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RESEARCH AND ECOCHECKICALLY SUSTAINABLE FOREST MANAGEMENT - A DISCUSSION PAPER

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# CONTENTS

## INTRODUCTION

CORPORATE PLAN REQUIREMENTS

ECOLOGICALLY SUSTAINABLE MANAGEMENT

DEFINITIONS IN RELATION TO SUSTAINABILITY

ASSESSMENT OF SUSTAINABILITY

1. **TIME**  
2. **SPATIAL VOLUME**  
3. **SCALE OF OPERATIONS**  
4. **DEVELOPMENT OF PARAMETERS**

RESEARCH OBJECTIVES FOR ECOLOGICALLY SUSTAINABLE MANAGEMENT

PARAMETERS FOR MONITORING

BASELINES AND INTERPRETATION

PRODUCTIVE CAPACITY

DIRECT PRODUCTIVITY MEASURES

MEASURES OF ECOSYSTEM STATUS

GENERAL CONSIDERATIONS

CONCLUSIONS

APPENDIX I  
Soil Nutrient Assessment.  
Interpretation.

APPENDIX II  
Soil Compaction Assessment.  
Interpretation at End of Rotation.  
Interpretation.

APPENDIX III  
Forest Productivity.  
Interpretation.

REFERENCES

<table>
<thead>
<tr>
<th>Table 1.</th>
<th>Effects of scale and the types of parameters estimated.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 2.</td>
<td>Indices and attributes which could be potentially used as ESM parameters in the broad categories relating to Productive Capacity. Direct Measures of production and Measures of ecosystem status.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Figure 1.</th>
<th>Relative time frames in relation to Ecological Sustainable Management (Hamblin 1991).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 2.</td>
<td>Definitions of productivity, stability and sustainability (adapted from Conway 1983).</td>
</tr>
<tr>
<td>Figure 3.</td>
<td>Schematic representation of the effects of clear-felling on water quantity and quality, soil loss and natural regeneration for animal and plant species in native forests in Australia (Hamblin 1991).</td>
</tr>
<tr>
<td>Figure 4.</td>
<td>Hypothetical growth relationship (from Daniel, Helms and Baker 1979).</td>
</tr>
</tbody>
</table>
CONTENTS

INTRODUCTION 1

CORPORATE PLAN REQUIREMENTS 2

ECOLOGICALLY SUSTAINABLE MANAGEMENT 3

DEFINITIONS IN RELATION TO SUSTAINABILITY 6

ASSESSMENT OF SUSTAINABILITY 8
  1. TIME 8
  2. SPATIAL VOLUME 9
  3. SCALE OF OPERATIONS 10
  4. DEVELOPMENT OF PARAMETERS 10

RESEARCH OBJECTIVES FOR ECOLOGICALLY SUSTAINABLE MANAGEMENT 12

PARAMETERS FOR MONITORING 13

BASELINES AND INTERPRETATION 15
  PRODUCTIVE CAPACITY 15
  DIRECT PRODUCTIVITY MEASURES 16
  MEASURES OF ECOSYSTEM STATUS 18
  GENERAL CONSIDERATIONS 18

CONCLUSIONS 19

APPENDIX I Soil Nutrient Assessment. Interpretation. 20
APPENDIX II Soil Compaction Assessment. Interpretation at End of Rotation. Interpretation. 21 21 22
APPENDIX III Forest Productivity. Interpretation. 23 24

REFERENCES 25

Table 1. Effects of scale and the types of parameters estimated. 11
Table 2. Indices and attributes which could be potentially used as ESM parameters in the broad categories relating to Productive Capacity. Direct Measures of production and Measures of ecosystem status. 14

Figure 1. Relative time frames in relation to Ecological Sustainable Management (Hamblin 1991). 4
Figure 2. Definitions of productivity, stability and sustainability (adapted from Conway 1983). 7
Figure 3. Schematic representation of the effects of clear-felling on water quantity and quality, soil loss and natural regeneration for animal and plant species in native forests in Australia (Hamblin 1991). 8
Figure 4. Hypothetical growth relationship (from Daniel, Helms and Baker 1979). 17
INTRODUCTION

State Forests of New South Wales is committed to managing forests on an ecologically sustainable basis through Ecologically Sustainable Management (ESM), and to carry out best forest practices internationally. This discussion paper is the background for a research and monitoring strategy and work program in relation to the ESM in N.S.W. State Forests entailing definitions, statements of objectives and specific program proposals. Some of the identified research is already being undertaken in existing research programs and will need to be maintained, while other work will be new.

For the strategy to be successful, there is a requirement for a common understanding of ESM objectives within State Forests of New South Wales, together with a need for broad external acceptance of these. Further, a program of long term monitoring is required to ascertain whether the ESM aims are being met, supported by an ongoing research program which allows for interpretation of the monitoring program results and provides options for management. A reporting system for ESM monitoring and research has to be established so that results are used and implemented, rather than have monitoring for its own sake. Further, ESM monitoring has to be economically viable and so any program has to be cost effective, well targetted and scientifically sound. Preferably this will be coordinated with other assessments or monitoring requirements, such as those for Environmental Protection Authority (EPA) licenses or in relation to the aims of State Forests for best forest practices. Program proposals and a schedule of activities to meet objectives will be documented separately.
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State Forests of New South Wales, through its Corporate Plan (1992), has stated it will manage its forests on an ecologically sustainable basis using best forest practices. Specifically, objectives of State Forests are:

A1. Achieve ecologically sustainable management by:
   a. Refining concepts and developing measurable indicators of ecologically sustainable forest use.
   b. Incorporating international best practice in ecologically sustainable developments into forest management planning.
   c. Promoting and participating in the development of adequate standards of forest practice.

As part of fulfilling this objective, one specific target is:

Develop a range of performance indicators of ecologically sustainable forest use through a focused research and development program.

In addition to this specific requirement, there are several related objectives and some for which the consequences have an impact. These are:

B1. Increase the economic productivity of State Forests by:
   a. Better utilisation of available timber yield within sustainable levels.
   b. Selective use of more intensive silvicultural management of regrowth forests.
   c. Expansion of native-species plantations.
   d. Improving returns from non-timber related uses of State Forests.

A specific research target within this objective is to:

Implement an enhanced program of research and development on native-species plantations and intensive management techniques for regrowth forests.

In addition to the specific targets, State Forests is committed to the completion of a series of Environmental Impact Statements, which may be expected to have some requirements which relate to, or parallel the objectives and requirements of Ecologically Sustainable Management.

The above provide a broad statement on the objectives of State Forests in this area, and the following discussions are a basis for their implementation. Addressing such a complex, important area is not easy, and hence the reliance on research and case studies in the initial stages, since there appear to be few land management agencies who undertake Ecologically Sustainable Management (ESM) and associated monitoring, to use as a model.
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A basic consideration is to determine what is understood and generally accepted as Sustainability and then to extend the concept to include Ecological Sustainability. A basic precept of forest management is that of sustained yield, that is, not cutting more from the forest than it grows. This concept is not inconsistent with ESM but the question arises as to whether, in maintaining timber yield, other ecological components have been adversely affected or compromised. It is of critical importance, as a baseline, to ascertain productivity and yield for forest areas being managed together with changes in other parameters in relation to this.

Sustainable development has been described as:

'Meeting the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987).

'Being fair to the future, leaving future generations a wealth of inheritance no less than that inherited by the current generation' (Pearce et al. 1989).

Huntley (1991) identified one of the principles of sustainable resource management as "Intergenerational equity: providing for today while retaining resources and options for tomorrow". However, this concept may be interpreted in various ways, for example for ecologists, according to Toman (1992), 'sustainability' connotes preservation of the status and function of ecological systems; for economists, the maintenance and improvement of human living standards. Hence, the broad definitions need to be presented in the context of the specific management undertaking.

In the Commonwealth Government sponsored Working Group on ESD (Green et al. 1991), no specific definition of forestry ESD was presented but referred back to general principles in earlier documents, their recommendations being based on the following principles:

- The need to optimise benefits to the community from all forest uses, in order to improve material and non-material welfare and to meet intra and inter-generational equity objectives;
- The importance of maintaining biological diversity of forests and the maintenance of ecological processes and systems; and
- The need to deal cautiously with risk and uncertainty in decision-making processes and forest uses.

These are broad statements and, even within the particular recommendations, do not suitably address some of the critical issues, especially those related to monitoring ESM in relation to scale of operations, spatial variability and temporal changes which are characteristic of forestry operations.

The Department of Primary Industries and Energy's working paper on sustainability (Hamblin 1991), addressed the principles and problems involved in some detail. In that document: 'Biological sustainability is the ability of a system to maintain its productivity, measured as biomass per unit area per unit time, over many decades - irrespective of short-term fluctuations of output resulting from inter-annual variations, the impacts of pest and disease outbreaks, fire or drought'. This definition focuses on productivity in tangible terms and tries to address consequences of this and as such is applicable to routine and
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practical forest management situations. In so far as forest yield is a component of biomass, if forest structural components are also considered, then 'sustainable yield' is covered in this definition.

Hamblin (1991) also emphasised the long term nature of ESD, and the problem of short term fluctuations, and focused on the Australian situation. Specific relevant conclusions were:

- **Primary industries are dependent on biological systems.**
- **Time scales relevant to biological, hydrological and soil processes are long - from one to many decades. They do not fit well within the short (annual) time-frames of political, monetary and production or harvesting systems (Figure 1).**
- **Major shifts of ecosystems have taken place since European settlement (modified ecosystems have developed and it is from these that we assess future trends in their sustainability).**
- **Adoption of successful sustainable practices will depend on adequate information bases, monitoring the performance of changed practices and improved management levels.**

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A State Forests of New South Wales Working Party proposed the definition of "using, conserving, enhancing community resources so that ecological processes on which life depends are maintained and the total quality of life now, and in the future, can be increased", and this in itself implies enhancement rather than simply maintenance, of ecosystem qualities.

Sustainability has a range of interpretations, however, and as a land managing organisation for a very variable forest resource, we need to consider the maintenance or improvement of productivity and health of the total ecosystem over the long term. Ecological Sustainability has to consider maintenance of both productivity and of the structure of the ecosystem. While there is not necessarily a causative relationship between biologically sustainable productivity and biodiversity, there is a relationship in the requirement for the maintenance of the structure of the ecosystem.
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DEFINITIONS IN RELATION TO SUSTAINABILITY

Definitions provided by Hamblin (1991) are marked with an asterisk.

Communities(*) are assemblages of plants, animals and micro-organisms which live in an environment and which interact with one another to form a distinctive living system: a community has a close-linked, interactive relationship with its environment, and together communities make up an ecosystem. All ecosystems used by humans may be characterised in terms of:

- Productivity (°) of their biological yield over time.
- Stability (°)
- Sustainability (°)

These characteristics are demonstrated in Figure 2 (from Conway 1983) and indicate the importance of sorting out the trend from fluctuations. Part of the problem with the definition of Conway (1983) is the implication that ESM aims to maintain the status quo and that response to change will be a decline, whereas many management practices will lead to an improvement or increase in parameters measured and will improve yield, and this itself may be an objective.

Productivity(*) is the amount of biomass produced per unit area per unit time.

Stability(*) is the degree to which productivity remains constant in spite of normal small-scale fluctuations (e.g. season to season variation).

Stress(*) can be defined as regular, or continuous relatively small and predictable disturbance(s).

Perturbation(*) is defined as irregular, infrequent, relatively large and unpredictable disturbance(s).

Sustained yield has been defined as the regular, continuous supply of the desired produce to the full capacity of the forest (Osmaston 1968), while Sustainable yield never falls, so temporary increases in yield are not admissible but only those that can be permanently maintained. The term Sustained productivity can refer to a continuity of growth and a continuity of yield or harvest and hence the term Sustained yield management most accurately refers to continuity of harvest (Davis 1966).

Sustainability(*) is the ability of the system to maintain its productivity with no net decline over many decades, even if subjected to stress or perturbation. Key indicators(*) reflect the status or condition of the different ecosystem components.

In addition, there needs to be clear distinction between individuals, species and communities, considering that ESM is targeted towards the maintenance of the community and the contained species. A species is a class composed of individuals having common characteristics.
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1. **TIME**

All discussions on ESM stress the requirement for inclusion of long term assessments, that is, a minimum of several decades. Hence, systems capable of giving accurate comparisons over this time period, and accounting for fluctuations over time, are required. Changes and fluctuations will vary with the component, as shown schematically in Figure 3. Hence, monitoring over time will need to consider:

![Graphs showing changes over time](figure3)

**Figure 3.** Schematic representation of the effects of clear-felling on water quantity and quality, soil loss and natural regeneration for animal and plant species in native forests in Australia (Hamblin 1991).
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(i) Background changes or biological variations.

(ii) Fluctuations due to stress (stress being primarily non-management related).

(iii) Short term and longer term changes due to perturbation. Perturbations are primarily resulting from management, although including natural phenomena, and thus are the main interest of monitoring and reporting.

Direct comparison with regularly monitored standards or controls is one way of overcoming the combination of (i) and (ii). The selection of appropriate controls is in itself critical, and will need to form part of the research undertaking. However, it is apparent that any ESM monitoring in the short term will show changes to the system (e.g. monitoring understorey immediately after a fire will show a major decrease in biomass compared with that before the fire), but it is the long term effects on overall ecosystem productivity, structure and function which are critical. Definitions of time frames are difficult and relate to the type of land use, but for forestry purposes it is proposed that 0-5 years is very short term, 6-12 years is short term, 13-30 years (up to one rotation in a plantation) is medium term, 31-90 years (the approximate cutting cycle in many hardwood forests) is long term, while beyond 90 years is very long term.

2. SPATIAL VARIATION

Spatial variation is generally high for forest ecosystems and how this is evaluated is dependent upon the parameter, the sampling methods and the size of the area considered. Where assessments are carried out, some variation may be accounted for by such a technique as stratification, but the strata will need to be parameter-specific in order to have relevance. For example, the strata and scale used for arboreal animals where a transect could be 0.5 - 1 km, may be irrelevant for soil nutrients or invertebrate assessments, that is the scale of measurement needs to take target size and abundance relative to the landscape into account.

Spatial variation is in itself related to the scale of forest management operations, and in sampling we need to consider units as:

(i) Region (10,000 - 100,000 ha).

(ii) Landscape/catchment/land unit/land management unit (e.g. 500 - 10,000 ha).

(iii) Ecosystem/forest type/strata (e.g. 1 - 500 ha).

(iv) Point/site specific/transect sampling.

The scale of operations may vary and be an amalgamation of catchments or land units. The Regional level is probably the scale at which initial forestry ESM needs to be undertaken, i.e. 20,000-50,000 ha depending upon the variability involved. Scale for key indicators is one aspect needing re-appraisal as case study information becomes available.
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3. SCALE OF OPERATIONS

The scale of management operations is an important consideration in analysis of ESM research and related monitoring. Specific intensive plot-based monitoring will reduce variation but the scale may not suit some components being measured and may not relate to the scale of management operations. Any analysis will need to be relevant at the management scale.

If ESM is being interpreted at the compartment scale, and if yield or a biological parameter is being used for monitoring, then areas taken out of production, such as snig tracks or log dumps need to be adequately accounted for. For example, if compaction due to snig tracks covers 10% of the area, the remainder of the compartment may have to additionally produce the equivalent of 10% in order to maintain sustainability overall where the initial compartment area is used for comparison. This difference will not be reflected on an individual plot basis and indicates that the basis for monitoring and analysis has to be stated prior to commencement of the work and *a priori* statements on interpretation need to be made - for example, baselines, rates of change, productivity rates and areas covered or included (Table 1). This type of consideration may become irrelevant at the large, for example Regional scale.

It is essential to define ESM in relation to scale of operations and as the differences of scales used in ESM will have varying consequences for interpretation. Ideally ESM should be over as large an area as possible as discussed above in point 2 (spatial variation).

4. DEVELOPMENT OF PARAMETERS

To ensure that management of an area is fulfilling ESM objectives, monitoring and development of key indicators are required. Considering temporal, spatial and disturbance factors, several indicators will need to be measured in conjunction. Over the range of possible variables that may be measured within a system a selection of meaningful, readily measured indicators needs to be identified. To this end, research is required to identify indicators and provide interpretation.
3. **SCALE OF OPERATIONS**

The scale of management operations is an important consideration in analysis of ESM research and related monitoring. Specific intensive plot-based monitoring will reduce variation but the scale may not suit some components being measured and may not relate to the scale of management operations. Any analysis will need to be relevant at the management scale.

If ESM is being interpreted at the compartment scale, and if yield or a biological parameter is being used for monitoring, then areas taken out of production, such as snig tracks or log dumps need to be adequately accounted for. For example, if compaction due to snig tracks covers 10% of the area, the remainder of the compartment may have to additionally produce the equivalent of 10% in order to maintain sustainability overall where the initial compartment area is used for comparison. This difference will not be reflected on an individual plot basis and indicates that the basis for monitoring and analysis has to be stated prior to commencement of the work and *a priori* statements on interpretation need to be made - for example, baselines, rates of change, productivity rates and areas covered or included (Table 1). This type of consideration may become irrelevant at the large, for example Regional scale.

It is essential to define ESM in relation to scale of operations and as the differences of scales used in ESM will have varying consequences for interpretation. Ideally ESM should be over as large an area as possible as discussed above in point 2 (spatial variation).

4. **DEVELOPMENT OF PARAMETERS**

To ensure that management of an area is fulfilling ESM objectives, monitoring and development of key indicators are required. Considering temporal, spatial and disturbance factors, several indicators will need to be measured in conjunction. Over the range of possible variables that may be measured within a system a selection of meaningful, readily measured indicators needs to be identified. To this end, research is required to identify indicators and provide interpretation.
Table 1. Effects of scale and the types of parameters estimated.

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RESEARCH OBJECTIVES FOR ECOTOLOGICALLY SUSTAINABLE MANAGEMENT

Monitoring carried out in relation to ESM provides information on the forest system and the effects of management. Research aims at carrying out analyses which explain the significance of the selected parameters and some of the underlying processes.

Research objectives for ESM are:

(i) To consider management alternatives for different forest ecosystems, including plantations, to determine impacts on long term viability and to provide options to managers.

(ii) To determine parameters that firstly indicate the potential for long term productivity changes, secondly, allow for direct assessment of ecosystem productivity and thirdly, assess the health and status of the ecosystem.

(iii) To develop base lines for parameters to ascertain any levels of change.

The first objective will require research into the interactions between different management procedures, and impacts on growth and health of the system. The experiments will vary according to the forest type but this will also include the potential for increasing the productivity of the system, as proposed in the corporate objectives of State Forests of N.S.W. Many trials already exist which relate or potentially relate to these objectives, but some new trials will need to be included.

The second objective is to provide parameters which measure the status of the ecosystem in terms of productivity and health, and also indicate possible future changes or patterns. There are three broad groups of parameters to be considered:

a) Those which affect the productive capacity of a site. These will primarily focus on soils (nutrients, erosion, soil compaction, loss of area due to roading) and are referred to as Productive Capacity Parameters.

b) Those which are direct measures of ecosystem productivity and are referred to as Direct Productivity Parameters. These would ideally include biomass production and organic matter turnover, but will be logistically difficult over wide areas and analogues will probably be required. Commercial productivity and yield are part of this, but as yield would vary over time due to market changes, it can only be considered a secondary measure.

c) Those which directly and indirectly measure ecosystem status or health, including vegetation and understorey diversity, animal populations and diversity, invertebrate populations, pests and diseases. Theoretically, a significant shift in species composition or population levels relate, directly or indirectly, to the production processes of the ecosystem, and hence to long term productivity. These relationships need as yet to be clearly defined. The parameters will not be universal and will have to be interpreted in relation to the research hypotheses and results, but they are referred to as Status Parameters.
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The third research objective is to develop baselines to enable measurement of change. The baselines may range from usage of control areas in natural systems to theoretical values for disturbed ecosystems. For many parameters, it is expected that the baseline will not be fixed or standard, but will change over time, for example due to forest development, which in itself requires theory and understanding of longer term forest dynamics.

PARAMETERS FOR MONITORING

In principle, parameters suitable for monitoring should be selected only after research is completed, but this would considerably delay monitoring programs. An alternative is to use expert advice to select some indicators and use these, at a management scale, in parallel with the research programs and as a feedback to research programs. The indicators may need to be modified as a result of improved research and in addition research can in part, be more focussed to allow for improved interpretation of the indicators. Considering that long term productivity and sustainability may be affected at a number of stages during a management cycle, the types of operations involved also need to be considered. However, it is apparent that multiple parameters need to be measured on any given area, that is, there is no single parameter which will give an indication of sustainability.

Expert advice via researchers within the Research Division of State Forests of N.S.W. provided some indices related to ecological sustainability. The definitions of time horizons are arbitrary but indicate when an effect potentially related to long term sustainability can be detected, rather than necessarily being able to detect a significant change per se (Table 2). As stated previously, very short term is 0-5 years, short term may be up to 6-12 years, moderate term 13-30 years and long term 31-90 years. Very long term varies up to 90 years plus.
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Table 2. Indices and attributes which could be potentially used as ESM parameters in the broad categories relating to productive capacity. Direct measures of production and measures of ecosystem status.

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A proposed list from which to select indicators for immediate use in routine management and research activity includes:

1. **Turbidity of water.**
2. **Soil nutrient status.**
3. **Soil compaction** (area or proportion of area affected).
4. **Regeneration of tree species.**
5. **Tree size class distribution** and change. Basal area and increment by species.
6. **Merchantable timber** and yield.
7. **Wood decay incidence** (defects).
8. **Vascular plant species richness and abundance.**
9. **Abundance and richness** of fauna.

A selection of parameters considered, and agreed upon as important, would be used within a management area and forest type.

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**BASELINES AND INTERPRETATION**

The critical characteristics of sampling and analyses for ESM relate to scale of activity over a long period of time. The definition of a baseline control or method interpretation for each parameter is fundamental to this. The measurements in relation to the baseline may be made by using a control area/plot/population/catchment or by using the commencing situation. However, whatever is used, the basis of comparison has to be stated from the outset and basic to this is a clear statement of the objectives. Rather than direct comparison with specified baselines for some parameters, increases or decreases in variability may be more relevant or more sensitive.

**PRODUCTIVE CAPACITY**

1. **Estimation of runoff water quality**, specifically turbidity of water. The aim would be to ascertain significant changes in turbidity, pH and conductivity in a relatively large catchment (e.g. 5,000 ha) in which harvesting is to be undertaken, and if change occurs then the time to return to normal. The main parameters will be measured on samples taken at the exit of the catchment. The control will be an adjacent, equivalent catchment. Absolute water quality of undisturbed catchments will vary due to geology differences and hence fixed standards are not appropriate. It is expected that with additional internal catchment sampling, that is, below logged and unlogged compartments, and above and below where roads cross creeks, that this will be of direct relevance to EPA licensing conditions. Reporting will need to be annual, and will include interpretative information, such as cumulative area harvested.
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2. Soil nutrient pool changes will only be measurable over a longer period and after some specific disturbances. However, characterization is required so that via research, 'more' or 'less susceptible' (susceptible to nutrient loss) can be defined. This will require being able to relocate the area and re-sample in the same way. Changes could occur through harvesting, burning, erosion or fertilizer additions. Monitoring programs would initially aim at defining the range of nutrient status as a baseline and would be formally reported. Past research areas can be used immediately for the purpose. An example is shown in Appendix I.

3. Measurement of soil disturbance due to harvesting or other practices. Aspects of the problem have been reviewed (Lacey 1992) and actual indicators now need further consideration. One aim may be to estimate the area and type of soil disturbances in selected compartments of pine plantations or native forests at the end of the rotation or after harvesting operations. The estimates, possibly from aerial photography, would be the area, as % of total disturbed and would include spot checking for verification and measurement. Research would be required to translate a level of compaction on each soil type into a productivity loss. Subsequent measurements would be needed to verify level of amelioration at time of conversion from 1R to 2R. Reporting on success of amelioration will be a critical factor and be reported periodically; a comparison of tree growth and compartment areas would be one indicator. The base line bulk density would be considered to be the area without snig tracks. Possible reporting format is shown in Appendix II.

DIRECT PRODUCTIVITY MEASURES

A direct productivity measure is organic matter production per unit area, although often only specific components of this are consistent.

Many of the measures of productive capacity are related to one another. For example:

a. Total aboveground nett productivity (t/ha/yr) = Tree productivity + Woody understorey productivity + Non-woody understorey productivity

Forest studies of this type are by necessity, long term (Attiwill 1979).

b. Tree productivity includes the productivity of commercial species plus that of non-commercial species for a range of size classes. The commercial volume is a component within the commercial mass. The productivity for a given period, can be affected by selectivity of harvesting, by increasing productivity through fertilizer application, or by reducing defect.

c. Woody understorey includes regeneration of commercial and non-commercial trees.

d. Non-woody understorey includes a large proportion of fodder for grazing.

Total productivity of the system could be maintained or increased but yield could decrease because of changes in acceptable defect or acceptable species or in size classes. Extension of productivity from a plot basis to a catchment or other land unit is more difficult, but is more relevant to management, and approaches to address this problem this will need to be developed (Turner et al. 1992).
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- Yield
- Mortality
- Thinnings
- Current annual gross increment
- Mean annual gross increment
- Current annual net increment
- Mean annual net increment

![Figure 4. Hypothetical growth relationship (from Daniel, Helms and Baker 1979).](image)
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![Diagram showing growth relationship](image)

**Figure 4.** Hypothetical growth relationship (from Daniel, Helms and Baker 1979).
4. *Regeneration of tree species* is critical for future forest productivity and will involve the number of stems regenerated per hectare, the abundance and distribution of species, and subsequent estimation of growth rates. The baseline will involve the specified average minimum number of stems regenerated per unit area, while the species distribution will relate to specified pre-harvesting condition or a modification thereof. Desirable or acceptable growth rates are difficult to define and will require modelling of the future stand, however, a defined acceptable baseline can be developed.

5. *Tree size distribution and change* (increment) will be based on a species, size class or plot basis and would use regional data from permanent growth plots or an equivalent system. The baseline would be an unmanaged system, a stated modification of this, or a selected modified structure. An example of the type of data is shown in Appendix III.

6. *Merchantable volume (and yield)* is in part market dependent but estimates of long term tree harvesting effects are critical in ascertaining sustainability (included in Appendix III). Reporting on these should commence as soon as practicable.

7. *Wood decay incidence* is a secondary measure of productivity, and the methodology and baselines are as yet unspecified.

**MEASURES OF ECOSYSTEM STATUS**

Measures of ecosystem status are probably the most difficult to estimate. Focus is on interactive typical components of ecosystems and not on the rare or unusual components of the system.

8. *Vascular plant species richness and abundance.* This will require re-assessment of a range of permanent plots. Standards will need to be plots which are undisturbed or infrequently disturbed or areas typical of the management area. The problem will be the short term species shift, especially with the effects of opportunistic species and hence results will need to be derived from intensively sampled long term study plots or large numbers of broader based plots.

8. *Abundance of fauna.* Assessments of vertebrate fauna will need to be on a broad regional basis and be calculated both from summation of strata and modelling approaches. The baseline will be a specified population level with a fluctuation range. Invertebrate fauna are being researched, but no proposal for routine monitoring has been developed to date.

**GENERAL CONSIDERATIONS**

Production forests are economically valuable ecosystems, managed on a commercial basis. As such, long term research and monitoring cannot be undertaken either for their own sake or just as an academic exercise. Both the process and the results of research and monitoring must be relevant to managers. The monitoring must:

- Be relevant, or potentially relevant to the ESM process.
- Have high level of relevance to the management goals of the forests.
- Be cost effective.
- Have a relevant and interpretable reporting system.
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Further, the research integral to ESM should:

- Provide sound and defendable scientific bases for the monitoring.
- Allow interpretation of monitored parameters.
- Provide options for change (that is provide a range of options for management).
- Develop questions to be considered in future management.
- Integrate measurement of parameters on reasonable scales.

Considering this, the main problems are the need for:

- Long term commitments to fulfil the requirements of ESM.
- Short term reporting to show the value to stakeholders, in addition to the long term value to State Forests of N.S.W.
- Interpretation of parameters.
- External acceptability of the process.
- The lack of simultaneously gathered parameters by research for one location/area.
- Determining the most significant or sensitive parameters, for example a focus on rare plant or animals may be a diversion from initial processes.

CONCLUSIONS

The aim of State Forests of New South Wales is to manage its forests in an ecologically sustainable manner and monitor the undertakings to both improve forest management and demonstrate the results of its management. ESM at this time has been defined in very broad terms and there are few monitoring programs in place which are sensitive to specific management practices. State Forests of N.S.W. propose to undertake monitoring, recognising that the initiative will be both valuable and may require modifications based on research results obtained.

Future research will need to be both long term and focussed. Some existing experiments will provide a basis for the program, but new trials will be necessary.

Initially, a plan to demonstrate approaches to monitoring and researching ESM will be undertaken in the short term on a case study basis for which a plan will be prepared. Thereafter, the system will be extended to cover the entire forest estate, with an initial aim to report on productivity and yield in relation to specific ecological parameters.
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APPENDICES

The Appendices include several possible areas of monitoring, showing types of results and how they may be interpreted. The aim here has been to keep them simple, short and, where possible, based on published data.

APPENDIX I - SOIL NUTRIENT ASSESSMENT

Soil nutrient supply is critical for maintaining long term forest productivity. However, short term fluctuations in nutrients do not reflect long term supply while fluxes and removals are more difficult to define (Gholz and Comerford 1991). At Manning River National Forest, two sites have been analysed.

Results have been calculated on the assumption of an average removal of wood of 1.25 m$^3$/ha/yr, predominantly blackbutt sawlog (based on Kendall Management Area). Over 80 years, this equates to 2.4 kg P/ha and 74 kg Ca/ha removed.

<table>
<thead>
<tr>
<th>Depth (mm)</th>
<th>No. samples</th>
<th>pH</th>
<th>Total P (kg/ha)</th>
<th>Ex - Calcium (kg/ha)</th>
<th>Percent removal in harvesting over 80 years P (%)</th>
<th>Ca (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-75 mm</td>
<td>6</td>
<td>5.18</td>
<td>132</td>
<td>655</td>
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<td>11.0</td>
</tr>
<tr>
<td>0-400 mm</td>
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<td>-</td>
<td>496</td>
<td>1423</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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This provides base information only, and for reasonable monitoring would include detailed information on nutrients, depth and description.

INTERPRETATION

There is differential nutrient removals and the more sensitive nutrients for specific sites need to be identified. We need to better refine our information on impacts and that the focus on nutrients will be site specific, for example, Soil 1 could have experienced an 11% decline in Ca over the last 80 years, but at this time we do not have evidence as to the implications of that removal. The focus should be more on calcium than on phosphorus, particularly for the poorer soils. This is supported by existing studies (Turner and Lambert 1986, Hopmans et al. 1993).
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APPENDIX II

SOIL COMPACTION ASSESSMENT

The aim is to ascertain, on sample areas, the area disturbed and the degree to which it is disturbed, impacts and possible amelioration. Data are based on a 1976 survey of Red Hill plus subsequent independent studies on soil parent materials for the Soil Technical Classification (Turner et al. 1990, Turvey et al. 1990).

1. Soil strength as measured by bulk density is the characteristic considered. Features include the area (%) affected in the management unit (compartment), the extent of effect and subsequent amelioration by site preparation. This last factor should be used as an indicator of the success of our management practices.

2. Location: Red Hill Section, Buccleuch State Forest, Compartment 27. Pine plantation at end of rotation, plus adjacent Eucalyptus forest both on Parent Rock Code II. Few sites would be available for a comparison of native forests, and for newer areas it is not applicable, but it is shown here as a base line.

3. Assessment date - from aerial photographs follow:

<table>
<thead>
<tr>
<th>Component area</th>
<th>29.0 ha (from Soil Technical Classification)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area in snig tracks</td>
<td>4.6 ha (16%)</td>
</tr>
<tr>
<td>Other soil movement</td>
<td>0.6 (2%)</td>
</tr>
</tbody>
</table>

4. Permanent transect assessment of bulk density in compartment plus permanent transect in adjacent native forest to be used as baseline.

<table>
<thead>
<tr>
<th>Mean B.D.</th>
<th>Standard deviation</th>
<th>C.V.%</th>
<th>No. of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>g/ce</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Native eucalypt forest</td>
<td>1.23</td>
<td>0.12</td>
<td>9.7</td>
</tr>
<tr>
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<td>1.33</td>
<td>0.16</td>
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<tr>
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INTERPRETATION AT END OF ROTATION

At the end of this rotation, there is increased compaction overall from the pine operations with marginal increases off-snig tracks. The overall variability is greater and 18% of the area is compacted to a level where its expected growth would be significantly (commercially) reduced. The reduction in this parameter may be entirely physical or include an element of soil organic matter loss.
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The same transects in pine assessed:

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</tr>
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* Small areas retained untreated for purposes of assessing value of management practices.

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The area was ploughed during site preparation, except for two small areas on and off snig tracks, again to be used for base line areas for tree growth. The ploughing reduced bulk density, and overall the variability i.e. C.V. was reduced from 22.8 to 10.3% to be more typical of the pre-establishment area. Growth estimates indicate the old snig tracks were lower than non-snig tracks, but better than the non-treated areas.

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FOREST PRODUCTIVITY

An estimation of sustainable productivity has been made using long term results from Kendall Management Area (Horne and Carter 1992).

AREA: KENDALL MANAGEMENT AREA
LOCATION: KENDALL
FOREST TYPE: BLACKBUTT

Consideration for forest productivity ESM assessments on a total area basis. Aiming for long term productivity, we need to retain growing stock intact. An approximate breakdown of forest types needing refinement in this area is as follows:

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</tr>
<tr>
<td>Unlogged</td>
<td>-</td>
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<tr>
<td>Regrowth with scattered veterans</td>
<td>147</td>
</tr>
<tr>
<td>Before 1945</td>
<td>1430</td>
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<td>1945-1960</td>
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<td>1960-1990</td>
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<td>2548</td>
</tr>
<tr>
<td>Other forest</td>
<td>3032</td>
</tr>
<tr>
<td>Non productive</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>22,865</td>
</tr>
</tbody>
</table>

(N.B. Areas adjusted from Management Plan)
Growth assessment based on 336 CFI plots over 30 years. Trees greater >10 cm. (Table 2, Horne and Carter 1992, Hoschke 1973).

<table>
<thead>
<tr>
<th>Year</th>
<th>Volume (m$^3$/ha)</th>
<th>Stocking (trees/ha)</th>
<th>Total removal over 70 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>128.2</td>
<td>212</td>
<td>101,836 m$^3$</td>
</tr>
<tr>
<td>1990</td>
<td>122.0</td>
<td>354</td>
<td></td>
</tr>
</tbody>
</table>

Changes over time due to logging (Table 4, Horne and Carter 1992).

<table>
<thead>
<tr>
<th>Stocking (trees/ha)</th>
<th>Area diameter (cm)</th>
<th>Bole Ht (m)</th>
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<tr>
<td>Logged plots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1960</td>
<td>218</td>
<td>34.9</td>
<td>103.9</td>
</tr>
<tr>
<td>1976</td>
<td>495</td>
<td>26.8</td>
<td>139.0</td>
</tr>
<tr>
<td>1980</td>
<td>349</td>
<td>29.4</td>
<td>119.6</td>
</tr>
<tr>
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<td>355</td>
<td>29.3</td>
<td>127.9</td>
</tr>
<tr>
<td>Unlogged plots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1960</td>
<td>204</td>
<td>43.5</td>
<td>160.1</td>
</tr>
</tbody>
</table>

INTERPRETATION

The structure, productivity and yield of the forests indicate it is being managed on a sustainable basis. There is the potential to further modify the structure in the future and this will be done in the light of the information on other values and processes.
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Total removal over 70 years 101,836 m$^3$

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<tr>
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<td>34.9</td>
<td>8.7</td>
</tr>
<tr>
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REFERENCES


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Copies and further information are available from:

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