A positive diameter distribution following a typical de Liocourt curve.

Provided that the number of desirable stems is greater below D_m or D_p than the number above, and provided that the stems are known to be growing, then

$$AAC \text{ of trees } > D_m = \frac{(V_m - V_o)}{(R_o - R_m)}$$

$$AAC \text{ of trees } > D_p = \frac{(V_p - V_o)}{(R_o - R_p)}$$

- b) A neutral distribution where the greater part of the diameter range has the same frequency
- c) A negative distribution where the smaller classes are deficient and frequency increases with diameter class

When the recruitment or stand below D_m (or D_p) is obviously inadequate to sustain the population of merchantable trees, the desirable species may exhibit a negative increment. A sustained yield cannot be calculated and it is only necessary to estimate the rate of felling to remove any mature stand before it becomes overmature. A minimum felling diameter is chosen, D_f , such that the density of trees smaller greatly exceeds the density of trees larger by at least a factor of two or three. Then a permissible yield of

$$\frac{(V_f - V_o)}{(R_o - R_f)}$$

may be used as a guide for management.

Osmaston (1968) concludes that, owing to its simplicity, the Von Mantel formula is very useful where yield tables are not available and where increment is not easily or quickly determined. It is also useful as a quick and ready check on the yield determined by other methods.

FAO (1998) gives the example of a procedure used in the Philippines dipterocarp forests. The AAC formulae differ depending on whether the forests have an approved management plan or not. The formula for where there is no plan is:

$$AAC = 0.75f \left(\frac{V_o A}{n_z} \right)$$

where V_o = 25% of volume of (70-80cm)dbh class + 55% of (60-70cm) class
 + volume > 80cm dbh
 f = recovery factor (a value of 0.7 is commonly used)
 n_z = felling cycle x 2

Control by volume and increment

One of the earliest of yield regulation formulae is known as the Austrian formula which originated in a set of papers in 1811 and 1812, although essentially based on a previous forest valuation decree issued in 1788 (Dwight, 1965). As Dwight points out the science of forest regulation is based on a very simple principle: if there is excess of old timber, the allowable cut should exceed the mean annual increment (MAI) of the forest; if, on the other hand, young age classes preponderate, the cut should be less than the increment. The Austrian formula is given by:

$$AAC = I_a + \frac{(V_a - V_n)}{P}$$

Where I_a = actual mean annual volume increment
 V_a = actual volume of the growing stock
 V_n = the volume of the normal growing stock
 P = the adjustment period for the forest to reach normality

During the next 100 years this formula was subjected to various 'modifications' which involved different estimates of increment, actual and normal volumes and different adjustment periods. Another problem arises; a forest having an excessively small growing stock will have a high MAI and an overmature forest will have a comparatively low MAI. Consequently the increment will be higher when the expression $(V_a - V_n)$ is negative, and will be lower when it is positive and high. The MAI will therefore oppose and delay the rate of adjustment of the forest to its normal state. Additionally, the value of the increment will vary from period to period. A modification by Gerhardt in 1900 used the average of the actual increment and the theoretical normal increment on the assumption that the latter might be expected to be attained by the end of the adjustment period:

$$AAC = 0.5(I_a + I_n) + \frac{(V_a - V_n)}{P}$$

Where I_n = theoretical normal MAI.

The use of the MAI, calculated by dividing the volume of each age class by its age, does not take account of any intermediate yields or thinnings. This would apply to even aged stands where intermediate and final yields can be separated. To apply the formula to uneven aged selection forests, where it is not possible to separate the yields, it is necessary to use current annual increment (CAI). The formula suggested in the recent FAO guidelines uses the CAI (FAO, 1998).

The drawback, of course, is the difficulty of estimating the values of the CAI and volume for the theoretically normal forest. An alternative method that also requires an estimate of increment but avoids the need to derive a theoretical normal forest structure is to use Cotta's formula. This is:

$$AAC = \frac{(V_m + 0.5I_p)}{P}$$

Where V_m = the average volume of commercial species above a specified diameter for a specified area of forest,
 I_p = volume increment of commercial species for a specified area of forest and for a specified number of years, known as the regeneration period,
 P = the length of the regeneration period.

This can be used for a forest being managed under an irregular shelterwood silvicultural system where a specific area of forest, having a known volume of exploitable timber, is to be logged over a specified number of years.

Control by numbers of trees

Regulation by number of trees has been used extensively in tropical forests. A characteristic of these forests is that they are usually composed of many species, only some of which are marketable and then only those above some defined merchantable diameter limit are harvested. This method of regulation was used by Brandis when working in the teak forests of Burma in the 1850s. It requires information on three attributes of the forest:

- a) the numbers of trees in each diameter class,
- b) the time of passage, that is the time taken by trees to grow through the various diameter classes to exploitable size, and
- c) the mortality percent of each diameter class.

A number of formulae were used, the basic one was given by:

$$Y = (T + 0.5t)P$$

Where Y = annual yield of trees

T = number of trees over 7ft girth (exploitable Class I)

t = number of trees in the 6-7ft class (Class II)

P = length of first felling cycle or time of passage through the 6-7ft class

This is because as the annual coupes are felled there will be zero Class II trees in the first year, then steadily more until the full class recruitment in the last year of the cycle. However, this formula depends on the relation between the period of the working plan, the felling cycle and the transition period. Indeed, Troup (1912) pointed this out and describes eight variations on the basic formula. Because of its

simplicity this method of yield regulation was applied over wide areas of India and Burma sometimes in inappropriate conditions. Various safeguards were introduced, such as: (i) an allowance for trees which it did not pay to extract, (ii) where few second and third class trees existed, some first class trees were left standing, to provide seed for regeneration and (iii) in the immediate vicinity of streams cuttings were made very sparingly. Schlich (1895) concluded that *"It is a method to be strongly recommended for adoption in countries where systematic forest administration is in its earlier stages."*

Obviously, to calculate the time of passage there must be some knowledge of the increment. This was determined originally by Brandis for Burmese teak by counting the annual rings. This, however, is not a practical method for tropical moist forest. Given information on increment it is possible to calculate how many trees reach exploitable size in any specified period. The periodic yield is then the number of trees that reach this size. However, an important condition for the utilisation of this method is that there must be a sufficient stock of trees on the ground at the start of the period; in other words, the diameter distribution must be 'normal' or balanced.

This method is essentially the classic stand projection method of forecasting future yields in which a diameter distribution is grown over time allowing for mortality and recruitment.

Maginnis (1994) describes the use of a simple derivative of the Brandis method in Ghana which uses the formula:

$$Y = 0.2t + 0.5T$$

Where Y = yield - number of stems per compartment

T = number of trees above minimum diameter per compartment

t = number of trees in size class directly below per compartment

This is based on a 40 year felling cycle and an assumed mortality of 20%. The yield amounts to approximately 60% of the trees above the minimum diameter. However, its general use without regard to the condition of the forest can lead to problems and therefore he suggested the use of a yield adjustment factor which is based on a scoring of the forest condition. This factor would be a multiplier ranging from 0 to 1; the latter applied to a forest in good to excellent condition, the former was assigned for a highly degraded forest.

In a paper arguing for the use of senility criteria rather than minimum diameter Seydack (1995) pointed out that the use of a minimum diameter limit for exploitation has a number of disadvantages. He listed these as:

- a) possible premature removal of fast growing trees with high value increment;
- b) this may have a dysgenic effect; (especially under a polycyclic system with short cutting cycles);
- c) a proportion of trees below the limit, but above a utilisable limit, are old, slow growing and succumb to mortality;
- d) if the minimum diameter is set high, losses under c) increase;
- e) there may be a site differences effect.

To this list might be added the danger of fixing the limit without regard to the phenological characteristics of the species. Cases have occurred where the limit was below the diameter at which a species commenced to produce viable seed (Tony Simons, *pers. com*). Seydack's proposed yield regulation consisted of the three stages: selection of felling cycle; choice of senility criteria; and calibration of these criteria to the rate of mortality.

Alder (1992) suggested a [simple] method for calculating the optimum felling diameter for a species based on increment and mortality data from permanent sample plots. Optimum diameter is determined by calculating the cumulative age and volume of the survivors from a regenerating cohort, to derive a mean annual increment per 100 seedlings. Times of passage are calculated for each diameter class which enables an equivalent MAI to be computed for each class enabling the class with the maximum MAI to be identified. (over what period? – what age range are being used here? It sounds like the interaction of growth rates and diameter of seedlings are being used to model growth rates and diameter interactions of adults – is this what you intend to say?). Conceptually, this measure of MAI is fully equivalent to that used in determining the optimum rotation for a plantation crop. Diameter is treated as a function of age; it follows that expressing a felling regime in terms of diameter limit is equivalent to using a rotation age for a crop. As Alder points out, the principle weakness is that there are interactions of growth rate with stand density, and of mortality with logging damage. However, this is an almost universal weakness of any blanket prescription. The use of species dependent diameter limits that take into account silvicultural characteristics, rate of growth, phenology, *etc.* must be an improvement over single fixed limits.

Increasingly exploitation is being preceded by stock mapping of the merchantable trees, often using a 100% sample, which allows a much greater awareness of the spatial configuration of trees when selecting those to be cut.

The method of control or check method was first proposed in France by Gurnaude in 1878 and then developed in Switzerland by Biolley and Favre for uneven-aged forests worked under the selection system. It is not strictly a method of yield regulation but rather a series of repeated inventories from which detailed information on the forest growing stock, its structure and increment by diameter classes is accumulated. It was the forerunner of what is now called continuous forest inventory and has been practised for decades in some of the forests of Switzerland. Here, where the interval between successive inventories (often 100%) was six to ten years, prescription of the yield presented no problems. The method is well described by Knuchel (1953) who also comments that wherever the growing stock is assessed at short intervals of not more than 10 years, the possible yield calculation loses much of its former over-riding importance because the effect of operations on the structure and quantity of the growing stock can be observed directly. Thus, mistakes that might have occurred as a result of using a yield formula can soon be corrected.

Estimation of cutting cycle

This has been discussed by Alder (1999) in his paper for this meeting and he has suggested that for many stands there is no definite optimum length, although from simulation studies using the Papua New Guinea PINFORM model there appears to be a real decline in the AAC with very short cycles. This would be expected as this

does not provide enough time for the forest to recover. Short cycles will tend to reduce losses through natural mortality but could well increase losses from induced mortality caused by repeated logging damage. As cutting cycle decreases then so does the yield per hectare which is often a major factor in the choice of length.

Catinot in a recent (1998) book on the sustainable management of tropical rainforests gives two methods for the estimation of the AAC. This book is based on many years of experience, and hence considerable amounts of data, from West and central Africa. Interestingly, he shows an almost perfect agreement between the diameter distribution from the Central African Republic and the pan-tropical curve given by Dawkins (1958). He considered that the optimum cutting cycle must meet the following criteria:

- it must be a multiple of four years: as, for economic reasons, the logging period for each management series was set at four years;
- it must allow trees in a given diameter category the time necessary to move up to the next category, i.e. it must be at least equal to the transition time, otherwise the forest will become progressively impoverished.

Given the multiplicity of species, the transition times are highly variable which means that the chosen cutting cycle tends to be a compromise. This publication lists transition times and maturity ages for some 29 species from Côte d'Ivoire where a cutting cycle of 32 years would suit some 60% of the species. He further states that in many cases in Africa and America the appropriate cutting cycle approximates 28 years for the richest forests and around 36 (or perhaps 40) years for the poorest forests and is usually around 32 years. The 40 year cutting cycle for Ghana forests, mentioned above, was based on the average time for 14 of the most desirable commercial species to pass from the diameter class immediately below the felling limit, into exploitable size ref??.

Final comments

Choice of yield regulation method will depend on individual circumstances; there is no one best method. Without a knowledge of increment or the 'normal' volume, the formulae that require these estimates cannot be used. Osmaston (1968) states that where there is a lack of quantitative and silvicultural knowledge of the growing stock and the influence of site on species and growth, yield determination is largely a matter of guesswork. Such a lack of knowledge is comparatively common in many of the situations in the tropics. This may also be combined with doubts on what the objects and policy of management should be. He ends by saying

"Repeated inventories of the growing stock, prescription of a yield (however flexible its application may be) to suit the growing stock and the objects of management and a constant check and record of what is cut with a comparison of that actual cut with that which was prescribed are essential features in any forest management."

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SOME ISSUES IN THE YIELD REGULATION OF MOIST TROPICAL FORESTS

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Summary

Yield regulation is a central concept in sustainable forest management. Yield usually implies standing volume commercial timber, but can include non-timber products. Allowable cut is the harvest corresponding to sustainable yield. Felling damage must be allowed for in calculating this. Mean annual increment (MAI) is often confused with current or periodic increment, whilst different volume equations, diameter limits, and the gross or net increment can further confuse the issue. MAI is not sustainable yield as the forest is not normal and an allowance must be made for felling damage. Yield regulation is not sufficiently defined by the classical concepts of felling cycle and minimum felling diameter. Felling cycle does not have a definite optimum in mixed forest, whilst diameter limit alone is too simple a criterion for management. Tropical forests are spatially and structurally diverse, and practically, MAI and annual allowable cut can only be estimated by simulation or stand projection. This should be done stand by stand, with a further calculation to then determine felling series by cutting parts or aggregates of stands. A strategy is discussed for simplifying these steps and applying it where only static inventory data is available, using tabulated data and simplified modelling tools.

Introduction

The concept of yield regulation is simply conceived as the process by which the objective of sustainable yield is translated into operational forestry practice via planning, monitoring and control. Wright (1999) has presented some appropriate definitions. Armitage (1998, p. 171) states that:

“Yield regulation or allocation involves making decisions that lead to clear specifications of where and under what conditions a harvest may be cut using AAC and technical information about a forest. It is a critically important part of sustainable tropical forest management”.

Whilst yield regulation as a technique can be explained with some precision in relation to plantations, for natural tropical forests there is considerable lack of clarity and semantic confusion. This is especially true of the phrases *sustainable yield*, *mean annual increment* and *annual allowable cut*.

This paper seeks to clarify some of the issues relating to moist tropical forest (MTF) yield regulation and to suggest strategies that will provide a basis for yield regulation in situations where there is little direct information other than from forest inventories and stock surveys.

Related concepts

Figure 1 shows some of the related ideas. There are five main topics that have to be considered. The first is the definition of yield. Tropical forests tend to be managed as multiple use systems, with a strong emphasis on non-timber products and values. Increasingly in future, it is likely that timber production may be seen as a minor component of the whole system. These non-timber uses will impose marked constraints on timber operations and yield allocation.

Timber yield itself depends on the commercial definitions of acceptable species, sizes

and stem qualities. These may vary greatly over time as markets develop and change.

Yield regulation requires a description of the forest resource through forest inventory and mapping. A part of this process will involve the development of volume tables or equations.

Sustainable yield, in terms of timber production, must be analyzed through some form of growth projection or modeling. This will use the stand table information derived from inventories, together with growth and mortality data from permanent sample plots, information on logging damage, and estimates of regeneration and recruitment rates, to show the levels of production possible from typical stands in the natural forest mosaic. This sustainable yield will depend upon the commercial definitions of volume.

The spatial allocation of yield is the next necessary step. The forest mosaic is very variable, and will be subject to spatial constraints arising from other aspects of the multiple use system and from land tenure aspects. This can be a complex problem but there are numerous algorithms and methods which can be applied to the solution once a database of forest management units has been set up and the constraints and objectives of management defined.

The planned regulated yield then needs to be translated into operations that can be specified in time and space and monitored on the ground. These usually involve general regulations covering logging practices, buffer zones, and the like, diameter limits for species, and a general concept of a felling cycle. Area controls delimit blocks or compartments to be felled and assign them specific dates for opening and closure. These can be monitored by foot patrol or remote sensing depending on the scale of operation. Tree selection methods involve numbering and marking individual trees, and are likely to be increasingly emphasised as natural forest management in the tropics becomes more conscientious and silviculturally based.

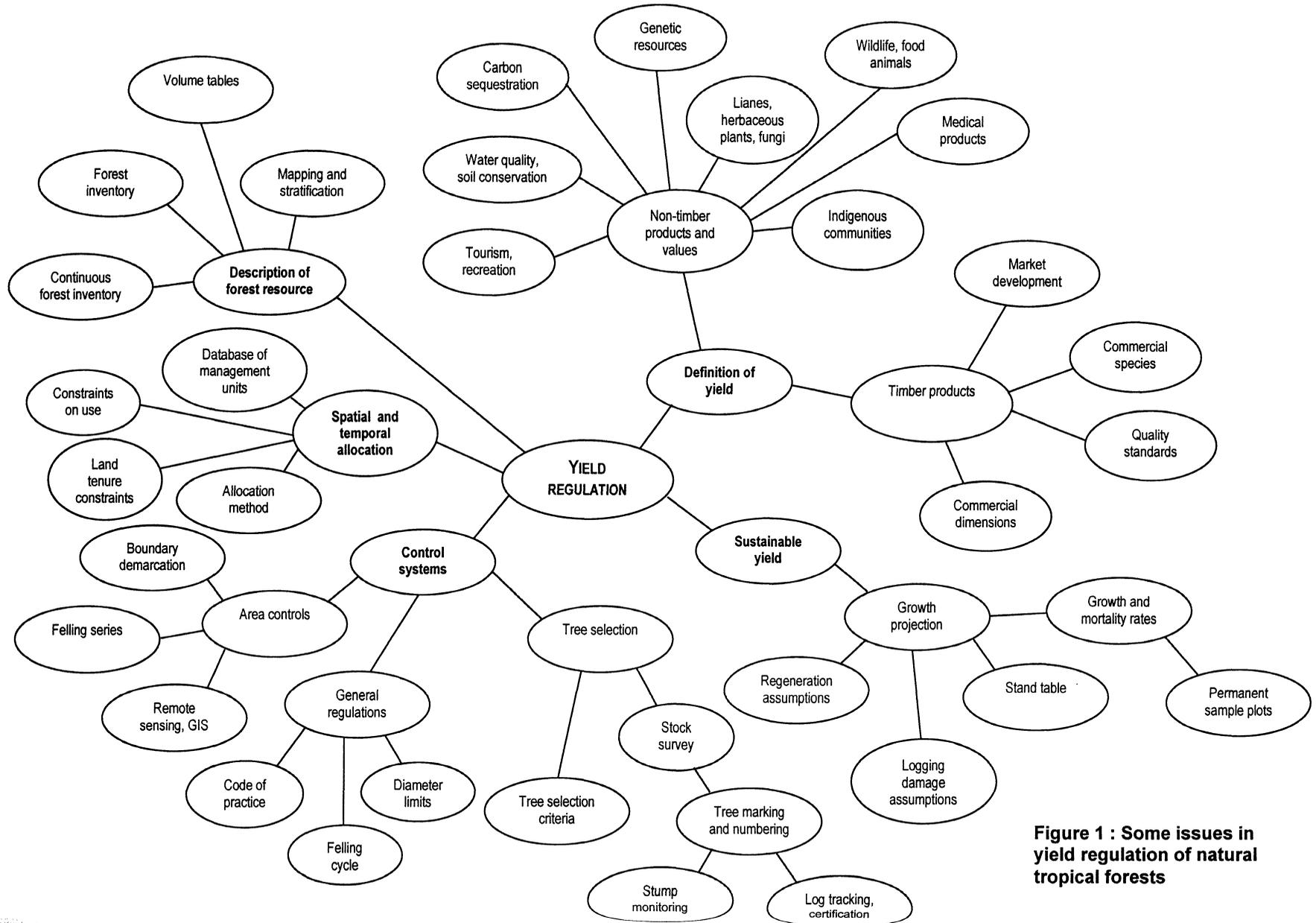


Figure 1 : Some issues in yield regulation of natural tropical forests

Sustainable yield, allowable cut, and annual increment

Yield regulation is the means to achieving sustained yield. Sustained yield itself implies that products removed from the forest are replaced by growth, with or without artificial interventions such as re-planting, liberation thinning, *etc.*

For both plantations and naturally regenerated or mixed-age stands, the sustained yield was classically equated to the *mean annual increment* (MAI) of a *normal* forest (eg. Brasnett, 1953; Knuchel, 1953). This theoretical equivalence leads to the various 'formula' approaches to yield regulation discussed by Wright (1999). It is also a source of some confusion, as commonly the term MAI is used loosely and equated to current or periodic increment of volume, as well as, very often, to periodic mean diameter increment. By blurring these definitions and omitting the underlying assumptions we come to the type of statement often found in the literature of natural forest management and economic development reports (eg. Lowe 1992, 1996):

"The sustained yield is equal to the increment of the forest"

This statement is NOT true for natural tropical forests. Current increment, as measured by permanent plots over periods of two to three years, fluctuates and shows structural changes over time. Increment of any particular species group depends on the diameter distribution of the species, especially when increment is based on volume above a given diameter limit. Volume increment of the whole stand can be calculated in at least three ways:

- *Gross periodic annual increment without recruitment (GPAI)*. This is the volume increment of live standing trees measured over a relatively short period, usually less than 5 years, and averaged to an annual value.
- *Gross periodic increment including recruitment*. This is the volume increment of live standing trees, together with the additional volume of recruit trees entering the lowest measured size class, again measured periodically and averaged to an annual figure.
- *Net periodic annual increment (NPAI)* is the total change in volume over a short period including growth and recruitment, and also deducting losses from mortality, averaged as an annual value.

The NPAI is the most simply calculated value from direct observation, requiring only a measurement of volume at the start and end of a period (say V_1 and V_2 over T years), giving:

$$NPAI = (V_2 - V_1)/T \quad \{eqn. 1\}$$

MAI, if used in the same sense as in plantation forestry, is equivalent to NPAI measured over the period since the last logging operation up to the time of measurement. If used strictly in this sense, then MAI can be equated to sustained yield of a plantation managed under a clear felling regime with equal areas under each age class.

However, in natural forests, the spatial and size class distribution of the stock is very

variable, especially with regard to the commercial species. Further, the losses that occur during and after harvesting from damage and mortality reduce the residual stock substantially. In classical theory we have:

$$\text{Residual stock} = \text{Growing stock} - \text{Harvest}$$

In natural forest management we have rather:

$$\text{Residual stock} = \text{Growing stock} - \text{Harvest} - \text{felling damage}$$

Figure 2 illustrates these points for a typical natural forest logging and recovery. Following a logging of some $30 \text{ m}^3 \text{ ha}^{-1}$ (the yield), the growing stock is actually reduced by $50 \text{ m}^3 \text{ ha}^{-1}$, from $100 \text{ m}^3 \text{ ha}^{-1}$ to $50 \text{ m}^3 \text{ ha}^{-1}$. From this point, in year 4 on the graph, MAI and NPAI can be calculated, as shown by the thin solid and dotted lines. Initially, net growth is slightly negative or static for some 10 years after logging, for two reasons:

- Regeneration, although stimulated by logging, has not yet reached the measurement limit for recruitment.
- Trees damaged or disturbed by logging, especially larger trees, show a higher mortality for a period, declining over about 10 years back to typical levels.

During this period, MAI drops from zero at the time of felling (the base time for calculation) to a negative value ($-2 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$) and then gradually starts to recover. NPAI is also negative, and fluctuates markedly from year to year. As recruitment starts to occur, and the mortality of larger trees declines, then there is a more rapid phase of stand development, with NPAI of the order of $2 \text{ m}^3 \text{ ha}^{-1}$ over a 10 to 20 year period. This drops away after some decades as the recruitment diminishes and growth of the trees is inhibited by competition.

This is a typical pattern, but many variations are possible, depending on the species mix and their response to logging, and the status of advance growth and saplings at the time of logging.

Figure 2 : Volume, current and mean annual increment in logged natural forest

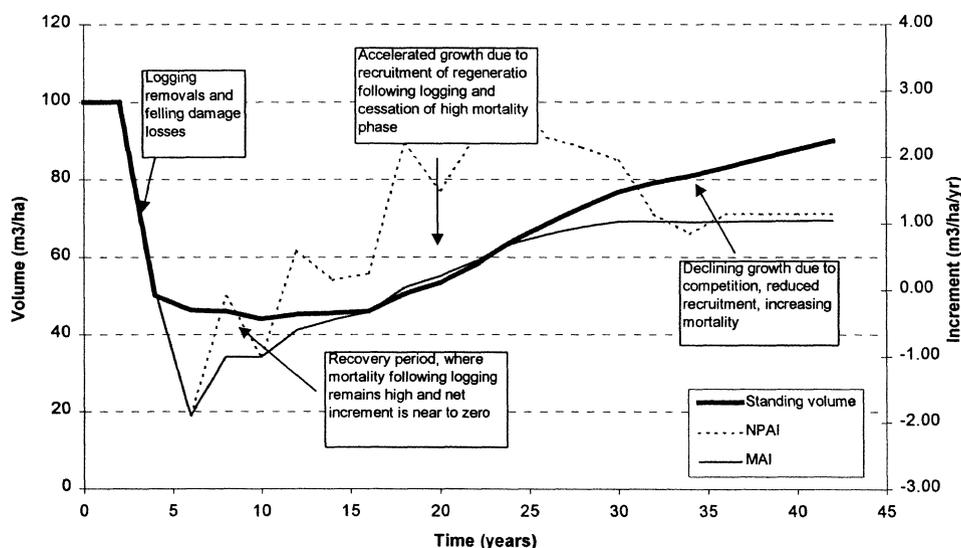
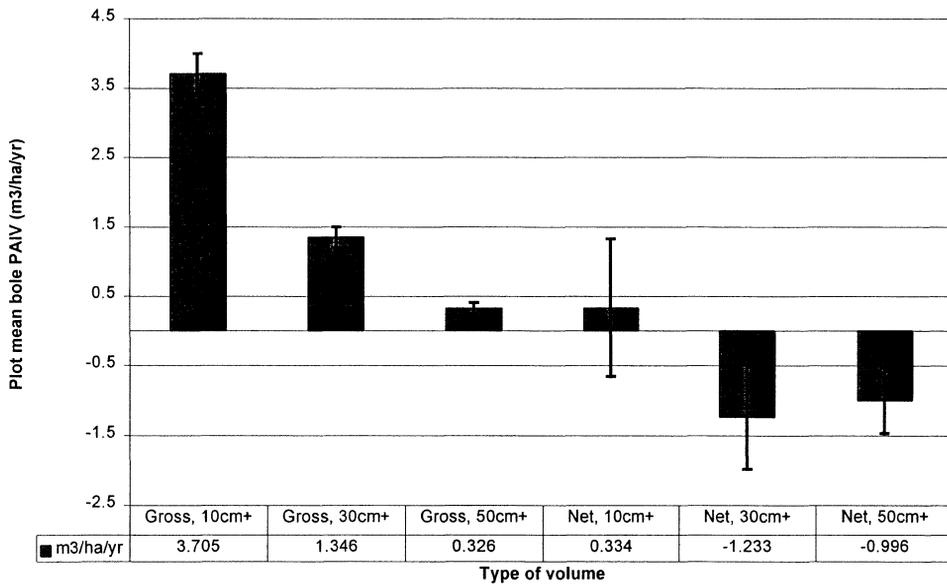


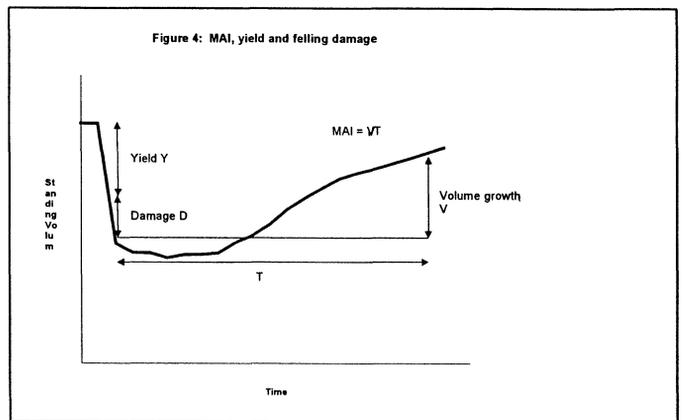
Figure 3 : Gross and net volume increment to different diameter limits, ITTO sample plots, Papua New Guinea



Volume and increment in natural forests can be measured above different diameter limits, from say 10 cm up to 50 cm or more. This will clearly have a major effect on the values of GPAI, NPAI and MAI that are calculated. Figure 3 illustrates how these statistics can vary. It is based on the increment of 72 PSPs of 1 ha measured over intervals from 2-4 years (Alder *et al.*, 1998). All the plots were established shortly after logging. The bole volume increment of all trees over 10 cm dbh is $3.7 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$, neglecting losses from mortality (gross increment). This declines to a gross figure of $0.3 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ for trees over 50 cm. The net figure, including losses from the growing stock due to natural mortality over the increment period, is negative and amounts to a net loss of $1.2 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ for trees over 30 cm dbh.

Annual allowable cut (AAC) is commonly used as loosely as MAI, and with a rather similar confusion of equivalences. AAC is the practical measure of the sustained yield and can be used to monitor forest production and set limits for timber industry supply. It is usually quoted as an aggregate figure, for all commercial species, but can be broken down by species and localities for more detailed planning. It will definitely relate to commercial yield and size limits.

Again, it should be emphasised that AAC is NOT equal to the increment of the



forest. Current increment, as it may be measured from PSPs (as for example in Figure 3) is almost completely irrelevant. Mean annual increment must be corrected for logging damage in order to calculate AAC. Figure 4 clarifies some of the definitions.

The total volume reduction at the time of harvesting is the yield Y plus the felling damage D . Mean annual increment is calculated as the incremental volume growth V_t over a period T from the last harvest:

$$MAI = V \sqrt{T} \quad \{\text{eqn. 2}\}$$

The AAC can be calculated as:

$$AAC = (1 - D\%) \cdot MAI \quad \{\text{eqn. 3}\}$$

where:

$$D\% = D/(Y+D)$$

In practical terms, AAC should be about 50-70% of the estimated commercial MAI, depending on observed levels of logging damage. This refers purely to volumes calculated as standing volumes, and does not consider an allowance for within tree wastage and degrade. The latter is necessary if AAC is monitored and controlled in terms of extracted volumes, and is likely to be an additional 50-70% reduction factor. Thus Dawkins' (1964) pan-tropical mean estimated of commercial MAI of $1 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ amounts in practice to pan-tropical AACs of around $0.25\text{-}0.5 \text{ m}^3 \text{ ha}^{-1} \text{ yr}^{-1}$ measured as logs at the landing or roadside.

Basal area and volume

Figure 5 illustrates how the volume equation used can influence the tree volume increment. Four general equations are shown, for Tapajós, Brazil (Silva, 1989), Ghana (Wong, 1989), Costa Rica (re-parameterized average equation, Alder, 1997), and Papua New Guinea (Romijn, 1992). For a tree of 70 cm dbh, these four equations give volumes between approximately 3 and 5 m^3 . A fifth equation, for woody biomass from a study in Subri, Ghana (Alder, 1982), is shown to illustrate how the measurement standard may influence the volume estimate.

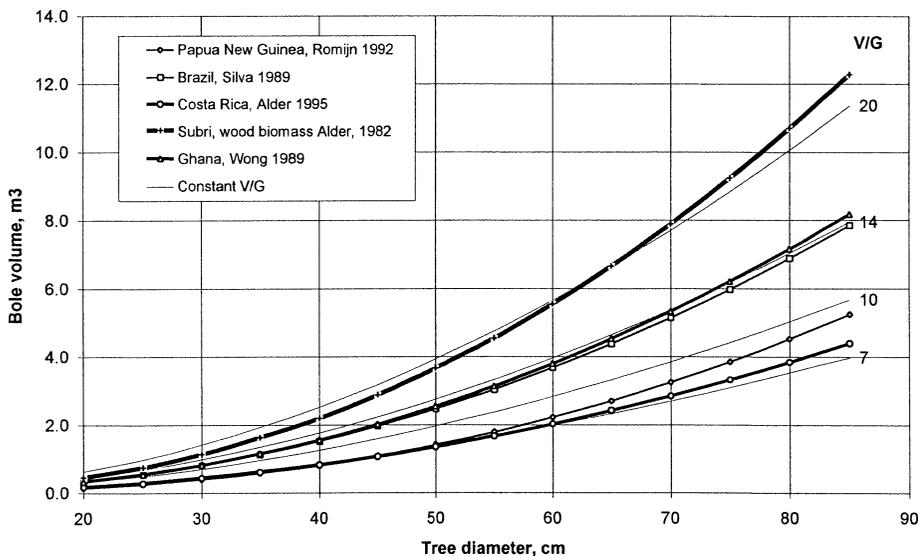
These comparisons show that by changing or improving a volume equation, or by applying different definitions or measurement standards of tree volume, yield and increment figures may change by as much as 50%. The forester's quoted volume, based on measurement of tree boles, will usually be at least double what can be effectively used as logs in a sawmill or plymill. Thus when relating mill capacity or intake requirement, in terms of round logs, to allowable cut and sustainable yield, a factor must be introduced for defect, length and diameter constraints, and simple operational wastage (logs felled but not transported).

For forest management purposes, basal area and basal area increment may be less

ambiguous than volume. Basal area and volume can be approximately converted by using an average form height, or volume to basal area ratio. Figure 5 shows the form-height lines for some values similar to the illustrated equations. It can be seen that the lower equations are equivalent to a form height of about 7 m (Costa Rica, PNG). The higher ones (Amazonia, Ghana) are close to 14 m, and a median value is near to 10. The biomass equation illustrated is close to a form height of 20 m. As a rough rule of thumb, we may therefore say that in natural tropical forest, we may expect bole volume to be about ten times basal area, whilst woody biomass is approximately 20 times basal area. The latter is a useful figure for carbon sequestration or wood fuel considerations.

Whilst basal area and basal area increment are not subject to the variations arising from a given volume equation, it is necessary to define the lower limit of measurement, and whether the statistic refers to all species or only commercial species. Basal area increment can, like volume, be defined as a net or gross figure, the latter including or excluding recruitment.

Figure 5: Comparison of some tree volume equations and form height equivalents

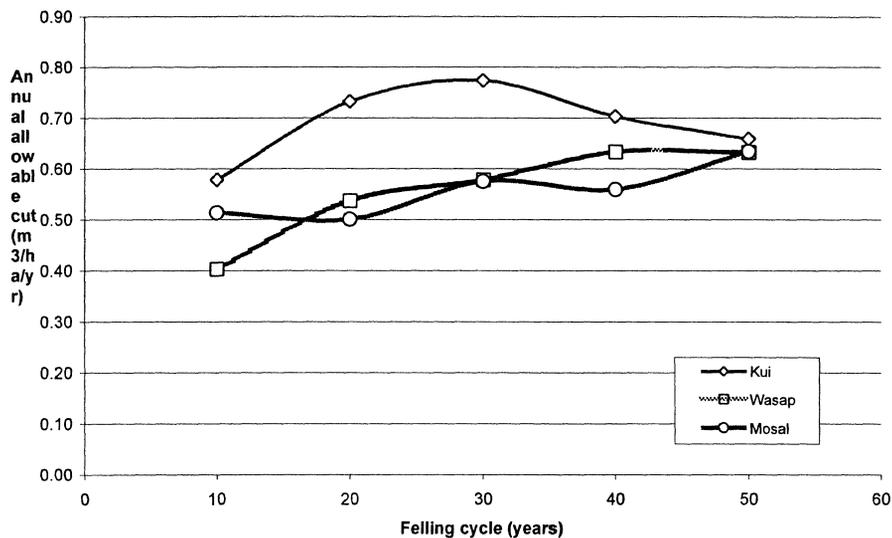


Felling cycle, minimum diameter, and allowable cut

The definition of felling cycle is often regarded as the central issue in regulated yield management, as Wright (1999) indicates in relation to the discussion of Von Mantel's and similar formulae. Theoretically, once a felling cycle has been defined, the forest can be divided into annual or periodic coupes, collectively termed a felling series (eg. Leuschner, 1984, pp. 159-168). The coupes are mapped, and can be monitored on the ground and by remote sensing.

Figure 6: AAC over different felling cycles for three locations in Papua New Guinea

(based on 100 years growth using the PINFORM model)



However, practical analysis suggests that there is no definite optimum felling cycle for many stands. Figure 6 illustrates this point for simulations of felling cycles from 10 to 50 years at three localities in Papua New Guinea using the PINFORM model (Alder, 1998; Alder *et al.*, 1998). At Kui, there appears to be an optimum at about 30 years, but this is not obvious in the other stands, and could simply be due to variations in stand structure and species composition. The decline with very short cycles appears real however, and due to the lack of time to recover from post-felling disturbance. The AACs in this diagram are calculated as the average actual yield over a period of 100 years, and can be seen to be 0.6-0.7 m³ ha⁻¹ yr⁻¹. This is based on bole volumes of commercial species only over 50 cm dbh.

The felling cycle may be constrained by the need to achieve a certain economic level of harvest at each cut, as indicated by De Kock (1999). However, where small scale harvesting systems are involved, as in community-based projects or farmer-owned forests, then shorter felling cycles may be indicated. Shorter felling cycles should also be combined with concepts of silvicultural treatment and more intensive forest monitoring and control.

The minimum diameter limit determines directly the level of yield. A higher limit will reduce the both the available stock of timber, and the commercial productivity. The most productive diameter can be determined by the method described in Alder (1992) if increment and mortality rates are known. It is likely to be necessary to reserve trees substantially above the diameter limit as seed trees if adequate regeneration is to be assured (Plumtre, 1995), whilst the spacing of such trees needs to respect their genetic and reproductive mechanisms (Kanashiro, 1998).

It is not necessarily a desirable management policy to always take the largest trees and leave the smaller ones. It may be desirable to reserve large trees as seed trees, even if, or especially if, they are deemed 'overmature'. It may also be a very desirable and effective policy to remove commercially competitors to higher valued reserved trees as a liberation thinning. Thus the diameter limit alone is not a

sufficient criterion for regulating the yield in a selection forest.

Yield estimation through stand projection

Because of the complexities of stand management in natural forests, it is probably essential to have some form of stand projection model that will take into account variations in stand structure from place to place, and allow mean annual increment to be estimated, preferably over several felling cycles. Vanclay (1994, 1995) and Alder (1995) give practical information for the techniques of modelling natural tropical forests. Examples of empirical methods of stand projection are given in Vanclay (1989) for North Queensland rainforests, Howard and Valerio (1992) for Costa Rica, and Alder and Silva (1999) for Brazil, among others.

Models can be simple or elaborate, and may use extensive permanent sample plot data or simple assumptions about growth rate and mortality. Simple models can be quite effective. Both the SIRENA and PINFORM models developed by the author (Alder, 1997, 1998) used only tabulated mean increments and mortality rates, without any elaborate diameter increment functions. These are supported by stand level functions for recruitment, for stand density effects, and logging damage. There is enough similarity between the performance of these models, for Northern Costa Rica and Papua New Guinea lowland tropical forest, and also the more complex CAFOGROM model (Alder and Silva, 1999), to suggest that pan tropical tabulations of these basic functions are possible and can be used to provide a basic and easily parameterized model for provisional use.

Spatial allocation of yield by management units

Species in natural forest tend to be clustered and to follow environmental gradients, both actual and historical. In addition, the forest is a mosaic of successional phases over scales from the individual tree gap to areas of many square kilometres. Treating a whole managed area as if it had an homogeneous average stand table will rapidly result in an impossible conflict between a management plan and operational reality. If a plan is to be feasible, it must reflect spatial variation. Yield regulation, which links the plan and operations through a monitoring and regulatory process, must reflect this spatial variation.

Essentially, there are two approaches. The first maps the forest mosaic using remote sensing and aerial photography, and uses a stratified inventory to derive average stand tables for each identified forest type or mosaic element.

The second uses a systematic inventory on a grid to map the forest mosaic directly from the inventory.

In either case, the yield regulation process should relate the allowable cut calculated for each management unit (a grid cell or map polygon) to an annual target or requirement for timber, and to operational or conservation constraints, including ownership units, access routes and sequences and the like. This spatial allocation of yield can be resolved by two basic approaches:

- *By a mathematical programming algorithm.* Conventional linear programming problems can be set up and solved using the standard facilities of *Microsoft Excel*, for example (the *Solver* module). Integer or zero-one programming are variants which would require specialised programming or packages, but are quite

suitable for 'all or nothing' situations such as the allocation or non-allocation of a grid cell for felling in a particular year. These methods are widely used for yield regulation in plantations and temperate mixed forests (eg. Rorres, 1978; Clutter *et al.*, 1983; Leuschner, 1984).

- *By trial and error.* This involves using a combination of maps and graphs to select management units (stands, sub-compartments, blocks, etc.) for felling in a way that reasonably satisfies the more obvious constraints and practical aspects. This is the more common technique in the tropics, and is most suited when many decisions cannot be based on fully quantifiable or logical criteria. The process can be assisted by GIS, or computer simulation. There are also a variety of algorithms that can completely or partially automate the trial and error process, including recursive decision tree searches and genetic algorithms.

The outcome of the process of spatial allocation will be a felling series that involves unequal sized coupes, but producing either equal volumes of timber, or yields which are within some limits of variation over time that can allow a stable industry to develop or continue to operate. In some cases, the goal might be to produce a specific balance of species; in others, it may reflect the need to provide continuous employment in different settlements adjoining or within the forest. The constraints on the plan will typically include a number of conservation factors.

Within a given stand, a further layer of yield regulation may be required, to respect fine scale conservation principles and ensure that logging is properly controlled. This will typically involve stock surveys to map and number larger trees, and the allocation of specific trees for felling.

Monitoring and control

A system of yield regulation will at the end amount to nothing if there is no monitoring and control, no matter how elaborate or complex the mathematical systems used, or how beautifully detailed and coloured the maps. A part of the process of yield regulation is to define specific targets for monitoring. In terms of areas, this involves having definable geographical boundaries. With modern GPS systems, this is a much easier task than formerly, and it may be less necessary nowadays to physically demarcate boundaries, since the location of operations can be checked directly against a GPS reading. However, a system of monitoring does need to be set up whereby the forest is patrolled, and reports made of the locations of any forest operations.

For tree level monitoring, felled stumps need to be identified and checked against lists of trees permitted to be felled. This requires a suitable numbering system, that will survive on the stump, and a tree map to check for ambiguities.

The monitoring party should not be engaged directly in enforcement. The latter is a simple recipe for corruption. Instead, monitoring data should be fed back into a main database that contains forest areas, yield lists, and operating rights and agreements. Where discrepancies occur which exceed those that can be tolerated as data errors, then a separate and suitably equipped (legally and physically) enforcement unit should be assigned to investigate.

A strategy for yield regulation with minimal data

The present workshop represents an initial step for the DFID project *Humid and semi-*

humid tropical forest yield regulation with minimal data. The direction the project will take will be informed by the conclusions for the workshop. However, the author considers that the following are the key elements that the project will address:

- A clarification of issues and terms, especially in relation to the concepts of yield, sustainable yield, allowable cut, and mean annual increment.
- A handbook of pan-tropical statistics, showing typical growth and mortality rates for many species from published sources, recruitment functions, logging damage, maximum basal area, volume and biomass, typical volume equations, and the like. Ideally, these will be provided in database form on a CD-ROM, as well as in a printed publication.
- A basic model for estimating allowable cut using the pan-tropical data, and combined with suitable inventory data. To assist this a simple inventory program will be provided, although it will also be easy to configure inventory data from other sources. This model will be supported by a user's guide.
- A spatial allocation model that will interface with the stand model and use a simple recursive decision tree approach to define coupes and felling series subject to various constraints and objectives.

Conclusion

A number of points have been discussed in this paper. Yield regulation is at the core of sustainable forestry practice, and must be based on the real world. This means especially taking account of some of the complexities of natural tropical forest management, which include strong human, conservation, and marketing constraints, a general lack of knowledge of species dynamics and ecology, and the spatial diversity of the forest at a variety of scales.

Even the simplest yield regulation method will therefore be relatively complex if it is to correspond to anything that can be practically implemented. However, the author feels that the basic data exists on general growth and yield to provide a start in this direction, and there is enough experience in empirical stand projection methods to show how reasonable estimates of sustainable yield and allowable cut can be made. A fundamental objective of the DFID project *Humid and semi-humid tropical forest yield regulation with minimal data* will be to serve this data and systems up in a simplified, useable format. This will hopefully help to bridge the rather large gap between the ideal of sustainable forestry and its realization in practice in the tropics.

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GROWTH AND YIELD PREDICTION: SOME EXPERIENCES FROM THE TROPENBOS PROGRAMME

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Abstract

Tropenbos develops methods for sustainable forest management in its programmes in Guyana and Cameroon. In both countries, growth and yield models are currently not available to guide management decisions, but they are developed as part of the research projects. In Guyana, a population model is available for Greenheart, the major commercial species. In this contribution this model is used to show that yield prediction based on limited data in the form of size class distribution data has limited reliability. Minor variations in dynamic characteristics may lead to substantial differences in expected yield. It is concluded that even in conditions of limited data availability some knowledge about population dynamics is required, but that this requirement can be reduced by classifying species in functional groups.

Experiences with yield regulation in Tropenbos

The Tropenbos Programme is involved in research projects supporting sustainable forest management, including aspects of yield regulation, at several sites throughout the Tropics. In Guyana and Cameroon projects have recently been concluded that focused on the design of reduced impact harvesting techniques for forests producing Greenheart (*Chlorocardium rodiei*) and Azobé (*Lophira alata*) timbers. A recent comparative review of these two projects can be found in van der Hout and van Leersum (1998). At both sites, periodic measurements of tree growth, survival and recruitment have accompanied the harvesting operations.

Logging in both countries occurs in previously unlogged forest. Reliable growth, mortality and recruitment data are not available to operators, preventing the possibility of adapting logging strategy to the requirements dictated by future harvesting needs. Similarly, the dynamic data generated in both projects were not available at the time of experimental harvesting. Little is known about annual allowable cut, both at the species and the stand level. Therefore, trees to be harvested were selected according to a combination of legal stipulations (a minimum felling diameter) and requirements related to the avoidance of large impacts on either forest structure, species abundance or future crop trees according to the best professional judgement of the responsible researcher.

In Guyana the following objectives were considered with tree selection:

- 1) An even distribution of small logging gaps over the area – based on research indicating that large gaps have negative ecological and silvicultural impacts.

- 2) A preference of a commoner species (on a plot basis) over less abundant species¹ - with a view to retaining seed trees.
- 3) A minimum felling diameter limit depending on the species - higher once the species attains a higher maximum diameter.
- 4) In case these criteria left a choice between trees, those trees were selected that suppress immature crop trees.

Directional felling was employed to facilitate skidding and to avoid damage to potential crop trees. In conventional logging in Guyana, the legal minimum diameter and timber quality are the only criteria used for tree selection.

In Cameroon, tree selection was based on the preferred species, minimum felling limits and requirement related to the experimental design (limited space for laying out the plots). A yield modelling system was developed, but parameterised with growth and mortality data from Liberia.

In Guyana, population dynamic data collected in undisturbed and previously harvested forest have been used to model population growth of *Chlorocardium rodiei* and two other species using matrix population models (Zagt 1997). Whilst these models are not sufficient for the establishment of annual allowable cut they provide a useful tool to organise and integrate available knowledge on growth, survival and fecundity of these species, and to assess alternative scenarios of logging. Currently the information covers a period of seven years and includes seedlings as well as larger individuals.

For the purpose of this workshop, which aims at developing methods for generating knowledge for yield determination using static information contained in size class distributions, the model was used to assess some of the opportunities and risks associated with this approach.

Information contained in population size distributions

Three sets of information are simultaneously expressed in population size class distributions: information about species-specific growth, survival and recruitment rates; information about the growth conditions and information about past events.

In the first place, size class distributions yield information about species-specific life history characteristics: size-dependent growth, survival and recruitment and a whole set of other parameters which together describe the life history of a species. For example, early successional species show different size class distributions than late successional species. The species-specific size structure is best illustrated by the stable size class distribution, which can be easily calculated using matrix models. It may be expected that many species growing in undisturbed forest show a size class distribution, which resembles the stable distribution.

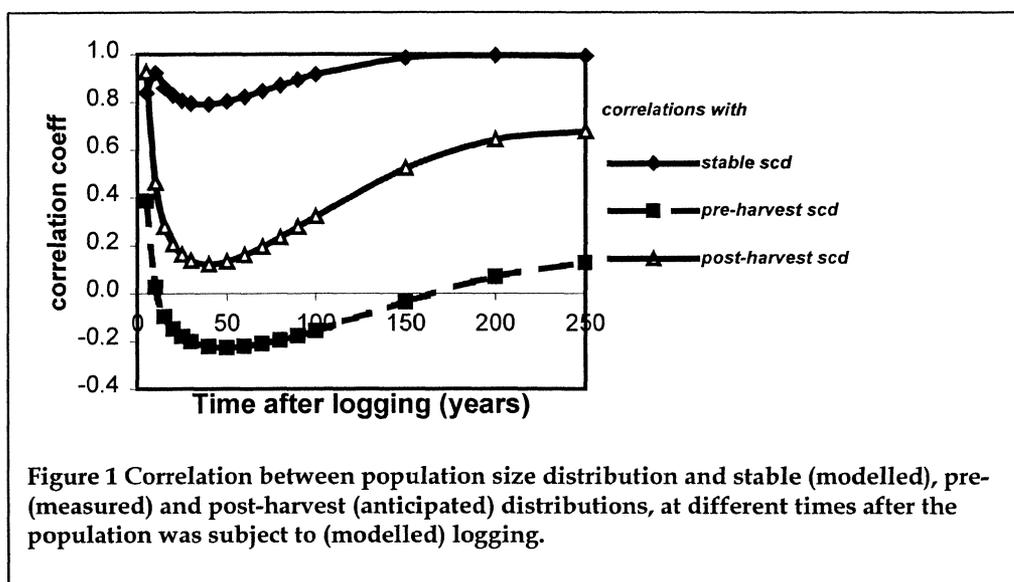
Secondly, size class distributions may reveal aspects of the environment in which a population is growing. This is evident in *Dicymbe altsonii* in Guyana, an abundant canopy tree species growing on two different soil types. On albic arenosols, the

¹ In logging units larger than experimental plots this method should be replaced by a method based on inventory-derived abundance estimates and information about annual allowable cut.

species is very common but does not exceed 80 cm in diameter (dbh), while on ferralsols the species is less abundant, but often exceeds 100 cm in dbh.

Thirdly, size class distributions bear witness to past events with a large impact on recruitment or survival, or even growth. Catastrophic events may completely upset the population structure of a species. For many species, logging may well be one of these events, which is unfortunate considering the purpose of today's exercise.

A major question with regard to yield prediction concerns a fourth set of information to be found in population size class distributions: how much does a population size class distribution reveal about the future? More precisely: is there a relationship between size class distribution now and at the moment of (a second) harvest? Is there a relationship between size class distribution now and the amount of timber to be expected at harvesting? Is it possible to anticipate differences in these parameters between species or groups of species based on their current size class distributions?



There are several reasons to believe that there are substantial problems associated with basing yield predictions on size class distributions.

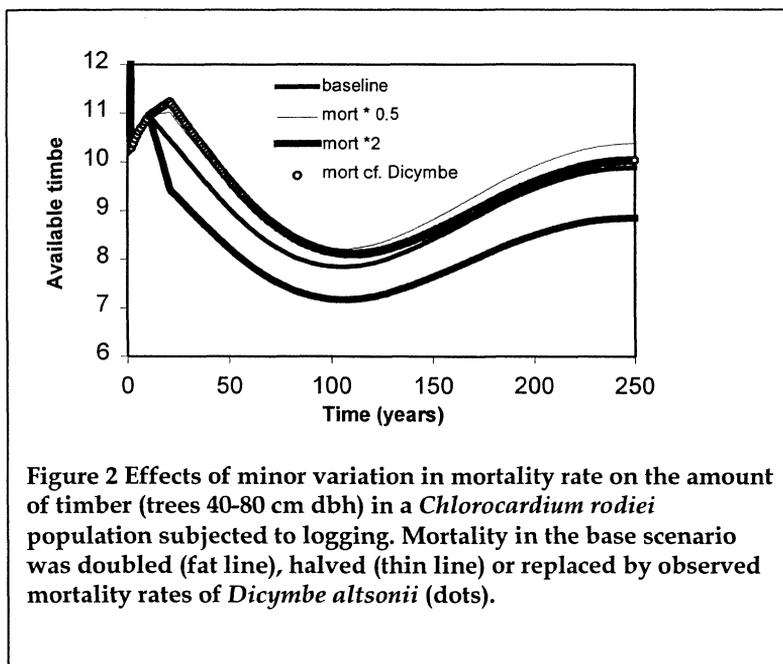
Theoretical analysis of population dynamics shows that all populations of species, growing following a fixed, species-specific set of growth, survival and fecundity characteristics, will converge into the same stable size class distribution, independent of the initial conditions. This is clear when carrying out an hypothetical experiment in which two *Chlorocardium rodiei* populations are allowed to grow, one consisting of only seedlings and the other of only adults. After 250 years of projecting growth the population size distributions have converged to a very large extent. Reality is more complicated, because vital rates are not invariant, minor and major catastrophic events may disrupt the pattern and density-dependent processes will affect population dynamics, particularly of somewhat less shade tolerant species. Still, this will also happen with projections based on initial stand structures.

In a less extreme example, the similarity was compared between projected size class

distributions and the original stand structure (before and after harvesting; both known in data-limited conditions) and stable size class distribution (which is unknown in data-limited conditions). The population was subjected to harvesting with associated damage, and underwent a post-harvesting stimulation of growth rates (5-10 years, depending on size), after which it continued growth following undisturbed forest dynamics. At no point over 250 years in time did the original pre-logging population structure provided a reliable "prediction" of the *Chlorocardium rodiei* stand (Figure 1), whilst this was much better for the stable size class distribution. An intermediate case was presented by the original pre-harvest structure of which the harvest and associated damage due to logging were anticipated. In all three cases the predictive power of the population size distributions was lowest over the timeframe during which current thinking expects a second harvest (20-70 years).

Effects of minor variation in mortality rates.

This analysis does not reveal the amount of timber available for harvesting. This was modelled in subsequent analyses using the same logging scenario, but with another purpose in mind: to demonstrate the effect of minor changes in population dynamic parameters, which are not known for most species but about which implicit assumptions are made in any yield predicting system. Minor variation in measured saplings (>0.4 cm dbh), pole and adult mortality (range 0.6-2.3% per year depending on size class) was introduced by doubling or halving class-specific mortality rates. The rationale to do this is that it is extremely difficult to distinguish reliably



differences in such low mortality rates. This may cause species to be grouped into functional groups on the basis of similar population dynamical behaviour, even though in reality such small differences may have appreciable consequences. To further illustrate this point, the mortality pattern as demonstrated by *Chlorocardium rodiei* was replaced by that of Clump Wallaba (*Dicymbe altsonii*), a relatively fast

growing late successional species that would represent the other end of the spectrum of regeneration behaviour as displayed in this forest type. This example is given to show the effect of lumping species into functional groups, that is, to give them equal growth, mortality and reproduction rates (in the example only equal mortality rates).

The results show a bandwidth of *c.* 15% (compared to the maximum estimate) in expected availability of stems for harvesting between the high and low mortality estimates (Figure 2). Replacing *Chlorocardium rodiei* mortality rates with those of *Dicymbe altsonii* initially had substantial consequences for projected timber availability, but they were diminishing over time.

The above was modelled with a fairly complete dataset on growth, survival and fecundity when compared with data usually available from inventories (just stand tables) or permanent sample plots (usually trees from 10 cm and up). Thus, important items of information are missing which are relevant for future stand behaviour, as well as for distinguishing usefully between functional groups of species displaying similar population-dynamical behaviour and possibly responding in similar ways to the effects of logging. There are more factors involved in determining population dynamics which are not often included in even the most advanced models, such as aspects related to plant-animal relations (pollination and dispersal), and effects of logging on these relations.

All this should not be understood as a case for developing full understanding of all species before proceeding with yield prediction, but as a case to simplify judiciously data requirements on the basis of what is important rather than what is easily available.

Data reduction.

A useful approach to simplification of requirements for dynamic data would be to classify species into functional groups. One may wonder whether the information contained in static and easily obtained characteristics such as size class distributions is sufficient to adequately capture variation between species in response to events such as logging. Information in "difficult" parameters, such as growth and survival rates, or in potentially important but usually unknown factors, such as plant animal relations (Fig. 3) is required to adequately classify the species and achieve improved yield predictions. Several examples exist in which grouping of tropical tree species has been carried out on the basis of population dynamical data (Favrichon, Condit)

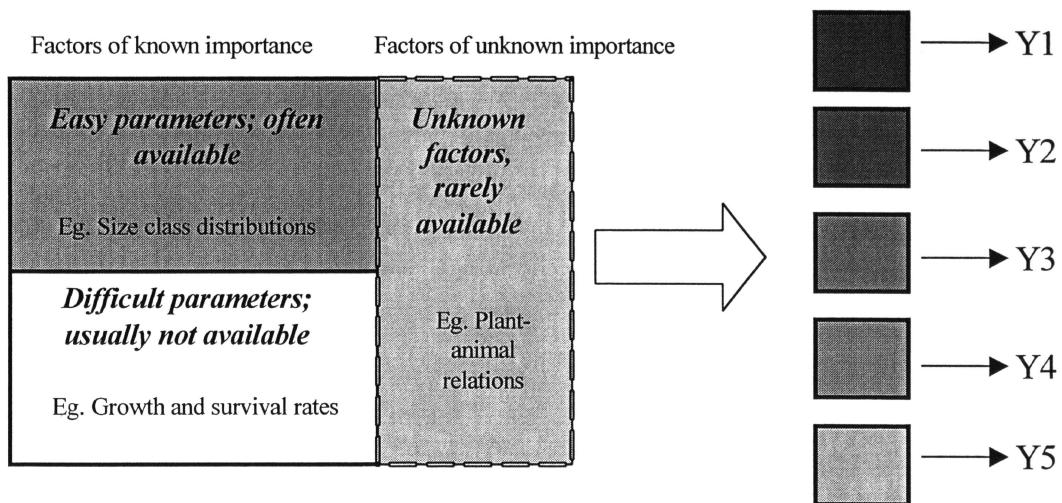


Figure 3 Different types of information with a different degree of availability and ease at which it is collected is required to classify species in functional groups (colours) with regard to yield prediction (Y1...5).

Further reduction of data requirements can be achieved on the basis of sensitivity analysis performed on models of species with well-understood population dynamics. Data collection should concentrate on those size classes with a significant impact on population-dynamic parameters and eventual yield prediction. A comprehensive but reduced set of characteristics which is still capable of capturing a significant amount of variation in population dynamic behaviour would provide a powerful tool for understanding population dynamics. This will still call for collecting dynamic data, but most likely this can be done in a much more selective manner than currently.

A recently started project in the Tropenbos-Guyana Programme attempts to follow this approach (with a purpose other than yield prediction - response of species to disturbance based on population dynamics). A relatively parsimonious individually based growth model serves as the basis for selecting a consistent set of parameters that contain a high level of information about species-specific growth, survival and reproduction rates. As many species as possible will be screened on these characteristics. Formalised sensitivity analysis of matrix models of long-lived species have revealed consistent patterns of sensitivity, with some size classes having a larger impact on population dynamics than others. The measurements will concentrate on those classes that influence population behaviour to the largest extent, and will be carried out over the widest range of light conditions possible. These parameters will be used to classify species in functional groups, which will serve as the inputs to the model which will be developed to make projections about shifts in species composition in tropical rain forest as a result of different disturbance regimes.

Final points

In this contribution an attempt was made to assess the consequences of utilising heavily reduced datasets on the outcomes of growth and yield models. It is contended that simplification of the complexity of dynamic patterns calls for distinguishing functional groups based on dynamic characteristics. Information contained in population size distributions reveals little about future population

behaviour. Further, variation in hard to measure parameters such as mortality could have substantial effects on model outcomes.

Lastly, modern yield regulation in multi-purpose forest management requires more than concentrating on potential crop trees of commercial species, or, indeed, on trees.

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SOME THOUGHTS ON TIMBER YIELD REGULATION BASED ON EXPERIENCES IN THE COMMUNITY FORESTS OF NORTH WEST ECUADOR

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Introduction

The SUBIR Project is an integrated conservation and development project run by CARE Ecuador with major financing from USAID. The geographical focus is primarily the province of Esmeraldas, north-western Ecuador, working with communities, in the buffer zone of the Cotacachi-Cayapas reserve. The project is made up of five components: social, legal, biodiversity monitoring, improved land use and commercialization. The aim of the project is biodiversity conservation through protecting the reserve and improving livelihoods in the buffer zone.

The province of Esmeraldas is estimated to have up to 300,000 hectares of natural forest designated for production. It has been, and is, the most important source of timber from natural forest in the country, supplying around 70% of national demand. The forest is owned by communities and privately. In theory the state also owns production forest though in practice all has been colonised.

Putting yield regulation and planning into context

Obviously yield regulation is a central concept in any attempt at rational forest management. However, community forest management in Ecuador is a very different situation to management of state tropical forest in Queensland or indeed European forest management where many of the classical yield regulation formulae were devised. The following factors need to be taken into account before attempting to develop a complicated yield regulation system:

1. Needs and practices of the communities

The community forests in Esmeraldas vary in size (100-10,000 ha) and the extent to which they have been harvested. Although legally land title is communally owned, there is division of agricultural areas and sometimes forest on a family basis. Traditionally, harvesting is on a family, group of families or a communal basis. Where harvesting has involved large tracts of forest being sold to logging companies, it is generally on a communal basis. Traditional non-mechanised harvesting of sawn timber or logs by community members near rivers (the normal means of access) is more usually by families or groups and meets needs such as the costs of holiday periods, schooling and health problems. With increasing population pressure, in most cases, accessible forest is being over harvested by traditional methods.

2. The forest

The remaining forest in the province of Esmeraldas has difficult access: being further up, and then further from, the rivers. The topography is often borderline to extreme considering accepted low impact logging norms, making net harvestable area estimates difficult. In addition, the forest is extremely variable in regard to levels of previous exploitation. Higher value sawn timber especially chanul (*Humiariastrum procerum*) has suffered. Information ranging from topographic maps through to

growth rates of commercial timber species is sorely lacking.

3. Government Policies

Historically, government land tenure policies have promoted conversion of forest to agricultural uses. The forest law has allowed timber extraction with no long term planning and the forest service has been under resourced and unable to exert effective control.

4. Poor profitability of forest management

The financial analysis of long-term natural forest management in Esmeraldas is no different to that noted in many other tropical regions. Without consideration of wider economic benefits the battle will be lost. Additionally, timber prices in Ecuador are very low.

5. Logging in Ecuador

Logging in Ecuador has generally lacked long term planning. However, the work by the Durini Group and its associated NGO, Fundación Forestal Juan Manuel Durini (FFJMD), at the research site of La Mayronga and in its contract with three Chachi communities is a notable exception. It is fair to say that there are few incentives to consider anything other than a liquidation harvest: there is no security of returning to harvest after a cutting cycle, there are means within the forest law to harvest without long term planning and there has not been effective control.

Current possibilities for rational forest management

The environment for rational forest management is, however, improving. The Ministry of the Environment is developing a new forest law, with support from USAID and involvement of SUBIR Project staff and representatives throughout the forest sector. Also, there are efforts to find funding for environmental payments. There is strong ministerial support for major reforms in the forest sector. Other government policies are less conducive to conversion of forest. On the industry side, the Durini Group continues to expand natural forest area under management plans as part of its long term timber supply planning.

At the local level the SUBIR project is working with communities along the Santiago and Cayapas rivers to develop community integrated land use plans incorporating natural forest management, agroforestry and different added value ventures.

Our simple approach in community forests

1. Forest delimitation - often there are no boundaries in place.
 2. Ordination of forest - mapping of major topographic features to aid both location of cutting areas and roading, allowing permanent identification, control and location of protected areas.
 3. Initial inventory - of total forest area, including qualitative biological inventory.
 4. Management plan - regulation by area.
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5. Stock survey – 100% enumeration, marking, measuring and mapping of commercial species over a minimum diameter (currently 60cm). Division into sub compartments by topographic features.

Tree selection based on:

- Maximum no. of trees per hectare (5)
- Spatial gap distribution
- Permanent watercourse protection
- Protection of other fragile areas
- Protection of endangered species
- Marketability / tree quality

6. Harvest plan.

7. Monitoring and environmental assessment.

Experiences to date of yield planning and regulation

a) Initial basis

Our first plans lacked a real attempt at yield planning, they just included assumptions regarding diameter and volume increments. The aim was to harvest with the lowest possible impact and reassess when more data regarding growth rates *etc.* became available. Annual cutting areas were regulated by area and the simple norms for tree selection mentioned above.

b) Calculations of the allowable cut by basal area (BA)

The next step was to incorporate the methodology developed at CATIE, based on diameter class distribution of basal area, dividing volume into accumulated (eg >80cm) and operational (eg 60-80 cm), and estimating cutting cycle and basal area removal to maintain the operational class. This was done in two groups: the harder species for sawn timber and others for shuttering or peeling.

The assumptions we used were those of CATIE, for example:

Growth of 0.5 cm dbh per year

Natural mortality of 1.5% per year

Damage: dbh 10-30cm: 30% of BA; dbh 30-40cm: 20%; dbh 40-70cm: 10%

And that the first diameter class would remain stable

The idea was to regulate by volume the harvesting areas.

In practice there were several problems. Firstly, the basis was the static inventory, the reality of annual cutting areas was at times decidedly different from the inventory averages. Secondly, the practical reality of tree selection did not fit in with harvesting a certain basal area in a specific diameter class.

c) Current methodology

Using the assumptions noted above but simplifying diameter classes to three, 20-40cm, 40-60cm and >60 cm, and calculating with number of trees instead of basal

area we used a simple spread sheet based model to simulate the development of the forest under different, but simple, harvesting scenarios. Five groups of species determined by timber use were chosen. Cutting areas are regulated by area and the simple guidelines noted previously are used in tree selection.

Objectives of future growth modelling

The following are our main objectives, and combine the local community level with the regional level:

- a) Predict sustainable timber harvest in community forests

The fundamental need at a local level is to predict the harvest of 'accumulated' volume and then the long term sustainable yield.

- b) Predict effects of different harvesting strategies and silvicultural treatments

We lack information on the effect of different harvesting strategies and the effect of silvicultural treatments; both are important and urgently needed.

- c) Allow regional level timber supply planning/control

At a regional level, there is a need for modelling to allow more reliable timber supply planning to the industry and to guide the forest service in control. We are working with satellite imagery (and possibly aerial photos) at the regional level and the aim with modelling would be to provide indications of the sustainable yield of permanent production forest.

- d) To design a user friendly and easily understandable tool

In order to be appropriate and to be used, we need a user friendly and easily understandable tool.

Conclusions

As is obvious from the above, we are in a situation of having minimal information, but in need of developing our yield planning and regulation. We are attempting to compile relevant information, and can design our initial inventories to the needs of modelling. Hopefully we can work with FFJMD to widen the information base, and we have time to dedicate to the project.

YIELD PLANNING AND CONTROL FOR SUSTAINABLE TIMBER PRODUCTION IN GHANA

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Abstract

The policy for natural forest exploitation within the forest estates of Ghana is that of sustainable management. In this connection, yield regulation is recognised as an essential component of sustainable management of the forest resources. Several approaches to yield control have therefore been tried in the past, often as a temporary measure until more information on forest dynamics can be obtained to improve the system. Some of these past methods, as well as the current yield regulation protocols are reviewed against the backdrop of the limitations that have rendered them impractical as tools for controlling over-exploitation of the forest resources. The development of a pan-tropical yield regulation system that uses the kind of minimal data that is often available from PSP programmes may enhance the effectiveness of these controls.

Introduction

Yield regulation is an integral part of forest management in Ghana, and various methods have been adopted in the past in an attempt to ensure sustainable management of the forest resources. This is in consonance with the dictates of the forest policy, which has the primary objective to:

'...Manage and enhance Ghana's permanent estate of forest and wildlife resources for preservation of vital soil and water resources, conservation of biological diversity and sustainable production of domestic and commercial produce.'

In this connection, efforts have been made over the years to evolve an efficient system for controlling the yields of forest produce in a way that would ensure the achievement of sustainable production.

These efforts have, however, been dogged by several limitations, principally borne out of the lack of adequate information. Nevertheless, the search for better methods continues, as more information becomes available with time.

In this paper, the evolution of the various methods that have been applied in the past is reviewed and the reasons for their failure are discussed. The current method in force is also discussed, together with the limitations inherent in its application.

Ghana's forest resource base

Ghana occupies a total land area of approximately 23.9 million hectares. About 34% of this total (8.23 million hectares) were closed forest at the onset of the present century (Sayer *et al.*, 1992). Currently, the permanent forest estate covers only about 1.63 million hectares of high forest, and 0.88 million hectares in the savannah zone.

The estimated national standing stock (Figure 1) in the high forest zone is 188 million cubic metres (Ghartey, 1989). For sustainable production, an annual allowable cut (AAC) of 1.1 million cubic metres, representing a 70% cut from an estimated total increment of 1.57 million cubic metres has been considered adequate. This AAC comprises 600,000m³ from the reserved forest and 500,000 m³ from off-reserves.

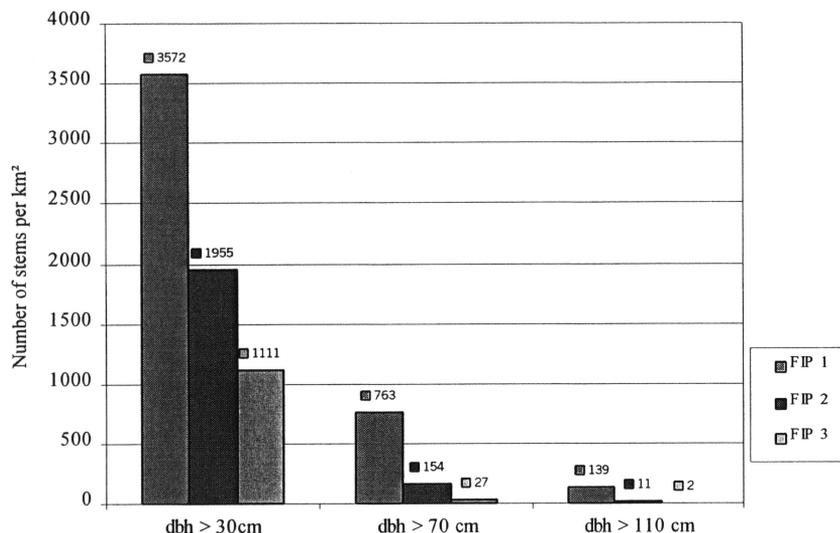


Figure 1. Summary estimates of stocking in the natural forests of Ghana.

FIP classes refer to export/utilisation potential of the species, their sizes and availability in the forest. Accordingly, FIP 1 refers to all species exported from Ghana between 1973 and 1988; FIP 2: - all species attaining 70 cm diameter and a frequency greater than 1 tree per km²; FIP 3: - all species not attaining 70 cm diameter or occurring at a frequency of less than 1 tree per km².

It is estimated (Aninakwa, 1996) that approximately 760,000 hectares of net productive area remain in the reserved forest estate for the production of timber. This area is expected to produce 600,000 m³ of all Class I species from a yield of 0.79 m³ha⁻¹yr⁻¹. But the 32 species that are actually harvested by concessionaires can yield about 300,000 m³, from an estimated annual yield of 0.40 m³ha⁻¹yr⁻¹.

It is the concern over a dwindling resource base, in spite of stringent efforts at regulating the yield over the years, which has accelerated the processes that would hopefully result in the development of a more efficient system for yield control.

Past yield regulation procedures in Ghana

Early attempts at yield regulation were by the time of passage system, mainly on a 25-year felling cycle. Yields were based on rough estimates of times of passage between one girth class and the next higher class, which could be the minimum exploitable girth. Time of passage was first calculated by Jack and Kinloch based on Girth Increment Sample Plot data from untreated forest for the various economic classes (Danso, 1975). But the increment data were not representative of typical growth rates, as they were generated from records obtained over very short periods. These earlier calculations were based on growth rates of up to 10 mm yr⁻¹, but more recent estimates show typical growth rates of 5 mm yr⁻¹ (Alder, 1989) for most high forest tree species.

In 1971, the salvage felling system was introduced on a 15-year felling cycle (Baidoe, 1976; Ofofu-Asiedu, *et al.* 1995). Essentially, this system was aimed at removing all over-mature, dead and dying trees in the selection forest to ensure that better forest regulation and silvicultural treatment protocols would be developed during the period. However, the objective of developing a new management and silvicultural system was not achieved, and the practice went into a second cycle until 1989, resulting in excessive canopy opening. All told, the system was not sustainable, as the prescribed yield tended to exceed the growth rate.

Four main yield regulation methods, mostly modifications of classical European methods for 'normal' forests, have been applied in the past and these are discussed in the following sections.

Yield regulation by area and basal area – the Kinloch method

This method involved the division of the working circle into annual coupes of nearly equal areas on a 25-year felling cycle and was known as the 'Kinloch Method'. In the absence of local volume tables or yield equations for the various species, basal area was the easiest means of expressing the yield. This, in itself, was not a serious limitation. The yield was calculated by predicting the increment accrued over the time of passage from a minimum breast height diameter (dbh) of 50 cm to a minimum exploitable dbh of 70 cm and 90 cm for the various species economic classes. The increment was calculated separately for each economic class and the yield equated to the increment of that class. Essentially, therefore, annual allowable cut was equated to the increment.

The deficiency in this method was that it was not based on reliable growth data. Also, mortality was neglected. Increment was calculated over two phases of the tree's growth cycle, i.e. from 50 cm - 90 cm dbh, and 90 cm - 150 cm dbh for the various economic groups of species, assuming the times of passage for the two growth periods. Therefore, the method had the tendency of retaining many over-mature trees in the forest. This resulted in the preponderance of over-mature trees, necessitating the introduction of salvage felling operations in 1971.

Yield regulation by area and girth limit

Another method was tried, which also allocated yield in basal area and assumed equal times of passage for all diameter or girth classes. Essentially, it was similar to the Kinloch method, the main difference being that it included a second minimum exploitable diameter for yield prescription. The annual coupe was determined on a felling cycle and time of passage of 25 years, without any consideration of mortality.

Adam (1989) has demonstrated that the method prescribed a slightly higher yield (about 10%) than the Kinloch method, and the yield for the next felling cycle was about 5% lower. Consequently, the tendency was to over-cut the forest if the stocking was irregular, as the method actually resulted in the removal of all trees above the minimum exploitable diameter instead of the increment. On the other hand, if the stocking was regular, yield tended to be confined to the minimum diameter and the next higher class. In effect the yield was likely to fluctuate, especially as increment was not taken into account. The management implication of this deficiency was that the prescribed yield was either high or low depending on whether the actual time of passage from one girth class to the other was longer or shorter than 25 years.

Yield by number of stems – Kadambi’s formula

A third method of yield regulation that was applied in the past was referred to as Kadambi’s formula. This method allocated yield in terms of number of stems, and assumed an equal time of passage of 30 years for all trees, using a diameter class interval of 20 cm for trees of 50-cm dbh and above. A survival rate of 75% was also assumed for trees moving from one diameter or girth class to the next.

Kadambi’s formula was a variation of the Hufnagl yield formula, which allocated the yield for a diameter class by multiplying the number of stems in that class by the average volume. Owing to the absence of volume tables for the various species at the time, the average volume was not factored into the modified formula. Yield for the subsequent felling cycle was predicted by Brandis’ method.

As indicated by Adam (1989), Kadambi’s method prescribed a higher yield in the first cycle than the two other methods discussed above. The value of the method depended on the accuracy in the time of passage and the survival percentage assumed. A comparison of the yield prescribed by the three methods discussed so far is presented in Table 1.

Table 1. Comparison of the yield prescribed by the Kinloch, Girth limit and Kadambi methods based on stocking data from an annual coupe of 7.25 km² in Asenanyo Forest Reserve, Ghana (after Adam, 1989).

| Method of calculation | 1 st felling cycle | | 2 nd felling cycle | |
|-----------------------|-------------------------------|---------------------------|-------------------------------|---------------------------|
| | No. of stems | Basal area m ² | No. of stems | Basal area m ² |
| Kinloch | 299 | 273.69 | - | - |
| Girth limit | 261 | 301.89 | 290 | 286.74 |
| Kadambi | 350 | 360.24 | 255 | 187.18 |

Salvage felling

In 1971 it became necessary to remove the large number of over-mature trees in the forest. The ‘yield’ therefore comprised all trees larger than the minimum felling girth by 30 cm. It was intended to last over a period of 15 years, but was carried over into a second cycle, without any regulation of the yield prescribed. The management implication was that the removal of over-mature trees would create room for the suppressed under-canopy trees to enhance their growth.

The limitation of this method was that it was applied without taking into account the diameter distribution of species or their increment; neither was there any provision for the retention of seed trees. This situation not only resulted in the creaming of the forest, but also led to the loss of genetic quality and biodiversity.

Current method of yield planning and regulation - the interim yield formula

In the early 1990’s, efforts were made to revise these earlier systems of yield control, with the aim of ensuring that the forest would be cut at a more sustainable level by regulating the intensity of exploitation. However, the lack of reliable growth and yield data continued to impose limitations on the development of a yield control system that was based on a well-researched understanding of forest dynamics. Therefore the revised formula was considered as an ‘Interim Yield formula’, pending

the availability of better growth data from the re-designed PSP programme.

The interim yield formula is based on a 40-year felling cycle, a period considered adequate for the forest to recover sufficiently from harvesting to allow sustainable removals in the next cycle. The number of trees to be removed is regulated by minimum diameter limits. The formula limits the number of trees of each FIP class 1 species to ensure that only the growth achievable within the 40 year felling cycle is removed.

Two variants of the formula are applied, depending on the species' availability and the vegetation zone in which they occur. For Red and Pink star species² in the wetter forest (i.e. wet evergreen (WE), moist evergreen (ME), moist semi-deciduous south-east (MSSE) and moist semi-deciduous north-west (MSNW) vegetation zones), the normal formula is applied as follows:

$$Z = 0.2X + 0.5Y \quad (1)$$

For scarlet star species in the drier forest (DS) zone a reduced formula is applied to increase the retention. The objective is to allow stocks of over-exploited species and those in fire-prone and degraded forests in the transition zone to build up. The reduced formula is:

$$Z = 0.2X + 0.25Y \quad (2)$$

Where Z is the number of trees above the felling limit to be harvested, X is the number of trees in the 20-cm size class immediately below the felling limit and Y denotes the number of trees above the limit. If Y is less than Z the yield is reduced to Y-2 to allow for the retention of a minimum of two seed trees per compartment of approximately 128 hectares (Wong 1995). Table 2 demonstrates the use of these formulae as applied to stocking data from a forest reserve.

A recent modification to the method is the introduction of a forest condition score from stock survey data. Scoring is done in each compartment at 60-m intervals on a scale of 1 to 6 during a 100% stock survey, indicating the general condition of the forest (1 = Excellent, 2 = Good, 3 = Partly degraded, 4 = Mostly degraded, 5 = Very poor and 6 = Not forest). This shows whether the forest is well stocked or generally degraded, and moderates the levels of harvesting in a particular compartment, depending on its suitability for exploitation.

A rule of thumb, which is also applied in allocating the yield, is that a maximum of 3 and 2 trees per hectare should be taken from the wetter and drier forests respectively, with a retention of 40% seed trees per compartment to facilitate regeneration of the forest.

² The conservation priority or action category on all species is expressed as star ratings based on their distribution (locally and globally), ecological, commercial, social and taxonomic details (Hawthorne and Abu-Juam, 1994; Wong, 1994). Scarlet star species are species which are common but under serious threat of depletion from exploitation, for which reason exploitation needs to be curtailed to ensure sustainable management. Protection of these species is therefore vital on all scales. Red star species are similarly threatened and careful control of exploitation is imperative. Pink star species are significantly exploited, but not at such a rate as to cause concern for their economic future.

Table 2: Calculation of the yield from stock data from Compartment 21 in Boi-Tano Forest Reserve, Ghana, using the IYF for species with felling diameter limits of 110 cm and 90 cm. The shaded portion shows the felling limit class.

| Felling limit 110 cm | | | | | | | | | | | |
|----------------------|-----------------------------|-------|------------|------------|------------|-----------|-----------|------------|------------|----------------|--------------|
| SPECIES | Diameter Class Distribution | | | | | | | Values | | Selected yield | |
| | 30-49 | 50-69 | 70-89 | 90-109 | 110-129 | 130-149 | 150+ | Y | X | Normal | Reduced |
| | | | | | FL | | | | | | |
| ANT | | | | 2 | | | | 0 | 2 | 0.4 | 0.4 |
| CAN | | | | 3 | 8 | 7 | 1 | 16 | 3 | 8.6 | 4.6 |
| CP | | | | 1 | | | | 0 | 1 | 0.2 | 0.2 |
| DO | | | | 47 | 49 | 39 | 22 | 110 | 47 | 64.4 | 36.9 |
| EA | | | | | 1 | | | 1 | 0 | 0.5 | 0.25 |
| KI | | | | 2 | 4 | | | 4 | 2 | 2.4 | 1.4 |
| LOP | | | | 13 | 8 | 9 | | 17 | 13 | 11.1 | 6.85 |
| MIL | | | | 2 | 4 | | | 4 | 2 | 2.4 | 1.4 |
| NAU | | | | 11 | 15 | 10 | 8 | 33 | 11 | 18.7 | 10.45 |
| RHI | | | | | | | | 0 | 0 | 0 | 0 |
| TIE | | | | 6 | 11 | 7 | 9 | 27 | 6 | 14.7 | 7.95 |
| TOTAL | | | | 87 | 100 | 72 | 40 | 212 | 87 | 123.4 | 70.4 |
| Felling limit 90 cm | | | | | | | | | | | |
| Species | 30-49 | 50-69 | 70-89 | 90-109 | 110-129 | 130-149 | 150+ | Y | X | Normal | Reduced |
| | | | | FL | | | | | | | |
| AFZ | | | 8 | 9 | | | | 9 | 8 | 6.1 | 3.85 |
| ALZ | | | | 1 | | | | 1 | 0 | 0.5 | 0.25 |
| AMP | | | 29 | 20 | | | | 20 | 29 | 15.8 | 10.8 |
| AMI | | | | | | | | 0 | 0 | 0 | 0 |
| DIA | | | 54 | 36 | | | | 36 | 54 | 28.8 | 19.8 |
| DIS | | | 7 | 6 | | | | 6 | 7 | 4.4 | 2.9 |
| GC | | | 1 | | | | | 0 | 1 | 0.2 | 0.2 |
| GT | | | 2 | 3 | 1 | | | 4 | 2 | 2.4 | 1.4 |
| HAN | | | 18 | 26 | | | | 26 | 18 | 16.6 | 10.1 |
| KLA | | | 18 | 17 | | | | 17 | 18 | 12.1 | 7.85 |
| LOV | | | 13 | 15 | 7 | | | 22 | 13 | 13.6 | 8.1 |
| MIC | | | 8 | 12 | | | | 12 | 8 | 7.6 | 4.6 |
| PAR | | | 28 | 13 | 3 | | | 16 | 28 | 13.6 | 9.6 |
| PEM | | | 21 | 13 | 1 | | | 14 | 21 | 11.2 | 7.7 |
| TI | | | 6 | | | | | 0 | 6 | 1.2 | 1.2 |
| TS | | | 4 | | | | | 0 | 4 | 0.8 | 0.8 |
| TOTAL | | | 217 | 171 | 12 | 0 | 0 | 183 | 217 | 134.9 | 89.15 |

The principal limitation of the Interim Yield Formula (IYF) is that it does not take into account tree growth rates, mortality, recruitment or other influences such as logging damage and its effects on regeneration. The introduction of the forest condition score was expected to compensate for this deficiency by minimising possible degradation of the forest.

Sustainability of the Interim Yield Formula

As Alder (1995) points out, a sustainable harvest is one that can be repeated indefinitely. The IYF has undergone several reviews (e.g. Vanclay 1993, Foli 1994, Alder 1995, Wong 1995) to test its sustainability. Not surprisingly, varying

conclusions have been drawn from these reviews. For example, Foli (1994) demonstrated that the IYF, variable between ecological guilds and star groupings, is generally sustainable when evaluated against Alder's (1992) simple spreadsheet technique for estimating yield over two felling cycles (Table 3). A sensitivity analysis of the latter method showed that yields are stable for mortality rates up to about 2.5%, after which the number of trees per km² declines (Figure 2). However, Vanclay's (1993) approach using de Liocourt's quotient, Q , to test whether the stand could sustain a second cut (Table 4) showed the IYF to be generally unsustainable (Wong 1995).

Alder's (1995) analysis of more current PSP data suggests that the critical de Liocourt's quotient values used by Vanclay are optimistic. He contends that Vanclay's analysis was based on optimistic assumptions of growth and mortality rates of 0.72-cm yr⁻¹ and 1.04% respectively from the old series PSP data, which were fraught with inaccuracies. From the sensitivity analysis in Figure 2 however, it appears that the mortality rate of 1.04% assumed by Vanclay would not make any significant difference to the yield. Vanclay also assumed that 80% of advanced growth would survive logging damage. Alder has suggested alternative critical sustainable Q values for different species groups from the new PSP data set and suggests an alternative formula, based on the PSP results. This has been discussed in some detail in his report (Alder 1995), to which the reader is referred.

Suffice it to say, however, that this alternative formula takes into account sustainable Q values, recruitment, mortality, retention, *etc.* It is obvious that this can not be realistically applied for management purposes until more information on these parameters can be obtained from an improved PSP data set with a logical relationship to increment and mortality rates. Alder emphasises the practicality of using this method at the district level by means of simple management tables that can be applied to stock survey summaries for estimating sustainable yield.

Table 3: Calculation of sustainable yield by the spreadsheet method (After Alder (1992)).

| Felling cycle | +80 yrs | +40 yrs | Present | Oversize |
|--|---------|---------|--------------------|----------|
| Present diam class | FI-40 | FI-20 | Felling limit (FI) | FI+20 |
| Stocking (N km ⁻²) | 289 | 39 | 11 | 35 |
| Survival % | 36 | 60 | 100 | 100 |
| Final stocking (F) (N km ⁻²) | 104 | 23 | 11 | 35 |
| Accrual from last cycle (A) | 0 | 8 | NA | NA |
| Harvest (Y) | 32 | 32 | 8 | 24 |
| Retained trees (R) (N km ⁻²) | 72 | 0 | 3 | 11 |

Alder's spreadsheet method (Alder, 1992) is based on the following assumptions and algorithms:

- A tree will grow through a 20-cm diameter class in 40 years. Inventory data are compiled into 20-cm classes, indicating trees that will be available in present and succeeding felling cycles.
- An annual mortality rate of 1.25% is assumed for trees of 20 cm or above. Over a 40-year felling cycle, this corresponds to a survival rate of $(1-0.0125)^{40}$ or 60.5%.
- By applying the survival rate to inventory data a final stocking at the time of harvest can be estimated. An iterative trial-and-error technique is then employed to calculate the number of trees to be felled which corresponds to uniform production for each cycle.

The stand table is organised into a spreadsheet by diameter class columns, each corresponding to a single felling cycle as above. The survival % is applied to the stocking to obtain the final stocking (F) at the time of harvest. Any accruals (A) from the previous cycle are added to the final stocking. The suggested harvest (Y) is subtracted from the sum (A+F) to determine the retention (R) from the harvest; i.e. $R = (F + A) - Y$. The harvest (Y) is adjusted iteratively to allow the spreadsheet to recalculate the values of R and A until R becomes negative. At this point Y is reduced fractionally until R just becomes zero. This value of Y represents the maximum sustainable yield.

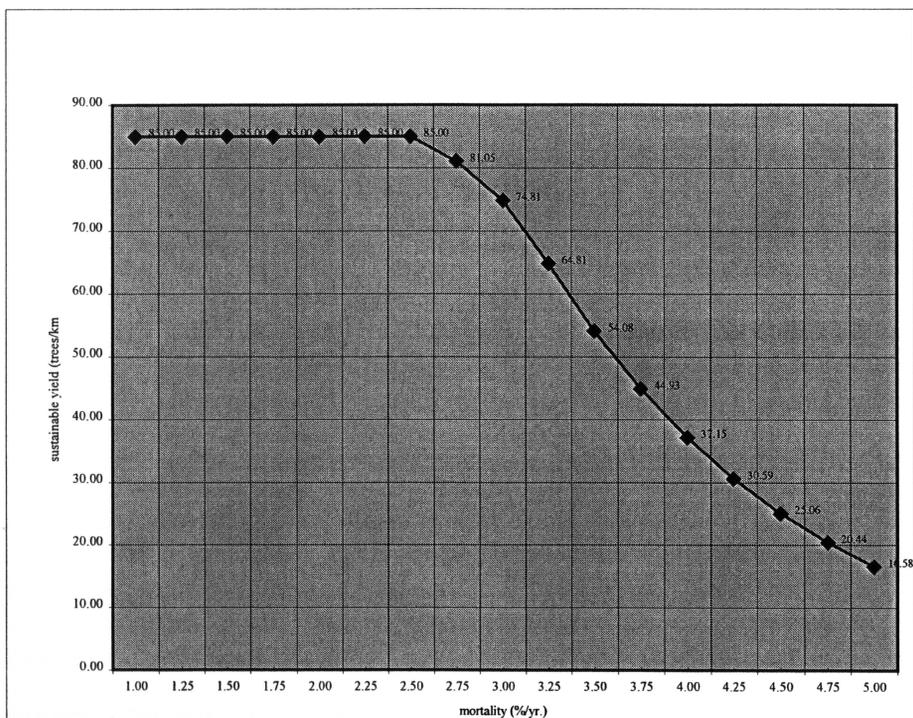


Figure 2: Sensitivity of timber yields to mortality rate (Foli, 1994).

Table 4: Evaluation of the sustainability of the Interim Yield Formula (Wong 1995).

| Star groupings | Guild | IYF (trees/km ²) | Alder's method | de Liocourt's Q |
|----------------|---------------|------------------------------|----------------|-----------------|
| Scarlet | Pioneers | 24.52 | + | - |
| | NPLD | 16.86 | + | - |
| Red | Pioneers | 22.67 | - | - |
| | NPLD | 46.74 | + | - |
| | Shade-bearers | 5.84 | - | + |
| Pink | Pioneers | 64.76 | + | - |
| | NPLD | 97.55 | + | + |
| | Shade-bearers | 150.87 | + | + |
| Total | | 429.81 | + | - |

Note: + sustainable; - not sustainable

Conclusion

The above scenarios show that conscious efforts have been made at evolving a practical method for determining timber yields that would be sustainable. But the major setback has been the lack of adequate data. Even though a great deal of data have been generated through the Forestry Department PSP programme, the inadequacies associated with the data have not made it possible to get sufficient information on growth rates, mortality and recruitment. Without these important parameters, it would be difficult to make any reliable estimates of yield.

Several improvements have been suggested, exemplified by Alder's approach discussed above. But until reliable growth, recruitment and mortality data become available it would not be practical to implement them. For these reasons, the concept of developing a pan-tropical yield regulation system that can be applied with minimal data is not only important, but also timely. Such an approach can, at least, control the rate of exploitation or forest loss associated with inaccurate yield regulation methods that tend to over-cut the forest. And, until more reliable information becomes available for fine-tuning, the many useful but impractical approaches that have been employed in the past, a simplified approach that would at least ensure that the forest is not over-exploited would be an invaluable means of minimising the rate of resource depletion.

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YIELD PLANNING AND REGULATION IN THE COMMERCIAL HARVESTING OF TROPICAL MIXED FOREST.

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Yield regulation in a commercial context.

Responsible forest managers need to know if the rate of resource extraction from a given area of forest is sustainable. Sustainability is poorly defined, but does imply a systematic approach to optimising resource utilisation over the long term. If forest managers are to harvest sustainably they need a systematic process by which concepts of yield regulation are included within strategic planning and daily operations.

Before committing capital a commercial forestry enterprise needs an estimate of the available yield that may be expected over the short term, and for long term projections an estimate of the cutting cycle and expected resource availability at the end of the first cycle.

Uncertainty over cutting cycle and available yield leads to inefficient resource allocation. This is a major constraint to achieving sustainable utilisation.

Harvesting companies equate uncertainty of available yield and cutting cycle with risk. To attract investment in timber extraction where the value of the resource is poorly known, it may be necessary for government to offer lower rental or greater incentives to the harvesting company. This implies a reduced level of rent capture. In addition, risk dissuades capital investment so that companies may be less inclined to invest in relatively expensive, but efficient, new machinery or highly skilled labour.

For a commercial harvesting operation to be sustainable in the long run, accurate estimation of allowable cut and cutting cycle is vital during the pre-investment feasibility phase. After capital investment there will be strong incentive to match harvesting rates to planned capacity to ensure adequate return on capital employed. This is especially true where there is high capital investment such as installation of processing plant.

Issues: Limitations

Commercial tropical timber harvesting operations usually operate with limited information of poor quality that does not facilitate efficient and effective management planning.

Information on the tropical forest resource is often difficult to capture. Poor access, heterogeneity of tropical forest, and absence of historical data combine to create significant obstacles to the collation of important and theoretically simple data, such as land area by forest type.

Information gathering and the provision of facilities for data analysis and input into management implies a range of skills and capacities that may not be perceived as

core to the activities of commercial operations. In many cases the skills associated with accurate data collection and processing are absent. Even though systematic approaches to management, with planning, implementation, and monitoring are key to efficient management, they can be difficult to develop where there is limited availability of trained operators and supervisors and poorly developed information systems. Manifestations of these limitations include high log waste rates, poor roading designs, inefficient skid trail layout and high unit costs.

The process of data collection requires skills that may not be associated with a traditional harvesting operation. In a simple example, a chainsaw operator who is required to tag and record trees he fells to reduce wastage requires literacy and numeracy skills, an ability to understand and manage the process, and a capacity to analyse data sets to identify and rectify mistakes. A consequence of changing his job specification is that the operator must acquire a new set of skills. For people who have little experience of management or paper based problem solving, some of these skills may be completely outside their previous experience.

Issues: Requirements

Commercial operators are required to make regular decisions on rates of extraction, which by implication affect the long term sustainability of the stand. In the absence of a clearly defined understanding of the response of mixed tropical forest to harvesting, regulation is based on criteria (e.g. minimum diameter felling limit) which are quantified on the basis of rules of thumb. If criteria and the quantified limits are poorly selected or defined there is a danger that: they may not actually directly affect long term sustainability of the forest in a predictable way; they may be combined with assumptions that are not be valid; and they may be misinterpreted in management planning. What is needed is guidance on developing a system of yield regulation that is both systematic and flexible, where criteria and their quantification have rational foundation. This is especially true in developing estimates of acceptable extraction intensities (or acceptable composition of the residual stand).

The long-term sustainability of the forest is dependent on the state of the forest after harvesting, rather than what is removed. Although quantified measures of what was extracted may provide a rough guide to the state of the post harvest stand, which may be helpful in desk top assessments, yield regulation should focus on assessing the state of the forest post harvest rather than what was removed. It is also important that monitoring of the prescriptions is within the capacity of the monitoring teams. It is, for example, much easier to count the number of trees standing in an area than to assess the standing volume.

If yield regulation is to be a feature of standard working practice, the guidelines need to be understood by operators and supervisors, the harvesting operation must be monitored against the yield regulation prescriptions, and findings must feed back into management. Simplicity of guidelines are important if understanding, enforcement, and monitoring are to succeed. Well defined procedures for data handling and information flow are necessary if management is to respond to the results of the monitoring process.

The objective of yield regulation needs to be kept in mind before developing guidelines or modelling changes in the forest. It is likely that objectives will include assessment of the sustainability of forest management, which itself has social,

environmental and economic components. Assessment of social sustainability may incorporate long term access to NTFPs, relative species mix may be an important environmental issue, and volume of merchantable logs at some point in the future may be important in assessing economic sustainability. These elements will each require different data sets and may require rather different analytical processes.

Sustainable forest management encompasses a wide range of operations and planning tools. The long-term sustainability of the forest is dependent on the condition of the forest after harvesting. Minimising damage to the residual stand is the key in this respect, and this is to a large part dependent on harvesting technique, training and supervision. Encroachment, shifting agriculture, and mining can all have significant impacts on sustainable forest use. Yield regulation is one element in the process of sustainable forest management, and growth modelling is one way to determine yield regulation.

Forest managers routinely discuss issues of yield regulation and resource availability but it is generally not formalised in terms of 'growth and yield regulation'. Although the concepts are familiar they may use different terms and have a different perspective to researchers. Concepts of growth and yield will be more readily accepted by these groups if they are introduced in familiar terms.

Investors, forest managers, land use planners and policy makers have different needs and priorities. For a new tool to be used, the user must have perceived a need to change in order to adopt it. It will be important to identify the context in which target groups operate, their needs and constraints, and to market the product effectively if it is to be adopted. Although GIS could provide significant benefit to forest managers, it is currently greatly under-utilised in commercial tropical forest management as many companies have not made the step of identifying a need to adopt GIS technology.

Options

Depending on the sophistication of the operation, and the quality of data available, a number of different methods of estimating cutting cycle may be appropriate. For an operation that has already begun, simple visual representation of areas harvested to date within the total concession area will give an idea of the proportion of area harvested in a given period and hence total cutting cycle. Similarly, where production data is available, calculations of productivity per unit area harvested to date and area remaining can provide useful guides to rotation length. Calculations need to be systematic if they are to incorporate correctly the key factors which affect cutting cycle. Calculations should include sensitivity analysis (worse case and best case scenarios) to determine influence of erroneous measurements or assumptions on calculations. Table 1 gives an example of an area statement used to estimate cutting cycle. Note the influence of 'pessimistic' and 'optimistic' 10% variations on the cutting cycle estimate.

Decision makers will have access to different levels of information. Maximum benefit will be derived if some analysis is possible for those with no data, and increasingly sophisticated analysis available for those with more data. Planners with no data would benefit from insight into growth rates and stocking densities which might be reasonably anticipated, and priorities for data to collect. For those with area statements and species lists additional analysis should be possible (e.g. better

defined growth rates). Inventory and long term PSP data should enable more subtle analysis.

Even very general, but accurate, estimates of the anticipated growth and future yield of the forest is of value. Broad indications of rotation length, for example, is the forest going to recover in 25, 50 or 100 years, or some general indication of future stocking levels, for example, high, medium or low, would provide useful signposts for planning. Over these time scales more precise estimates are vulnerable to other changes, *e.g.* national land use policy, timber markets, illegal encroachment. Where other data, such as area statements, are inaccurate the value of predictive models will be limited by these data.

Yield regulation of tropical mixed forest will not be brought about through provision of technical fixes alone. Even if decision makers are not able to reach a definitive conclusion on growth or yield regulation rational, decision making should evolve from developing a clear understanding of those factors which impact and how they affect estimates. This implies that learning and experimentation will be a key part of the process. Key information that will assist those taking these steps will be:

- Distillation of the current state of knowledge on forest growth in a manner that is brief, accessible and clear to non-technical foresters.
 - A systematic framework of steps to follow in setting yield regulation limits and in estimating cutting cycles.
 - A systematic framework for monitoring of operations against limits.
 - Guidance on key empirical rules of thumb on forest stocking and growth rates and their application in growth and yield estimation.
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Table 1. An example of a concession area statement used to estimate cutting cycle. Harvesting began 1993.

| Area statements (ha) | | Optimistic +10% | Pessimistic -10% |
|---|------------------------------------|--------------------|--------------------------------|
| Total concession area | 334,002 | 367,403 | 300,602 |
| Indigenous land claims | 21,407 | 19,267 | 23,548 |
| Biodiversity reserves | 23,445 | 21,101 | 25,790 |
| Other land use | 6,713 | 6,042 | 7,384 |
| Gross harvested area | | | |
| 1993 | | 2,500 | |
| 1994 | | 4,300 | |
| 1995 | | 4,320 | |
| 1996 | | 3,320 | |
| 1997 | | 4,200 | |
| 1998 | | 5,100 | |
| TOTAL | 23,740 | 23,740 | 21,366 26,114 |
| Total unharvested gross area remaining at | 258,697 | 299,628 | 217,766 |
| Assumptions and allowance for error | | | |
| Additional unharvestable | 20% | | |
| Mapping error, unproductive, mining losses | 10% | | |
| TOTAL | | 89,888 | 65,330 |
| Adjusted gross productive area at 31.12.98 | 181,088 | 209,739 | 152,436 |
| Average gross area harvested 1993-1998 | | | |
| Model | | | |
| At gross area harvesting rate of | 3,957 hectares per year for future | 3,561 | 4,352 |
| Rotation length remaining | 46 years | 59 | 35 |
| Total rotation length | 52 years | 65 | 41 |

GROWTH AND YIELD MODELLING IN PENINSULAR MALAYSIA: A CASE STUDY, STATUS AND PROBLEMS

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Summary

Growth plots to monitor the growth and diameter increment of trees were established as early as 1901 in Peninsular Malaysia however these plots were invalidated later due to non-conformity of measurements. The first endeavour to study growth and yield in Peninsular Malaysia was only started in 1974 when the first permanent sample plots (PSP) were established. The first PSPs in Peninsular Malaysia for this purpose were set up at Terengganu. The study was initially conducted to investigate the economic and silviculture implications of forest management under various cutting intensities and cutting regimes. For this purpose, about 150 ha of PSPs in hill forest were established. Other than that, many more such study areas were established in various parts of Peninsular Malaysia so as to cover the major different forest type of the country.

The concept of growth and yield modelling is indeed new in Malaysian forest management. For Peninsular Malaysia, except for several isolated studies, there is no growth and yield model available that has been used in the current management system. Several documented studies before are FORSTAM, Linear Regression, Individual Tree Distance, Log Production Models, GandY Functions, STANDPRO, DIPSIM, FORMIX and Single Tree Model. The only growth and yield model in Malaysia is DIPSIM (A Dipterocarp Forest Growth Simulation Model for Sabah) and STANPRO (Stand Projection Model for Sarawak). DIPSIM was developed in 1994, and purposely formed for Sabah's mixed dipterocarp. Currently DIPSIM is being modified before it can be used in Peninsular Malaysia. Problems encountered in growth and yield studies in Peninsular Malaysia can be divided into four aspects namely: nature of the forest, management operation, permanent sample plot management and data analysis and modelling aspects.

A case study on growth and yield models (individual tree and plot scale) is developed for a permanent sample plot data set established and re-measured over a 15 year period. The models predict that the next harvest will consist primarily of non-Dipterocarp species, due to high mortality of residual Dipterocarps and low recruitment. A sensitivity analysis indicates that the mortality rate has the biggest influence on the forecasts, and obtaining more precise estimates of mortality is needed. Because the mortality for Dipterocarps was still high (3-4%) up to 10 years after logging, mortality models fitted using these data may be overestimating future mortality, as there is evidence that the mortality drops to 1 or 2 percent by the 15th year. Nevertheless, the observed high levels of mortality during years 1-10 are real and result in considerable reduction in the stocking of Dipterocarps in the stand. This indicates that the effects of harvesting may last over longer time periods than previously thought.

This paper reports the status of growth and yield modelling in the country, and its related problems. A case study that presented the results from growth and yield plots managed by FRIM is also highlighted.

Introduction

Growth and yield prediction strategies are important components in the management of tropical mixed forests in Peninsular Malaysia. To manage better about 2.78 million ha of its productive forests within 4.88 million ha of permanent forest estate, accurate data and projections of the ability of forest to grow and yield is important to outline the management strategies in the efforts to achieve the state of sustainable forest management. This is due to the fact that central to sustainable

forest management is knowledge of the growth and yield of the forest over time and permanent sample plots are often the means used to collect this information. Studies on growth and yield were initiated as early as 1901 (Revilla, 1980), however, until now the information gathered through those earlier studies has little been incorporated into forest management, especially when most of the forests are in hilly and higher elevation areas.

As in other tropical countries, Malaysia also is weak in this discipline even though many plots have been established and a huge amount of data have been collected. The main reason for this is that many of the old plot no longer exist as most of them were located in lowland forests which have been excised to other land uses. As forest management moves to higher elevations with different forest ecosystems, efforts have been made to establish series of permanent sample plots in newly managed areas. Yong (1997) reported the establishment and some preliminary results of the data analysis of these plots. Since most of the plots were established after 1973, the data are found to be limited for management application.

This paper reports the status of growth and yield studies in the country, and its related problems. The results of a case study from growth and yield plots managed by FRIM is also highlighted.

Growth and Yield Studies Status

Even though many efforts has been initiated in the early 1900s, the first endeavour to study growth and yield in Peninsular Malaysia was only started at 1973 when the first PSPs were established under the UNDP/FAO Project. The first PSPs in Peninsular Malaysia for this purpose were set up in the State of Terengganu. The study was initially conducted to investigate the economic and silvicultural implications of forest management under various cutting intensities and cutting regimes. For this purpose, about 150 ha of PSPs in hill forest were established. Other than that, more study areas were established in various parts of Peninsular Malaysia so as to cover the major different forest type of the country. In 1982, a series of 11 growth and yield plots were established under the ITTO FD Project to test the growth behaviour of several forest stands under different harvesting intensities. FRIM joined the bandwagon by establishing 36 plots in two forest reserves to test different harvesting methods and intensities. On top of that the Forestry Department has established about 46 continuous forest inventory plots throughout the country to incorporate them with the National Forest Inventories carried out every 10 years .

The concept of growth and yield is indeed new in Malaysian forest management. Many of the previous efforts are only study based models. Furthermore they are confined to specific sites or forest stand. Currently, there is no specific growth and yield model developed that has been used in the management of tropical mixed forests in the country. The only growth and yield model in Malaysia is DIPSIM, A Dipterocarp Forest Growth Simulation Model for Sabah (Ong and Kliene, 1997) and STANPRO -Stand Projection Model for Sarawak (Korsgard, 1988). DIPSIM was developed in 1994, specifically for Sabah's mixed dipterocarp forest.

The first attempt to develop a computer simulation model was under taken by Salleh (1997) who developed a preliminary forest stand management model (FORSTAM) to simulate the tropical forest stand under management. The model took

consideration of the cutting regime, silvicultural system and logging system as part of management strategy and alternatives and determines their impacts on forest stand.

Borhan (1985), developed a linear regression model to predict the growth of a selectively cut dipterocarp forests in Labis F.R. , Peninsular Malaysia. He found that the total standing basal area and volume of trees and above, immediately after harvest, were the best independent variables to predict the standing basal area and volume yield four years after harvest.

Individual tree distance independent models were developed by Wan Razali (1986) to model the diameter increment and mortality of the mixed tropical forest of P. Malaysia. He used linear and non-linear models in his study.

In 1990, comprehensive growth and yield functions were developed (Yong 1990). In this study, growth functions by species groups and diameter limits for three stand variables (number of stand, basal area and gross volume) were developed and used to predict the future yield of all trees with a 30 cm and larger diameter.

Based on a stand table projection model developed by Kofod (1982) for the state of Sarawak, Korsgard (1989, 1995) had improved and adapted the model for use in Peninsular Malaysia. The projection is based on an initial stand table and is projected over one or more periods and the effects of harvesting damage and silvicultural treatments on growth simulated.

Currently the DIPSIM is being modified and adopted to Peninsular Malaysia based on the original DIPSIM developed for Sabah State. This individual tree based model can be used to model the annual growth in term of number of stems, basal area and volume. The model can be used to determine stand dynamics for periods of up to 60 years and the effects of different harvesting prescriptions to provide support for decisions in yield regulation.

A case study

In 1979, 18 permanent sample plots were established in Compartment 5A, Tekam Forest reserve in the state of Pahang, Peninsular Malaysia. The study areas were logged and immediately after logging, eighteen one hectare plots were established. In each plot, data were collected for each tree greater than 10 cm in diameter including diameter at breast height (dbh) and species. Measurements were made each year after logging for the first five years and at 2-3 year intervals afterwards, spanning a 15 year period (1980, 1981, 1982, 1983, 1984, 1985, 1987, 1989 and 1994). For the purpose of this paper the species level data has been aggregated into separate analyses for three tree groups; all Dipterocarps, all commercial non-Dipterocarps and the remaining non-commercial species.

Growth and Yield models are explored for data from logged over Dipterocarp forests at two scales: predicting the diameter growth, percentage mortality and number of recruits for individual trees per hectare per year and predicting the growth, mortality and recruitment in terms of basal area per hectare. The data for model fitting consists of all trees 10 cm dbh and above in the 18 growth and yield plots.

Individual Tree Model

For the individual tree model, growth is expressed as diameter increment (cm/yr) as a function of plot basal area with separate increment functions for dark red meranti, light red meranti, white/yellow meranti, non-meranti heavy hardwoods, non-meranti medium hardwoods, non-meranti light hardwoods, non-Dipterocarp heavy hardwoods, non-Dipterocarp medium hardwoods, non-Dipterocarp light hardwoods, non-commercial species. Separate mortality rates (percent/ha/yr) are used for Dipterocarps, non-Dipterocarps, and all non-commercial trees (Figure 1 and 2) and are modelled as a function of plot basal area. Mortality is modelled as the proportion of trees in each group that die per hectare per year as opposed to modelling the probability that each individual tree will die. Recruitment is modelled as number of trees/ha/year entering the 10 cm dbh size class as a function of plot basal area, and group basal area, where the groups are the same as mentioned above for the diameter increment functions. Volume is computed using volume-diameter equations for the different groups that were developed elsewhere (Anon, 1996). The procedure for forecasting begins by computing the total basal area and basal area per group per hectare from an input stand table or from the previous years' forecast. These two values are then used in the prediction equations to compute growth increments, mortality rates, and recruitment counts for the year. Then, the number of 10 cm trees that are predicted to be recruited are appended to the list of trees, trees are removed from the list by randomly selecting trees from each group for mortality according to the specified proportions, and the diameters of the remaining trees (except for those just recruited) are increased according to the predicted growth increments. Once the tree list has been updated in this manner, estimated volume is computed and saved, the total basal area per hectare and group basal area per hectare is re-computed and the process is repeated.

The fitted equations for diameter increment, mortality rates and recruitments are shown in Appendix I.

Simulation Results

Results of simulation are given in Figures 1 and 2 at different mortality rates. The results using these fitted equations give dismal results. In particular the volume for Dipterocarps is predicted to decline for an additional 60 years after logging. It is evident that the estimated mortality rate is the major cause of this model behaviour. As an illustration, the fitted mortality rate for Dipterocarps (which ranged between 3-4 percent per year) is replaced by a fixed rate of 1 percent and the forecasts recomputed. The result under this scenario is an increase in basal area over the same time period. This illustrates the need for having good estimates of the long-term mortality rates for Dipterocarps. The results of Wan Razali (1987, 1988) are based on longer term data sets. He models the probability of mortality of individual trees over a seven year period as a function of tree and stand attributes, rather than modelling the proportion of trees that die in each species group. For this application, the predicted mortality using his results is adjusted from a seven year mortality rate to an annual mortality by raising the mortality to the power of 1/7. The result is an increase in Dipterocarp volume over the 25 year forecast period and a decrease in the commercial non-Dipterocarp volume.

Plot Scale Model

For the plot scale model, growth, mortality and recruitment are modelled as the gain,

loss and gain in basal area per hectare per year for all Dipterocarps, non-Dipterocarps and non-commercial trees, so the entire system is governed by these nine equations.

Simulation Results

The results using the plot scale model indicate that the Dipterocarps will maintain their present level of basal area occupancy over the next period (the model actually predicts a slight rise and fall) and the commercial non-Dipterocarps and the non-commercial species will increase in basal area considerably (Figure 3). The model predicts that the forest will become a primarily non-Dipterocarp forest, but with 40% of its basal area consisting of non-Dipterocarp trees of commercial value.

GAUSS Thu Jan 8 15:10:01 1998

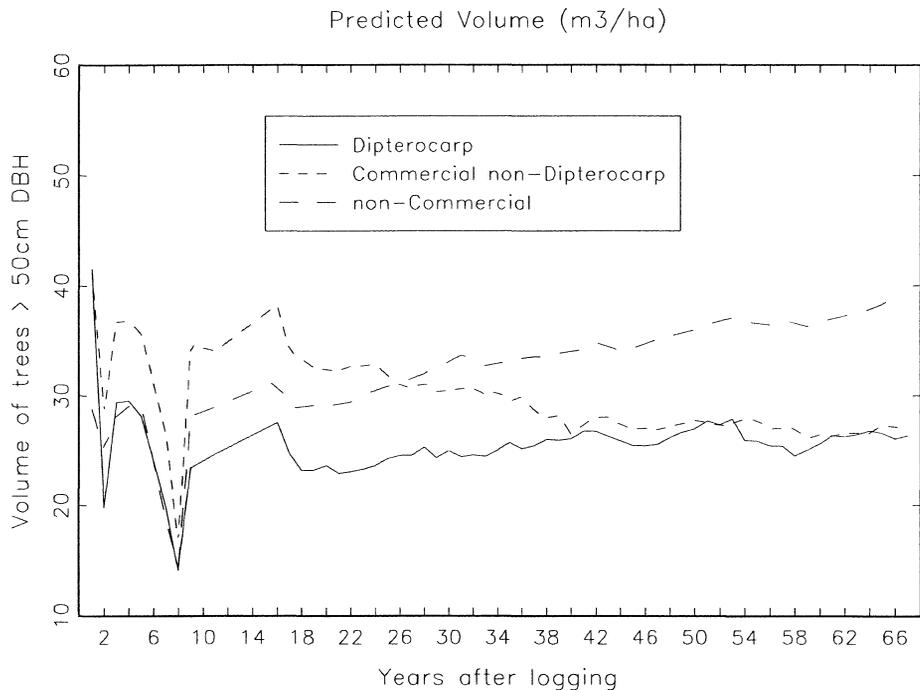


Figure 1: Forecasts using fixed mortality rates of 1.5% for Dipterocarps, 2% for Commercial non-Dipterocarps and 2.2% for non-commercial trees: Individual tree model.

GAUSS Thu Jan 8 15:14:17 1998

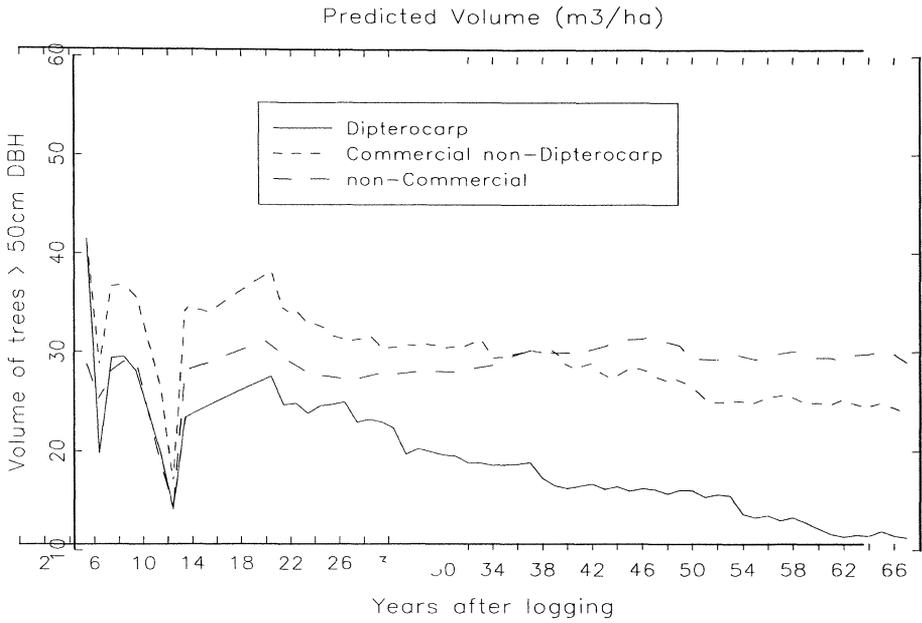


Figure 2: Forecasts using fitted mortality rates for Dipterocarps, Commercial non-Dipterocarps and non-commercial trees: Individual tree model.

GAUSS Thu Jan 8 16 14:35 1998

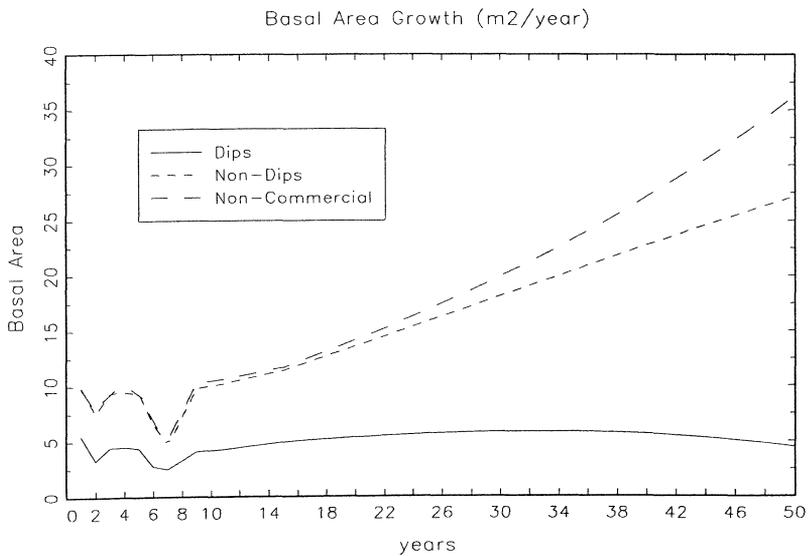


Figure 3: Forecasts using fitted mortality rates for Dipterocarps, Commercial non-Dipterocarps and non-commercial trees: Plot scale model.

General Observations

It is clear from both of these models that the basal area and volume of Dipterocarps not predicted to increase in a significant way. Both models predict the forest to shift from a Dipterocarp forest to a primarily non-Dipterocarp forest, the degree to which depending upon the model. There is considerable unexplained variation in the growth, mortality and recruitment rates for these simple models. However, the message seems to be clear that the forests will have timber of commercial value in the future if left as they are but it will consist primarily of non-Dipterocarps.

Problems related to growth and yield predictions

Some considerations regarding the Minimum data requirements for growth and yield data projections from experimental plots is as given in Appendix II. However some major problems related to growth and yield predictions are given as below:

Nature of the forest

To model future yield for logged-over forest, one should bare in mind that it is difficult as the forests are different in stocking due to different harvesting intensities and damages. At the moment, understanding on competition complexity is also very limited to incorporate into growth model. The same condition applies to soil productivity as there is no initiative taken to classify forest soil into different productivity classes.

Management operation

In modelling forest growth and future yield, information on harvesting intensity and damage, and different silvicultural treatment is very important. Stand with treatments normally yielded higher in the future than the one without any treatment. In many studies and permanent sample plots, these information/records are missing.

Permanent sample plot management

Some considerations to an ideal way to manage permanent sample plots for the purpose of yield prediction is given in Appendix II. There is always the case where insufficient data are collected, trees are not fully identified and the number of plot replications is not correctly determined. With the current yield prediction by incorporating competition in the model, information such as crown diameter, tree location, light illumination class and etc. are required.

Data analysis and modelling.

In many plot data analysis cases, data errors are very high. Data cleaning sometimes took longer period than the analysis. Beside that sufficient number of individual needed for very high output accuracy is still unknown. In Malaysia, different person analysed the data differently and it is very difficult to compare analysis result (Yong, 1997). Standard protocol is required and the question of what to be modelled is also needed to be clearly defined. As of now what is the best the modelling approach is unclear and the same thing occurs in model fitting and validation.

Conclusion

Growth and yield studies and yield projection models are among the most important elements in forest management for continuing timber production. Even though many growth and yield plots have been established with frequent measurements, not many of them are properly analysed and the results are not fully used to model or project future yields. This has resulted in abundant data and information especially in

Malaysia. However this huge amount of information is confined to dipterocarp forest only and there is little on mangrove and peat swamp forest. Even in dipterocarp forests, which consist of many forest associations, it was found that the available plots and data are not representing all of them. Future actions and analysis should take this in consideration too.

There have been some common problems related to growth and yield modelling for tropical mixed forests. Beside an abundance of growth data, the lack of expertise, co-ordination and funding are a common problem shared by countries with tropical mixed forests. There is a need for an action plan which should be operated in four major areas *viz.* standardisation of procedures in growth and yield studies, sharing of data collected, extensive and comprehensive analysis and modelling, and establishment of research networks on this matter in the future. With this action plan, it is anticipated that most of the problems in modelling growth and yield in tropical mixed forests can be further reduced.

In the future, the model needed to predict growth and yield is the one that is simple and accurate. The model also should be able to be used in the event where there is insufficient data. The model also must be able to incorporate the complexity of tropical mixed forest and environmental parameters such as soil and climate.

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Appendix 1 Diameter increment, mortality and ingrowth equations used in the models

Diameter increment equations:

- di=change in diameter (cm/yr) of an individual tree
- X=total basal area of all trees in the 1 hectare plot at the beginning of the forecast period

Dark Red Meranti

- $di = \exp(-0.15539 - 0.011392 \times X) - 0.2$

Light Red Meranti

- $di = \exp(-0.191158 - 0.0112268 \times X) - 0.2$

White Yellow Meranti (insufficient sample size, so just average the increments for DRM and LRM)

- $di = ((\exp(-0.15539 - 0.011392 \times X) - 0.2) + (\exp(-0.191158 - 0.0112268 \times X) - 0.2)) / 2$

Non-Meranti Heavy Hardwood

- $di = \exp(-0.107701 - 0.0150806 \times X) - 0.2$

Non-Meranti Medium Hardwood:

- $di = \exp(-0.107701 - 0.0150806 \times X) - 0.2$

Non-Dip Heavy Hardwood

- $di = \exp(-0.27367 - 0.0135317 \times X) - 0.2$

Non-Dip Medium Hardwood

- $di = \exp(-0.3326 - 0.01265 \times X) - 0.2$

Non-Dip Light Hardwood

- $di = \exp(-0.03232 - 0.0204071 \times X) - 0.2$

Other non-Dip commercial species

- $di = \exp(-0.09459 - 0.0206 \times X) - 0.2$

Non-Commercial

- $di = \exp(-0.269411 - 0.013844 \times X) - 0.2$

Mortality equations:

Proportion dying in a 12 month period for each of the Dipterocarp groups

- $a = \exp(0.6417 + 0.008025 \times x)$; $\text{proportion} = \{a / (1+a)\} - (0.5/37)$
randomly delete this proportion of trees from each of the groups (DRM, LRM, WYM, NDHHW, NDMHW)

Proportion dying in a 12 month period for each of the non-Dip commercial groups

- $a = \exp(1.9176 - 0.00222 \times X)$; $\text{proportion} = \{a / (1+a)\} - (0.5/120)$
randomly delete this proportion of trees from each of the groups

(NDHHW,NDMHW,NDLHW, other nonDip commercial species)

Proportion of non-commercial trees dying in a 12 month period

- $a = \exp(3.747 - 0.1206 \times X + 0.00252 \times X^2)$; proportion = $a / (1+a)$;
randomly delete this proportion of trees from the noncommercial group

Recruitment equations:

Number of 10 cm diameter trees added to the 1 hectare plot in 12 months, round the result to the nearest integer.

Dark Red Meranti. note: $x2d1$ is the total basal area of DRM in the 1 hectare plot

- $N = \exp(0.34405 - 0.00875 \times X + 0.0355 \times X^2 d1) - 1$;

Light Red Meranti

- $N = 0 \times X + \exp(0.34196)$; ???

White Yellow Meranti

- $N = \exp(0.149 - 0.0042 \times X) - 1$;

Non Meranti Heavy Hardwood (insufficient sample size)

- $N = 1$

Non Meranti Medium Hardwood

- $y4 = \exp(0.53578 - 0.01274 \times X) - 1$;

Non Dip Heavy Hardwood.

Note $x2nm2$ = total basal area of NDHHW in the 1 hectare plot

- $y5 = 0 \times X + \exp(0.05848 + 0.03675 \times X^2 nm^2) - 1$;

Non Dip Medium Hardwood (insufficient Sample Size)

- $N = 1$;

Non Dip Light Hardwood

- $N = \exp(1.911 - 0.02864 \times X) - 1$;

Other non Dip Commercial. Note $x2nd4$ = total basal area of these non Dip

Commercial trees in the 1 hectare plot

- $N = \exp(1.8898 - 0.05361 \times X + 0.2955 \times X^2 nd^4) - 1$;

Non Commercial

- $N = \exp(2.3986 - 0.0178434 \times X) - 1$;

Appendix II Minimum data requirements for growth and yield data projections: Some considerations for growth and yield data projections from experimental plots

Plot establishment

Plot size and shape

- size and shape of plot
- smallest sub-plot
- problems of edge effects

Logistic consideration

- accessibility

Sampling

- number of plots per treatment
- basis for stratification – stand basal area, topography, soil
- minimum number of replicates

GPS

- future relocation
- overlays using GIS
- mapping

Proper execution of treatments

- all marked trees for treatment should be treated
- least damage to trees marked for retention
- control of felling

Data collection during establishment

- what variables to be collected
- important variables for model prediction – site factors e.g. slope, elevation, aspects, site quality
- tree mapping by quadrants e.g. 10 x 10 m
- tree numbering in each sub-plot should be unique
- tree identification – what level e.g. vernacular names, species or genus, requires skilful person to identify trees
- minimum tree and plot attributes

Treatments

- untreated stand included
- standard treatment included
- cover wide range of treatments

Road and skid-trail

- what percentage allowed to be included in the sample plots

Data collection

- First measurement
 - should the stand record before treatment be included
 - growth parameters, site parameters, plot and subplot attributes
-

Frequency of measurement

- 1, 2, 3 or more years, longer interval reduces potential errors especially with negative increments but might lose important information on stand dynamics depending on the objectives of the experiments – more frequent during early stage after treatment

Time/ date of measurement

- effects of rainy season on stem size
- rains cause bark swelling – especially in tree with corky bark
- if possible measure during dry season (?)

Point of measurement

- changes in point of measurements
- large buttress trees, difficult to measure, not included in the increment model but mortality model. Important plot/subplot attributes *e.g.* plot basal area
- large trees > 100 cm dbh with flaky barks, increment not significant to tree size

Remeasurement

- tree mapping required
- plot location
- pass record required

Missing tree

- what to do – trees not found dead but missing

Data entry and screening

- Data entry and checking
- Revisiting for measurement checks

What to screen ?**Data errors**

- measurement errors, entry errors
- errors detection
- deleting error data
- acceptable limits of data errors - -ve and +ve increments limits

Data editing

- displaying changes of tree size over time for checking
- should we delete error data at this point (before exploratory analysis)

Exploratory data analysis

- what graphical displays suitable for the analysis
- histogram, density plot, scatter plot, boxplot, etc.
- outliers analysis

Model building

- growth or yield model
- individual or stand level model
- types of model *e.g.* regression techniques such as linear, non-linear, non-

linear but can be linearized through transformation

- component of model – tree size, tree position, site factors, stand productivity etc.

Model fitting

- minimum number of sample required to develop growth model
- reasonable number of variables, stepwise regression, C_p stats etc.
- strategies for grouping of species *e.g.* based on commercial timber classification, botanical, ecological, diameter increment equations
- rare species
- diagnostic plot
- assessment of model errors

Model validation

- data for validation
 - validation technique – computing intensive method *e.g.* Monte Carlo, bootstrapping
-

THE CODEFORSA NATURAL FOREST MANAGEMENT STANDARDS

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1. The intensity of the harvesting and silvicultural treatments are determined according to the species abundance. The harvesting intensity will not exceed 60% of the number of trees with diameter at the breast height (dbh) of 60 centimetres or bigger, per species. A smaller reference dbh will be established for those species which do not reach a dbh of 60 cm, in this case, a technical justification is needed.
 2. The harvesting rate will not exceed the resource growth rate.
 3. The number of trees to be felled is proportionately distributed among the maximum possible number of commercial species at present.
 4. The forester can determine the felling cycle according to the natural forests growth information available and taking into account the particular dynamics of the forest.
 5. In logged forests there are not harvestings before a period of 15 years since the last intervention.
 6. Those species with no more than one tree every tree hectares (0.3 trees per hectare), based on a preliminary survey of the trees with dbh of 30 cm or bigger, are considered as rare members of the ecosystem and will not be extracted.
 7. Protected or restricted species' trees with dbh of 60 cm or bigger are marked in the field and located in a harvesting base map. These individuals are considered as seed trees but they are not part of the the 40% left during the selection of the trees to be felled.
 8. Damage limits
 - a. Damaged area due to felled trees do not exceed 15% of the area defined as productive forest.
 - b. Landings are no more than 1% of the productive forest area.
 - c. Primary roads, those in wich lorries circulate, are less than 2% of the productive forest area, likewise, the road edges do not exceed 2% of this surface.
 - d. Secondary roads, those in wich the tractor or skidder circulate, do not exceed 8 % of the productive forest area.
 - e. The skidding tracks do not occupy more than 3% of the productive forest area
-

- f. In every case, the total harvesting impact will not exceed 25% of the productive forest area.
- g. The diagnostic and silvicultural surveys will show that the combination of the harvesting and the damage will not exceed 15% of the original basal area after the harvesting.

APPROACHES ADOPTED TOWARDS YIELD REGULATION IN THE BRAZILIAN AMAZON

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Introduction

Roundwood production in the Brazilian Amazon ranks third in the world, only surpassed by Malaysia and Indonesia. In 1996-1997, annual volume of logs produced was c. 28 million m³ corresponding to an annual logging area of 1.0-1.5 million ha (Nepstad *et al.* 1999). Pará and Mato Grosso States are the main timber producers, accounting for 78% of the total production.

For timber production to be sustained, *i.e.* employing sound forest management practices, the area of closed forests needed to be under timber production would be around 30-45 million ha, considering a 30 year cutting cycle. The area under forest management plans in 1997 was 1.8 million ha. If we add the area of national forests (meant for production) in the North region, which amounts to c. 15 million ha, we find out that it is necessary to establish a further 13 to 28 million ha of production forests. This emphasises the strong need for establishment of a permanent forest estate in the country.

Brazilian forest management regulations

The present forest management regulations (Instruction 6 from 28 December 1998) require that the total forest area to be managed for timber production will depend on three factors: i) industry's annual demand for logs, ii) stand volume growth, and iii) the cutting cycle adopted. Annual coupes are defined on the basis of the annual consumption of logs and on the cutting cycle adopted. The length of the cutting cycle and the annual allowable cut (AAC) must be based on published and reliable growth data. The minimum felling diameter is flexible according to the species. IBAMA³ accepts, as a rule of thumb, 45cm dbh for most of the species. There are particular cases such as small trees of *Hymenaea courbaril* L. Leguminosae, which present too much sapwood and therefore the minimum felling dbh adopted is 60-70 cm. In some States, the local IBAMA office establishes specific regulations. For example in the State of Pará, logging intensity is set to 30% of the total standing volume over 45 cm dbh, provided that it will not be greater than 60 m³ ha⁻¹.

For *Virola surinamensis* there are specific management regulations. IBAMA's Instruction 1 from 8 January 1999 establishes the following requirements: cutting cycle not less than 25 years; no felling is allowed during the fruiting season; the average number of trees to be felled must be less than 75% of the available stock over 45 cm dbh (provision for seed bearers); and the distance between seed bearers must be less than 100 m. Silvicultural treatments (mainly tending) to assist natural regeneration must be carried out on the 2nd and 5th years after logging. If natural regeneration is not well distributed, wildings must be transplanted to gaps created

³ IBAMA: Brazilian Institute of Environment and Renewable Natural Resources is the government institution responsible for establishing the country's forest policy and law enforcement regarding the environment and forest management.

by logging.

Instructions for forest management by local communities has also been recently issued (IBAMA's Instruction 4 from 28 Dec. 1998). In this case a so-called simplified management plan is required. The main features of the plan are as follows: forest area no greater than 500 ha; stocking map based on 100 % inventory showing location of harvestable trees and seed bearers; number of trees per ha to be felled limited to a maximum of five; and cutting cycle of at least 25 years.

Control of logging and commercialisation

Once a forest management plan is approved by the local IBAMA's office, a pre-logging inspection of the annual coupe is carried out by IBAMA's foresters. Pre-logging activities such as census of the logging coupe (100 % inventory), mapping of the harvestable trees, climber cutting (if prescribed), and marking trees for felling and seed bearers are checked. If the pre-logging activities indicated in the management plan are performed accordingly, the annual coupe is liberated. An AAC is then set up, in accordance with the pre-logging forest inventory and with the maximum logging intensity established by IBAMA (see above). Logging permits are issued by the local office covering the total volume approved for a particular year. Loggers must list on the logging permits forms, the species and the volume harvested. The logging permits must accompany the logs from the forest to the sawmill. Loggers are fined if they cannot exhibit the logging permits during a transport control operation. An additional control is carried out by IBAMA's central office during the commercialisation phase. When industrialised timber coming from a forest management project area is sold, the sale receipt is stamped to indicate that the species and sawn volume of that particular sale refer to an annual coupe already approved by IBAMA. Conversion factors from logs to industrialised wood are used to cross check the total volume of logs approved to be logged and the correspondent volume of industrialised timber commercialised.

Yield regulation approach adopted at Mil Madeireira

Mil Madeireira is a subsidiary of the Swiss company Precious Woods. The Brazilian forest management unit is located in the municipality of Itacoatiara, State of Amazonas. The forest operations are concentrated in Fazenda Dois Mil, in 80,000 ha of forests, of which about 61,000 ha are assigned for timber production. The sawmill has a capacity to process 30,000 m³ of logs per annum. The approach adopted by the company towards yield regulation is briefly described in the following paragraphs.

Based on a 100% pre-harvest inventory, trees to be harvested are selected taking into account economic and ecological criteria. When these selection criteria are defined or revised for a new annual coupe, a special meeting is organised between the Forest Manager, the Sawmill Manager and the Sales Manager for internal negotiations on the following items.

Economic criteria:

- Of the 65 tree species that are managed on the long term, only those having a guaranteed market possibility for that particular year will be included in the selection.
- Selection priorities are defined for each chosen species based on the commercial value and the potential marketing volume.
- For each species also a minimum felling diameter (dbh) is defined as a function of

the sawmill yield and the available volume in the current compartment.

Ecological criteria:

- No harvesting is allowed in the preservation areas (buffer zones along the creeks and rivers, steep slopes > 45 degrees).
- For each selected species, logging intensity is set to a maximum of 80% of the volume of the existing trees above 50 cm dbh.
- The volume to be harvested must not exceed 40 m³ per ha, and the trees selected for felling should be as much as possible spatially well distributed, as an attempt to reduce canopy opening.

The selection criteria are entered into a computer program (GIS) developed at Mil Madeireira to help on the best selection of the trees to be felled. The outputs are logging maps showing the location of the trees and tables giving details of the trees to be felled. This information is used for planning all harvesting activities in the field. The harvesting system does not allow searching for some particular species in case a sudden market demand appears, nor to increase felling intensity which would violate one or more of the established ecological criteria.

In case there is a significant change in market demand for some particular species, the economic criteria are adjusted and a new selection of the harvest is run, but always including the ecological criteria. In case the market and/or the industry needs more volume than the AAC in a particular year, then the only option allowed is to increase the harvest area. This procedure may interfere with the length of the cutting cycle in the long run (e.g. the total harvest area available for a harvest cycle of 30 years will support only a period of 25 years), but this kind of problem can be solved in the future by expanding the total area to be managed or by decreasing the roundwood production during some years in the future.

Conclusions

Brazil's approach for yield regulation is on an area basis. However, control needs improvement in order to avoid illegal logging in forest areas not covered by management plans. A kind of chain of custody to track the logs from the forest to the mill would help to alleviate this problem. Although growth data exist for some forests, there is a strong need to expand the network of permanent sample plots in order to cover different forest types in the Amazon region. Establishment of a permanent forest estate is urgently necessary for a better control of logging activities and regulation of timber production in the region. This measure should be complemented by regulating forest concessions in the country.

Acknowledgements

We thank Dr. Denis Alder and Mr. Howard Wright for inviting us to participate in the Workshop. We are also grateful to the following persons who provided information on IBAMA procedures: Dr. José de Arimateia Silva, Mr. José de Ribamar Santos Costa and Mrs. Maria de Nazaré Mergulhão.

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YIELD REGULATION IN THE TROPICAL MOIST FORESTS OF UGANDA

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Introduction

Uganda is a tropical country located between latitudes 1° 30' S and 4° N and longitudes 29° 30' East and 35° E. It covers an area of 24 million hectares, 17% of which is open water and permanent swamp. Altitude averages between 900 - 1500 m above sea level. Rains average 1000 - 1200 mm while average temperatures range between 20°C - 28°C.

Population is about 20 million people averaging at about 100 persons per km². The rate of growth is about 2.5% per year.

Uganda's Tropical High Forests (THFs) cover nearly 900,000 ha. About 700,000 ha of these are in Protected Areas (includes patches of grassland). Nearly 60% of the PAs are in Forest Reserves (FR) while the rest are in National Parks.

Management of forest reserves

Today, management of Forest Reserves is divided between the central and local governments. Central Forest Reserves have been managed by the Forest Department for a long time. The THFs have been managed under the monocyclic uniform management system. The intended rotation was 80 years for the larger forest tracts.

Today, a Forest Nature Conservation Master Plan is about to be launched and is already a guide in the management of natural forests in FRs at the national level. It provides for the zoning of major forest reserves into Strict Nature Reserves (20%), Production Forests (50%) and Buffer Zones (30%).

At the FR level, each reserve is managed under a 10-year plan. The plan divides the FR into working circles, which today reflect the provisions of the Nature Conservation Master Plan. The Management Plan is implemented through Annual Work Programmes.

For purposes of harvesting, the management plan prescribes sawmilling (fixed) areas and areas for low impact harvesting (pitsawing) and small mobile sawmills.

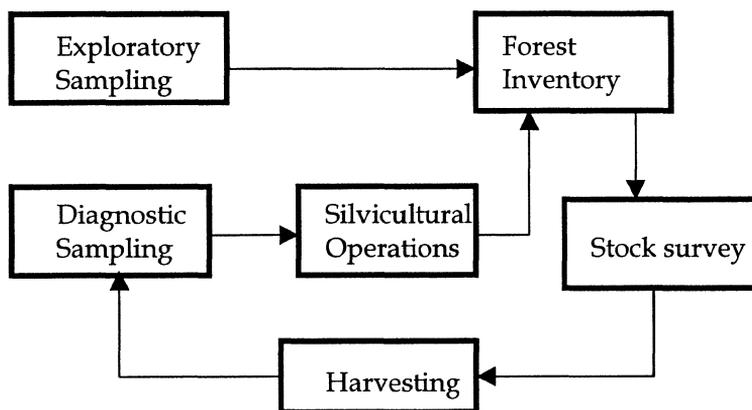
For over 20 years, forest reserves have been managed in an unprofessional manner. However, work has now been initiated on Permanent Sample Plots, Forest Management Plans, Stock Survey and management inventories.

Production of timber

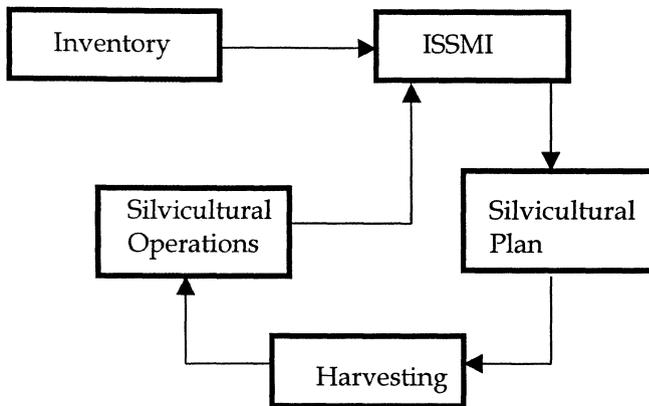
At a harvesting rate of 0.8 - 1.0m³ per ha per year, the production zones of FRs covered by Natural Forests which are reasonably well stocked for sustainable harvesting can produce an annual allowable cut (AAC) of about 100,000 - 120,000m³ of round wood. Today, there is little legitimate harvesting in these FRs. Less than 10,000m³ were harvested during the year ending June 1998. That means, most of the timber from natural forests on the market comes from private lands or is illegally obtained from protected areas.

Approaches to yield regulation

Traditional approach



- A forest which has never been formally managed is sampled at an intensity of 0.1% to determine stand characteristics *e.g.* species and their distribution, volume and basal area.
- A full scale inventory using an intensity of 0.6 - 1% follows later to determine details of vegetation types, species composition and to establish stand tables and site conditions. At this stage, the forest is divided into management units (compartments) and AAC is prescribed.
- Working in each compartment, all harvestable trees (above a minimum diameter) are enumerated (and mapped for high value forests). Each tree is given a stock number to monitor progress of harvesting.
- The AAC established earlier determines how much can be removed, but in each felling coupe, all harvestable trees are removed, excepting seed trees (2 tree/ha for the high value species are normally recommended).
- Two years later, a diagnosis of the harvested area is made to establish the silvicultural condition of the remaining crop. This guides decision making on subsequent silvicultural operations to assist regeneration and improve quality.

Integrated Stock Survey and Management Inventories (ISSMI)

- This is now at a fairly early stage of implementation as it is still being developed. It arose out of a need for intensive management of the diminished production zones. The aim is increased stocking per unit area and high quality stems. In view of the current pressures on the resource, intensification of management keeps staff in the forest. As a result, protection against illegal removal is enhanced.
- It feeds into a polycyclic selection management system. Each management cycle will be 15-25 years.
- Inventory is carried out as in the traditional inventory practice. A sampling intensity of 0.6 - 1% is being used today.
- ISSMI is then carried out as in the traditional stockmapping. At this stage, a management inventory (5% sample) is carried out concurrently. This generates information on harvestable trees, species composition, volumes, basal areas, silvicultural condition of individual trees, site conditions and regeneration.
- Harvesting aims at taking off increment in a 15-25 year management cycle. Because of inadequate data on diameter increment, mortality and recruitment, estimated figures will be used until Permanent Sample Plots are re-established and assessed.
- The management unit is a 4-ha block.
- It is expected that ISSMI will require less costs than the aggregate costs of stockmapping, inventories and diagnostic sampling.

Permanent Sample Plots (PSPs)

Uganda has some of the oldest PSPs in tropical high forest in the world. Many of them were established in the 1930s. Unfortunately, assessment stopped in the mid-1970s. Worse still, most of this data cannot be traced easily today.

The Forest Department is now re-establishing new PSPs and re-opening old ones as far as they can be traced on the ground and past assessment records unearthed. In time, it will be possible to predict growth trends and thus set realistic and sustainable yield levels.

Editor's note

For an account of the long-term Uganda PSPs see

Sheil, D. 1996 The ecology of long term change in a Ugandan rain forest. Doctoral thesis, Oxford Forestry Institute, University of Oxford. Contact d.sheil@cgiar.org

YIELD REGULATION PROBLEMS IN INDONESIA

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Introduction

No less than anywhere else in the world, ensuring sustainable forest management in Indonesia is a highly pressing issue. The significance of the forest sector in the national economy and the increasing global market demands for eco-labelled forest products have led the Government of Indonesia to pay increased attention to the subject. One of the primary problems surfacing recently is the urgent need for appropriate methods, techniques, or tools necessary for accelerating the progress toward accomplishing sustainable management of natural forests.

In the prevailing Indonesian forest management system, natural forests are divided into units of forest concessions or HPHs. The accomplishment of sustainable forest management at the national level is therefore dependent upon the degree of accomplishment at each concession. Meanwhile, one of the most important prerequisites for sustainable management at the concession level is the quality of long-term management planning, in which yield regulation is a major component. The problem faced in Indonesia today is that the existing procedure of yield regulation for natural forests no longer fits the actual conditions. On the other hand, any attempt to devise or adopt more proper methods or techniques is in turn prohibited by a serious shortage of an essential input, *i.e.* growth models of logged-over natural forests. A conventional solution to this problem would be waiting for more representative growth data to become available, which is not favoured given the urgency of practising sustainable forest management.

This paper is intended to provide an overview of the nature of yield regulation problems faced in Indonesia.

The existing yield regulation method

Yield regulation in the current practice of natural forest management in Indonesia is performed through the determination of the annual allowable cut (AAC) at the concession level using the following set of formulae:

$$(1) \quad AAC_L = L / T$$

$$(2) \quad AAC_V = AAC_L \times \bar{V} \times fe$$

where

- AAC_L = annual allowable cut in terms of area (hectares)
- L = total production area (hectares)
- T = rotation (35 years)
- AAC_V = annual allowable cut in terms of volume (m³)
- V = average harvestable stand volume (m³/hectare)
- fe = factor of exploitation (usually 0.7 - 0.8)

Formula (1) divides the entire production area (excluding non-effective portions such as conservation areas) of a forest management unit (FMU) into n equal annual cutting blocks (n being the rotation length). One of these annual cutting blocks is assigned for harvest every year. Formula (2) gives AAC_V which is the upper limit of

the total production every year over a 20-year period. The actual volume that can be harvested from an annual cutting block is the annual allowable production (AAP) given by:

$$(3) \quad AAP = HV \times \bar{fs}$$

where:

AAP = annual allowable production,
 HV = actual harvestable volume of a particular cutting block obtained through 100% timber cruising,
 fs = a safety factor (currently set at 0.7) intended to accommodate likely overestimation of harvestable volume due data inaccuracy.

AAP is determined specifically for each annual cutting block a year preceding logging and is based on stand volume estimation obtained through a 100% pre-logging timber cruise on the particular block. AAC on the other hand, is determined once every 20-year period (being part of the long-term management planning) and based on standing stock data obtained through a forest-wide inventory using a 0.1% - 0.3% sampling intensity.

In practice AAP is restricted not to exceed AAC_v , meaning when AAP turns out to be larger than the predefined AAC_v , AAP is defined to be equal to AAC_v . AAP is strictly to be achieved within a single cutting block; when the harvestable stand volume contained within a particular cutting block is in fact smaller than the resulting AAP, logging is not allowed to continue on to another block. On the other hand, logging in a particular block must be terminated whenever AAP has been reached, although the block might still contain substantial harvestable stand volume.

It is apparent Formula (1) is more determining than Formula (2), meaning the method is in essence a variant of the classical area control method. The method is fairly conservative considering the use of AAC_v as the upper limit of timber extraction and the incorporation of a safety factor fs.

Why an alternative is necessary?

In the present system of natural forest management in Indonesia, a forest concession is granted for 20 years, which is extendable in 20-year increments. Likewise, the long-term management plan is prepared for every 20-year period. With a given 35-year rotation length, by the time a forest concession entering the second 20-year period, more than a half of the forest within the FMU would have been logged-over. And this is currently the case in Indonesia.

The prevailing method of yield regulation (the set of formulae) seems valid for management of virgin forest during the transition period (from virgin forests to mixed uneven-aged production forests) but not for logged-over forests in the subsequent periods. Unlike virgin forests that are in a state of stable equilibrium, logged-over forests react to reduction in stand density with growth. Moreover, growth of logged-over stands varies greatly due to differences in site conditions, previous logging intensities, logging damage, species composition, post-harvest silvicultural treatments, as well as external disturbances. The prevailing method

does not account for these factors, and therefore is inappropriate for FMUs entirely or partially consisting of logged-over forests.

One could conjecture that the method was adopted with an intention to attain “normal” or “regulated” mixed uneven-aged forests at the FMU level by the end of the first rotation, hence ensuring a stable annual production henceforth. The accomplishment of this goal however, is dependent upon several conditions including: (1) no significant reduction in forest area over the rotations, (2) no excessive external disturbances (forest fires, illegal logging, and land encroachment), and (3) logged-over stands do grow toward the growing stock level of their former virgin stands. The fact of the matter today is that virtually none of these conditions hold. As a result, after nearly three decades of application, no FMU is quite close to a “normal” or “regulated” forest, and sustainable production seems to remain theoretical. In short, the method is both conceptually and practically unfitting for the real situation.

In general, if a new method is to be devised or adopted, the following considerations need to be taken into account:

1. The currently emerging new paradigm of forest resource utilization in Indonesia put special emphasis on the multiple-use nature of forests. In line with this, sustainable management must be perceived as a state in which timber harvest proceeds within a set of conditions that also ensures the sustainability of non-timber values of the forests.
2. From financial stand points, secondary forests are not as attractive as virgin forests; while expected yield is significantly smaller, expenditures have to be made and risks incurred before any harvest takes place. The yield regulation procedures should lessen this liability by providing sufficient room for manoeuvring, such as using flexible rotation ages and allowing variable annual cuts.
3. Notwithstanding the mitigation efforts undertaken, there is still no guarantee that loss of forest areas due to either legal conversion or illegal encroachment will cease to occur in the future. This fact ought to be explicitly incorporated into the yield regulation method.
4. Conventional yield regulation methods rely strongly on yield simulation based on growth models. Despite the extent of natural forest management in Indonesia, reliable growth models of natural forests are still scarce. Growth data has just begun to accumulate but still prevents development of growth models through traditional modelling approaches. Thus the alternative yield regulation method should be either one that does not demand growth models or alternatively integrates a modelling module that is capable of resulting in growth information from less perfect growth data.

Currently proposed alternatives

Some alternatives are being proposed for replacing the current AAC determination method. They include: the Austrian Formula and some variants of a computer simulation system.

Austrian Formula

Some foresters suggest the adoption of the classical Austrian Formula. Thus, AAC is to be determined using a combination of Formula (1) and the following formula:

$$(4) \quad AAC_V = V/T \times fe$$

where

$V = \Sigma V_i$ in which,

V_i = volume of stand i at the rotation age (35 years),

which is projected using $V_i = V_0 + \Sigma t_j I_j$

where V_0 = present volume of stand i ,

t_j = time period j , and

I_j = estimated periodic annual increment of stand i in time period j .

It appears the only difference with the prevailing method is the incorporation of a growth component in the AAC_V computation, making it suitable for management of logged-over forests. However, it is still an area-control method and implicitly assumes that no reduction of forest area will take place in the future. Since there is no substantial improvement from the prevailing method, this alternative does not warrant adoption.

DIPSIM

DIPSIM (Dipterocarp Forest Growth Simulation Model) was first developed for management of dipterocarp forests in Sabah, Malaysia (Ong and Kleine, 1995). It is currently being applied in a pilot project in Central Kalimantan, Indonesia (Hinrichs and Kleine, 1999). In DIPSIM, AAC is a harvest volume in a given year that does not deplete the growing stock but instead allows it to build up to a desired level. Basically DIPSIM evaluates predetermined AAC levels by demonstrating the impacts on the future stocking condition of the forests. Thus, the appropriate AAC is obtained through a process of "trial and error" using various logging intensities. It follows that a key input to run DIPSIM is a set of growth models including models for tree diameter increment, mortalities, recruitments, and logging impacts. Combined with inventory data these models are used to simulate the annual growth in terms of stem number, volume and basal area of each compartment within a management unit. By comparing the future stocking conditions with an optimal growing stock level and considering other user defined conditions (minimum economic cut, maximum number of harvest trees, diameter cutting limit, minimum residual trees, etc.) DIPSIM identifies stands that are economically and environmentally viable to be cut in a given year and an appropriate AAC can be identified. It follows that the rotation length is therefore not strictly predetermined at 35 years, but rather is determined on a per-compartment basis. Depending on its simulated development, a logged-over stand of less than 35 years may be cut, while another logged-over stand of 35 year old or older may be left for a later harvest.

Yield Simulation System (YSS)

YSS is similar to DIPSIM in the sense that it applies a "trial and error" approach to determine harvesting levels and rules (annual cut, cutting limits, cutting intensity, cutting cycle) that best meet the user defined management objectives. Accordingly, YSS main inputs include a set of growth models in addition to inventory data. YSS

was developed by Rombouts (1998) for dipterocarp forests in East Kalimantan. Applications to other forests/regions are subject to the availability of appropriate growth models.

Like DIPSIM, YSS is a volume-based yield scheduling system; areas to be harvested are output rather than input. A distinguishing feature is that reduction in forest area is explicitly handled by a forest conversion module that reduces the simulated forest area at a rate specified by user.

KPHP Yield Regulation System

KPHP is a proposed tenure system intended to replace the prevailing concession system (currently being implemented as pilot projects). In KPHP's scheme, yield regulation uses basal area as the primary control variable. This preference is based on an observation of an interesting characteristic of tropical rain forests, *i.e.* basal areas of virgin forests vary surprisingly little around $35\text{m}^2\text{ha}^{-1}$ and maximum increment is usually reached at a basal area of around $25\text{m}^2\text{ha}^{-1}$. Thus, the basic logical concept is to log a given stand up to a basal area level in the neighbourhood of the maximum increment, as far as financial considerations allow.

Like DIPSIM and YSS, the KPHP yield regulation system also requires appropriate growth models, in this case basal-area growth models. Robert de Kock (*pers. com.*) provided an illustration describing the implementation of the KPHP approach on a lowland dipterocarp forest in East Kalimantan. A set of simple models relating stand basal area and basal area increment was employed to simulate the development of the forest over a number of successive rotations. The outputs indicated that the simulated forest attains a maximum commercial volume CAI of about $1.8\text{m}^3\text{ha}^{-1}\text{yr}^{-1}$ in the neighbourhood of a total basal area (all species over 20cm dbh) of $25\text{m}^2\text{ha}^{-1}$. This optimum basal area corresponds to a total gross standing stock of about $240\text{m}^3\text{ha}^{-1}$ (the figure is obtained using stand volume functions). Meanwhile, under the present Indonesian circumstances, an extracted volume of about $32.5\text{m}^3\text{ha}^{-1}$, which includes a roughly 50% logging waste, corresponds to a $65.5\text{m}^3\text{ha}^{-1}$ harvest. These figures lead to a decision to log the forest when it reached a basal area of $29.2\text{m}^2\text{ha}^{-1}$ (total gross volume of $285\text{m}^3\text{ha}^{-1}$), leaving a residual basal area of $23.0\text{m}^2\text{ha}^{-1}$ (total gross volume of $220\text{m}^3\text{ha}^{-1}$) about 28 years after the former logging.

Problem: shortage of growth models

DIPSIM, YSS and KPHP are all promising, but none of them are immediately applicable. They all require growth model inputs, and this is exactly the problem prohibiting their wide application. At present, growth models for Indonesian natural forests are extremely scarce, available for only limited lowland dipterocarp forests in Kalimantan (which have, in fact, been incorporated into DIPSIM, YSS or KPHP systems).

The first and most important factor behind the shortage of growth models is the insufficiency of data on the growth behaviour of logged-over natural forests. This is due to a prolonged ignorance on the part of forestry authorities about the essential need for accurate growth and yield prediction in sustainable forest management. As a result, only a very limited set of growth data (including those used to develop growth models for lowland dipterocarp forests in Kalimantan mentioned earlier) was accumulated during the last three decades, a prosperous time for natural forest exploitation. This limited data represent just a small fraction of the highly diverse

and site-specific natural forest conditions across Indonesia.

On that account, it is quite encouraging that, lately, there has been a notable change of attitude. A Ministry Decree was issued in 1994 which makes it mandatory to collect growth data on forest concession areas. Each forest concessionaire is required to establish and monitor series of permanent sample plots (PSPs), which eventually will amount to 7 series of 6 PSPs (a total of 42 PSPs). This project is beginning to result in growth data; up to this moment about 150 (out of about 400) concessionaires have complied with the requirement, which means at least 900 PSPs have been established. The whole project however, is still in the early stage. Many concessionaires are still lacking skilful personnel to undertake work that is usually carried out by trained researchers. Consequently, except for a minor portion, the accumulating growth data is in general of insufficient quality (Rombouts, 1997). In addition, the majority of the PSPs were established in the last 2 - 5 years, meaning the data series is still very short-term.

Another expected source of growth data is The National Forest Inventory (NFI) of Indonesia. NFI is designed from the outset to produce data for monitoring changes in forest resource at the national level. For that purpose, clustered plots (consisting of nine one-hectare sub-plots) are placed on a 20km x 20 km regular grid nation wide. One of these clustered plots is treated like a PSP. This scheme is also starting to yield a large quantity of growth data, but in terms of quality is not much better than the concession PSP data.

The second factor leading to the shortage of growth models is associated with growth modelling methodology and its perceptions on the part of both modellers and users. Growth modelling methods described in the literature are naturally dominated by those for temperate forests, which are commonly less complex ecosystems compared to tropical rain forests. For that reasons, applying those modelling methods to tropical rain forests requires some simplifying assumptions which means, to an extent, a possible degradation in model reliability. Many modellers strangle themselves between hesitation to accept this forfeiture and inability to invent alternative approaches that better fit conditions obtaining in mixed tropical rain forests, especially under selection cut management regimes. Given the urgent need of growth models, both modellers and model users are forced to become more rational. By its nature modelling always involves some simplifying assumptions; there is no model that can portray the reality, that are not necessarily observable in actual practice, without flaws. The question is whether the assumptions are quite tenable or not.

An alternative scheme for growth data collection

Notwithstanding the encouraging progress achieved lately, it will still take quite a long time to obtain growth data of sufficient coverage and quality for developing the needed growth models. An efficient shortcut is to merge growth data collection into the periodic stock-taking survey or Forest Orientation Survey. Under current Indonesian practice, a Forest Orientation Survey is carried out every 20 years, that is for the preparation of the long-term management plan. This survey is generally conducted using a systematic strip sampling method with a sampling intensity of 0.1% - 0.3% or, with proper stratification, reducible to 0.05%. In conjunction with the intention to merge growth data collection, it is recommended that this period be shortened to 5 years. In any case, considering the current pace of change in forest

resource condition, 20 years is indeed much too long. A revision of sampling method is also necessary. The suggestion includes systematic plot sampling, customized line-plot sampling proposed by an Indonesia-GTZ Pilot Project in Central Kalimantan, or plot-less probability proportional to size sampling proposed by the KPHP Project. Growth data are to be collected by setting aside a [small] portion of the plots to be remeasured every 2 – 5 years.

Growth modeling with minimal data

As described earlier, a large amount of PSP data is expected to accumulate in the near future, but it is mostly of insufficient quality. Before data of a better quality are available, maximum use can be made of these data. If data sets of at least two measurements are available, regardless of their imperfect quality, some sorts of growth models are attainable. Some variants of conventional modelling approaches have been shown to be quite feasible with such data. The transition matrix approach for instance, has been shown to be quite applicable for obtaining stand projections, at least for a fairly limited period (5 – 10 years) with minimal data (Kock, 1996; Rusolono *et al.* 1997; Parthama, 1999). Another option is developing diameter-distribution or stand-structure equations for each measurement, followed by developing equations regressing parameters of diameter-distribution function at time $t+\Delta t$ against those of time t (Parthama, 1998). It is also possible to develop equations regressing periodic annual increment (PAI) in terms of basal area (BA) or standing volume (V) against years elapsed after logging (YEAL).

But the real problem is when the data available is only of one-time measurement, or in the data collection scheme described earlier, only of the first measurement. Fraser (1997) used such data in a preliminary work and indicated a significant dependence of gross volume (trees with diameter of 20cm and up) on YEAL, base rock type (land system), altitude class, and position on slope (land facet). This result suggests a possibility of obtaining growth model from such one-time measurement data. It should be noted, however, that it demands similarities across plots in terms of pre-logging stand conditions and former logging intensities. In addition, plots must be free of significant disturbances following logging (i.e. illegal cutting, fire). If these conditions do not hold, the resulting regression will be dubious. Proper stratification is therefore very crucial and historical data about pre-logging conditions and logging intensities are necessities. At this moment, there is no discernable suggestion beyond what has been done by Fraser.

Concluding Remarks

Under Indonesian condition, the volume control yield regulation approach is more suitable. In addition, the method has to accommodate inevitable reduction of forest area over time due to legal conversions, illegal encroachments or natural disturbances. It also has to take into account the variable stand conditions and allow flexible rotations.

A number of simulation-based yield regulation systems have been proposed. The core of the problem, however, lies in the lack of growth models and data needed to implement these systems. In a sense devising or adopting sophisticated yield regulation methods or techniques is not yet a solution to the problem faced until the shortage of growth models/data is overcome. Thus what is really urgently needed at present is a simple but reliable methodology or technique of producing growth

models from less perfect growth data; exactly what is the focus of this workshop.

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ON YIELD REGULATION FOR SUSTAINABLE FORESTRY, WITH EXAMPLES FROM QUEENSLAND

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Summary

Personal anecdotes are used to highlight some important considerations for yield regulation and to introduce some pertinent literature. A checklist of key issues and research needs is offered. Perhaps the most important consideration is to maintain a holistic systems view, and to involve clients and to ensure their needs are met.

Introduction

When I first joined the Queensland Department of Forestry in the mid-1970s, I, like many other foresters before me, was assigned to an inventory team to undertake strip assessment in a remote area of the state. It was good experience for me, but an inefficient way for the organization to gather resource information. This intensive systematic sampling was based on the premise that there was no prior information, and that stand-level inventory data were the weakest component in the yield estimation system. This is a common enough assumption: many inventory and yield regulation systems assume a "virgin" resource without prior information that should be converted to a "normal" forest. However, this is rarely the case: prior knowledge usually exists as local experience and satellite remote sensing data, and changing expectations (e.g. losses to other land uses and new conservation obligations) may have subverted the felling series away from that elusive normal forest. It certainly wasn't the case in Queensland at that time (Vanclay 1996b). A few years later, I took charge of resource assessment procedures, and had the opportunity to make some changes. Here I'd like to share some of the insights we gained in reviewing the inventory and yield regulation system in Queensland (Vanclay *et al.* 1987). Despite the passage of a decade, this review remains relevant, and still reflects current procedures in Queensland today.

Reconciling information needs with data gathering

I got a surprise when I returned to the Queensland Forest Service in 1984 to lead their native forest resource assessment programme. I was stunned to see row upon row of grey steel cabinets full of computer cards, partly because they contained the only copy of much irreplaceable data, but especially because card-readers had become scarce museum pieces. My first action was to find the last card-reader remaining in Queensland, and to arrange for several tons of cards to be read onto a couple of magnetic tapes. We didn't have time to decide if it was all worth keeping, we just needed to make sure that we kept all options open. As it happened, some of the cards were redundant computer programs that were eventually discarded, but most of the data was salvaged and eventually used again. Some data were lost, perhaps in the chaos of conversion or possibly earlier, but we managed to retrieve those data from field records. Since then, changing technology has precipitated another transfer, from tape to disc drive, and it is now probably time for yet another transfer from disc to CD-ROM.

Lesson 1: Computer technology changes fast, so make sure that your storage media remain up-to-date and accessible, keep more than one copy, and keep the original field records.

We saved all that old data (and we did use most of it later), but I was sure that it wasn't all necessary, and I didn't intend to continue routinely collecting data in that way. Firstly, the relative costs of manpower and computers was changing steadily, so it made sense to make better use of existing data, and to become more efficient and selective in collecting new data. Secondly, Colyear Dawkins had reinforced my conviction that there were more efficient sampling procedures for situations where prior data existed (see Vanclay 1994a p.227), notably stratified sampling. And thirdly, I was sure that existing procedures didn't really satisfy the needs of our clients, and that it would be useful to get our clients more actively involved in the collection of data and interpretation of results. The notion of clients was pretty novel; I'm not sure if anyone had looked at inventory in that way in Queensland before! So I set off to meet the clients (District Foresters, Harvesting and Marketing staff, *etc*), to see how they used the existing outputs and to discover what information they really needed. That was instructive...

Most potential clients didn't get any information, didn't use it, or didn't trust it. They had never previously been consulted about what information they needed or in what format they might like it. They generally regarded Resources Branch as a "black hole" (data went in, but nothing ever came out), and felt no obligation to provide reliable data. This legacy made it hard to gain their trust and commitment, and made it hard to assess what information they might find useful. Most potential users couldn't imagine what was possible, so we built several mock-ups to illustrate what we had in mind and to precipitate discussion. These discussions formed the basis of a good relationship and allowed a gradual transfer of responsibility for much inventory work. Together we created a system that could support operational planning as well as regional and state wide resource estimates. Once local staff were committed to the new system, we encouraged them to do the field inventory themselves, greatly reducing the travel costs involved. Since they were using the system to support their own work, we achieved consistent estimates at all scales, and could be sure that the data were up-to-date and accurate, a win-win situation all round.

Lesson 2: Identify your clients, get them involved in the design and implementation of the system, and foster their involvement through the use of mock-ups and prototypes.

Implementing a systems approach

Dissatisfaction with previous forecasts made us committed to providing a system that would allow efficient comparisons between our predictions and harvest outturn; thus we needed to provide spatially explicit predictions. Our first step was to set up a framework for an information system by tessellating forest land into what we called management units (MUs), so that every scrap of forest land existed in one and only one MU, each clearly marked on a map and labelled with a unique identifier. This was easy to do, as our MUs were generally based on existing administrative boundaries, and were often delineated by roads, rivers and ridges. The unique identifier provided the key to our Area Information System, a simple dBase III database detailing for each MU information relevant to resource calculations, to Head Office and to field staff (Vanclay 1990). The maps were initially maintained on paper, but have since been converted to GIS, a process greatly facilitated by our previous work.

MUs were defined for administrative and management convenience, and this meant that many were too heterogeneous for efficient inventory. Thus we encouraged field staff to further stratify MUs into two or three subunits (SUs) as necessary to improve the homogeneity within SUs, conditional that they could nominate some plots to represent each SU. Because of the emphasis on field inventory in the past, plots already existed within many SUs, but where SUs had not previously been sampled, we “borrowed” plots from other SUs considered similar. This was just to get the system operational – these “borrowed” plots would be replaced with new inventory as opportunities arose. Our intention was to obtain two or three plots to represent each SU, an efficient sampling scheme (Schumacher and Chapman 1954) that allowed us to calculate the overall sampling error attributable to field inventory. Because forest inventory data are durable (in the absence of catastrophes, natural forests grow rather slowly and predictably) we were happy to use old data, provided that MUs had not been logged or otherwise damaged (e.g. cyclones, *etc*). However, we encouraged local field staff to be critical of our estimates, and urged them to replace existing data with new inventory for any MUs challenged, something that they could easily do in the course of their work routine. They were specifically encouraged to replace obsolete data and supplement other contested data with new inventory, but were forbidden to introduce bias by discarding “unrepresentative” current inventory or by locating plots subjectively. When first put in place, this system was rather contrived with a misleading amount of plot “borrowing”, but with time and use, it has evolved into a reliable and versatile system.

Lesson 3: Think big, but start small: Devise a way for a simple beginning to evolve efficiently into the grand plan.

A resource forecast combines five components:

1. Area actually available to be logged within each SU. Note that inaccessible areas may comprise areas that can be mapped (roads, buffers, steep slopes) as well as small fragments not able to be mapped but which nonetheless may constitute a significant reduction, especially in steep terrain (Vanclay 1994b)
2. Inventory data characterizing the forest stand within each SU. If sampling errors are desired, at least two plots are necessary for each SU.
3. Growth models to predict increment, mortality and recruitment (Vanclay 1994a).
4. Harvesting models to simulate removals and damage to the residual stand.
5. Volume equations, including adjustments for any defect.

It is unrealistic to expect good agreement between the prediction and outturn for any given MU, since there will always be natural variation and other errors. However, the running average over several consecutive MUs should be comparable. Any discrepancy can be traced to one or more of these five basic components. Some components are easily eliminated; e.g. if inventory data are recent, little or no growth forecasting will have been required so any discrepancies cannot be attributed to the growth model. Similarly, if the reported logging outturn includes tree or log diameters, it may be possible to eliminate volume equations from the list of suspects. It is common for foresters to become preoccupied with amassing inventory data and in honing diameter increment functions, but empirical and simulation studies (Vanclay 1988) show that faulty area estimates are a more common source of discrepancies.

Lesson 4: Maintain an holistic view of the system: identify and work on the weakest component, and try not to finesse your favourite element.

Many yield formulae imply untenable assumptions such as a “virgin” resource, a normal forest or a suspension of harvesting until mid-cycle. Thus for many situations, it is expedient to simulate the actual sequence of harvesting operations across the forest estate and thus to predict the characteristics of the harvest and the residual forest directly (Preston and Vanclay 1988). This is easy with a computer and a system like the one proposed. Our Area Information System provides the basic input to a simulation program that updates all inventory to the present, and then

- a) selects one of the MUs (eg. based on time since logging, stand basal area, or timber yield),
- b) simulates the harvesting of that MU,
- c) calculates how long the target cut can be sustained by that MU,
- d) updates all the plots and other MUs information to that date, and

repeats this cycle endlessly until the resource is destroyed or sustainability is demonstrated (Vanclay 1994b). A relatively simple iterative program of this kind can thus simulate the sequence of harvesting across the resource, provide details of the anticipated harvests (volumes, log dimensions, species composition, etc), and offer several indicators of sustainability (e.g. average stand basal area, standing volumes, prevailing time since last harvest, etc). Various embellishments are possible to make the simulation more responsive to operational constraints (Vanclay 1994b).

The tree-list modelling approach (Vanclay 1994a) is particularly suited for this application because it maintains the inventory data in a relatively unchanged form throughout the simulation, so that it can be saved in temporary files and processed in the same way as any other inventory data. The approach also offers a robust framework that can be adapted to a broad range of forest types. Queensland continues to use the original framework, now applied to a dozen forest types ranging from tropical rainforest to semi-arid woodland. Despite this flexibility, the system is tuned to the Unix operating system and is customized to management *milleau* in Queensland. State Forests of New South Wales have on at least two occasions, considered purchasing it from Queensland as a “turn-key” system, but have prevaricated, apparently because of their different management style. Is it possible to design a system that has broad general appeal but is easily fine tuned to individual client needs?

Challenges and opportunities

Every forester knows the importance of site index in plantation management, yet we seem to overlook the influence of site in tropical high forest. A number of alternatives show promise (Vanclay 1992) but have not received much attention, and warrant further research

Similarly, most of us involved in growth and yield research in the tropics have been frustrated by a lack of data for certain sites and species. It seems reasonable that a well-established relationship for another species occupying a similar niche elsewhere should provide a good basis for inferring growth in data-poor situations. It would be helpful to have some guidelines for choosing such comparable relationships in an objective way (perhaps through plant morphology, e.g. Vanclay *et al* 1997), and for

adjusting them to the new application (perhaps using Bayesian estimation).

When we construct a system as complex as a yield forecasting system for tropical moist forest, it behoves us to examine it carefully to identify its strengths and weaknesses. Sensitivity testing is a good way to gain such insights (Vanclay and Skovsgaard 1997), but it can be a time consuming and tedious undertaking. Such testing could be greatly facilitated if offered as an automated option in the system software, a challenge for software developers.

Ratios of successive (simulated) harvests have been suggested as indicators of sustainability, despite several weaknesses. I find these simple ratios unsatisfactory (Vanclay 1996a), and propose that the potential of the residual (post-logging) stand offers a better basis for inferring sustainability. Unfortunately, a simple index summarizing the vigour of residual stands has not yet been established.

Inventory plots are expensive to establish and maintain, and efficient inventory demands optimal placement of our plots. Temporary inventory plots should be representative of their stratum, and that random placement of two to three plots within each SU is a good way to achieve this. The permanent sample plots on which we base our growth models are even more expensive, and since they are a long-term undertaking they warrant special consideration. They too, should be representative, not of the forest at large, but of the response surface that we try to establish. Thus it is appropriate to sample strata based on the principal predictor variables entertained in our model, to ensure that the response surface can be described reliably (Beetson *et al* 1992).

Conclusion

I think that we have established a good paradigm and clear precedents for yield regulation in tropical moist forests, including those for which data are lacking. Perhaps the most important aspects of the approach outlined above are the need to

- a) adopt a systems approach encompassing a holistic view of forest management, and to
- b) recognise clients, involve them in design and implementation, and ensure the system delivers the information they want, in a format they can use.

Many opportunities exist for further research and development, for application to remaining forested areas in the tropics, and for training and institutional strengthening.

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WORKSHOP CONCLUSIONS

Denis Alder

During the course of this workshop, we have heard of several approaches to yield regulation in tropical moist forest (TMF). These can be generally divided into formula approaches, that assume a large measure of homogeneity of the forest over space and in terms of species and stand structure; and methods based on simulation modelling using more or less detailed information about tree growth and local stand tables. The formula methods necessarily aggregate species into a single 'commercial species' grouping and assume, as well as spatial and structural homogeneity, standard growth and mortality rates. Assumptions or simple calculations have to be made to determine felling cycle and minimum girth limits. Most existing yield regulation formulae neglect felling damage, and terminology is often confused between annual allowable cut, mean annual increment, current increment, and sustainable yield.

Simulation models, on the other hand, do not require assumptions about felling cycle, or girth limit and can to some extent allow for the effects on growth of changes in stand density. In more complex examples, models can be applied to a forest that varies from place to place, so that assumptions about the homogeneity of the stand are not essential. Such models serve as *what-if* platforms for testing various management regimes. The realism of the output depends entirely on the accuracy and completeness of the model. Such models require a knowledge of species growth rates and dynamics which is most frequently not available in a given location.

The present project, of which this workshop forms a part, proposes pooling available data from the institutions represented by the workshop participants. From this database, estimates of growth, mortality and recruitment rates for a large number of species will be obtained in different localities. This can provide a basis for estimating this dynamic data for new localities, based on species size-class distribution and some knowledge of ecology or preliminary indications of growth rate. The results will be a general model that can be applied in a series of easily defined steps to a new situation, given suitable inventory data.

In simpler forest types, such as boreal or temperate broadleaved forests, most or all of the stock may be commercial, and it is possible to effectively model growth in a simple way using an aggregate model for estimating annual allowable cut and sustained yield. In MTF, it is normal that only a small fraction of the growing stock is commercial; the commercial species change over time; and the size-class distribution of commercial species often shows little or no regeneration under closed-canopy conditions. These issues represent very difficult management problems. An effective model can highlight the issues, by demonstrating, for example, that almost any regime that involves the high-grading ('creaming') of a light-demanding species may be non-sustainable without artificial regeneration. On the contrary, management practices that involve use of a broad mix of species can normally be shown to be silviculturally sustainable, but may be economically and commercially unfeasible.

The general yields of MTF calculated in different locations and by various methods are all quite low. Mean annual increments are typically around $0.5\text{-}1.5\text{ m}^3\text{ ha}^{-1}\text{ yr}^{-1}$

for commercial species and trees above 50 cm diameter, with the upper end of the range being mainly associated with Dipterocarp forests in Malaysia and Indonesia, and lower being more typical for Amazonia and Papua New Guinea. West African forests may lie somewhere in the middle of this range. Current increment can vary widely, and may be negative for forests after logging or close to zero in old-growth stands. Direct measurement of increment from permanent sample plots is therefore often confusing, as there is no simple way to estimate mean annual increment; only current increment can be measured. Current increment over all sizes above 10 cm diameter and species can be of the order of 6-8 m³ ha⁻¹ yr⁻¹.

Mean annual increment itself cannot be equated to annual allowable cut, as is done in many formulae for yield regulation. Logging damage typically destroys residual volume on a more or less 1:1 basis, so that each cubic metre removed will be associated with a further cubic metre in losses as lethal damage or total destruction of residual trees. Therefore, AAC should more typically be about half the mean annual increment.

National and institutional approaches to yield regulation often appear to halt at the point of AAC estimation. Even common certification standards such as those of the Forest Stewardship Council appear to be content with designating the existence of PSPs, inventories, yield calculations and plans, without any actual monitoring of their implementation. However, yield regulation implies feedback and control of harvesting operations to keep within sustainable limits.

This workshop, by presenting detailed discussions of these and other issues and giving specific examples of current yield regulation methods in TMF, has provided a basis for the next stage of the project, during which practical procedures will be developed. As the workshop and project title suggest, this will focus on the situation in which many smaller projects, in particular, find themselves of attempting to devise methods and rules for yield regulation in the absence of permanent sample plot data.

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ANNEX 1

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