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EVALUATION OF SANTIAGO DECLARATION (MONTREAL PROCESS) INDICATORS OF SUSTAINABILITY FOR AUSTRALIAN COMMERCIAL FORESTS.

A NEW SOUTH WALES ALPINE ASH FOREST AS A CASE STUDY

John Turner

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STATE FORESTS
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INTRODUCTION

International recognition of the importance of the maintenance of ecological diversity has resulted in a number of initiatives designed to ensure the sustainable management of the world's forests. Australia is a signatory to the *Santiago Declaration on sustainable management of boreal and temperate forests* (refer to Turner *et al.* 1996a, Appendix 4), which includes the aim of maintaining or achieving sustainable management of forests by the year 2000. The Santiago Declaration includes seven criteria and associated indicators which it claims "characterise the conservation and sustainable management of temperate and boreal forests". The document also states that "given the wide differences in natural and social conditions among countries, the specific application and monitoring of the criteria and indicators, as well as the capacity to apply them, will vary from country to country based on national circumstances". The Forest & Wood Products Research & Development Corporation and the members of the Research Priorities Coordination Committee for the Standing Committee on Forestry are funding a national project to assess the applicability of the proposed criteria and indicators to Australian conditions and begin the process of applying them.

The objectives of this project have been described in *Evaluation of Santiago Declaration (Montreal Process) indicators of sustainability for Australian commercial forests* (Turner *et al.* 1996) and are outlined below.

1. Review, define and further develop indicators of sustainable management for Australian production forests (native and plantation), based on the indicators proposed in the Santiago Declaration.
2. Apply selected indicators from (1) over a range of Forest Types to test for their general applicability.
3. Define and implement research programs which:
   - test and calibrate standard methodologies for measuring the selected indicators;
   - interpret and report on sustainability indicators;
   - provide alternative strategies for sustainable forest management based on the indicators; and
   - identify further research and development priorities.
4. Provide a basis for the development of a cost-effective internationally recognised certification scheme for sustainably managed forests in Australia.

This report is part of the second part of this process. It deals with the application of the indicators to case study areas to test their applicability, the availability and suitability of information and, where necessary, identification of research and development requirements.

This report presents information on Bago and Maragle State Forests. It relies on the initial analysis of Turner *et al.* (1996a) along with more detailed information provided in the appendices. The aim is to apply information to proposed indicators and consider whether they are relevant or valuable at the management unit level. Where indicators are considered to be of little value, alternatives are discussed. Information was only available for a select number of indicators, consequently not all indicators are discussed in this report.

CASE STUDY AREA

Bago/Maragle State Forests are situated near the towns of Batlow and Tumbarumba on the south-west slopes of New South Wales. The total area is approximately 48,000 ha, located between 400 m and 1,440 m a.s.l. Annual precipitation ranges from approximately 1,100 mm in the lower altitude areas to 1,400 mm in the higher central portion of the plateau.

Bago/Maragle State Forests fall within a broader regional context containing National Parks, private land and considerable areas of plantations. Kosciusko National Park is situated in close proximity to the east with pine plantations and cleared land on the other boundaries.

Both forests are commercial, production forests primarily utilising alpine ash (*Eucalyptus delegatensis*) with secondary species of mountain gum (*E. dalrympleana*) and peppermint (*E. radiata*). Parts of these forests have been utilised for timber production since the turn of the century and it is this long history of timber production that make them of value as a case study area.

ANALYSIS OF INDICATORS

The criteria and indicators discussed in this section are analysed in the order presented in the Santiago Declaration. Indicators are considered in terms of their relevance to management, whether they are site specific, the ease of obtaining data and their reliability.

CRITERION 1: BIODIVERSITY

Criterion 1 is composed of three sub-sections with specific indicators related to each. These sub-sections are:

- Ecosystem Diversity;
- Species Diversity; and
- Genetic Diversity.

Species Diversity and Genetic Diversity are not discussed in this report as the indicators listed under these sections are considered mainly inappropriate at the management unit level (Turner *et al.* 1996a).

1i. ECOSYSTEM DIVERSITY

Indicators

a. *Extent of area by forest type in relation to the total area of forest.*

b. *Extent of area by forest type and by age class and successional stage.*

c. *Extent of area by forest type in protected area categories as defined by IUCN or other clasification systems.*

d. *Extent of areas by forest type in protected areas defined by age class or successional state.*

e. *Fragmentation of forest types.*

Discussion

Forest Types may be defined in a number of ways. Within Bago/Maragle State Forests, Forest Types are classified according to the New South Wales State Forests Forest Typing system (Anon 1989) based on the overstorey canopy species. This system does not address structure or understorey species. The areas of Forest Types within the forest management unit can be addressed easily, however at a regional level this becomes more difficult as lands under other tenures are mapped using different systems or not at all. The distribution and areas of Forest Types in Bago/Maragle State Forests and known values in other tenures are shown in Table 1.

Within adjacent areas, these Forest Types also exist, although precise information on their extent is limited. Comparable Forest Types are found within neighbouring Kosciusko National Park (although using a broader system of description) as shown in Table 2. Reference to these Forest Types indicates significant communities within the 670,000 ha of Kosciusko National Park but not their actual area (except for Alpine Ash in Montane Sclerophyll Forest).

Table 1. Forest Types within Bago/Maragle State Forests and comparison of Alpine Ash Types within other land tenures.

Forest Type No.	Description	Bago/Maragle State Forests Area	%	Other	National Park* Area	Private Area	Total Area
103	Apple Box	11	0.0				
111	Peppermint	1,813	3.7				
124	Red Stringybark	2,560	5.3				
125	Red Stringybark/ Brittle Gum	68	0.1				
131	Peppermint/Mountain Gum/Manna Gum	11,211	23.1				
136	Snow Gum/Black Sallee	2	0				
137	Black Sallee	419	0.9				
138	Snow Gum	399	0.8				
140	Snow Gum/ Mountain Gum	13,708	28.3				
143	Broad-leaved Sallee	390	0.8				
147	Alpine Ash	8,659	17.9}	4,840	62,000	3,000	83,400+
148	Alpine Ash/Gum	4,901	10.1}				
159	Mountain Gum/ Manna Gum	1,313	2.7				
160	Manna Gum	3	0				
164	Eurabbie	1,308	2.7				
	Treeless	1,416	2.9				
	Research/reserve	209	0.4				
Total		48,430	100	4,840	62,000	3,000	83,400

* The National Parks include Kosciusko and Brindabella.

\+ Includes the area of Forest Type 148 in Bago/Maragle State Forests.

Table 2. Forest Types within Kosciusko National Park.

Forest Type	Description	Comparable Type in Table 1
Dry Sclerophyll Forest	*Eucalyptus macroryncha* (red stringybark) and *E. rossii* (scribbly gum) with *E. dives* (broadleaved peppermint) on colder sites. Ground cover includes grass (*Danthonia* spp.) and herbs (e.g. *Helichrysum*).	124, 125
Wet Sclerophyll Forest	Dominated by *E. fastigata* (brown barrel) and *E. viminalis* (ribbon gum) together with *E. radiata* (narrow leaved peppermint). Understorey species include *Dicksonia antarctica* (tree fern) and *Acacia melanoxylon* (black wattle).	111, 159, 160
Montane Sclerophyll Forest	Alliance of *E. dalrympleana* (mountain gum) and *E. delegatensis* (alpine ash*). Understorey may include *Daviesia* spp., *Platylobium* spp., and *Acacia dealbata* (black wattle).	131, 140, 147, 148
Montane Savannah	Associations of *E. pauciflora* (snow gum) and *E. stellulata* (black sallee) or *E. stellulata* (black sallee) alone are found in areas with poorly drained or aerated soils. A grass understorey of *Poa caespitosa* forms.	136, 137
Subalpine Woodland	Dominated by forests of *E. pauciflora* ssp *niphophila* (snow gum).	138

* Refer to Table 1 for information on area of Forest Types 147 and 148.

Indicator a. Extent of area by forest type relative to total forest area.

Within Bago/Maragle State Forests, the extent and percentage of overstorey Forest Types (Table 1) is an indicator of the sustainability of a Forest Type. Utilising existing Types (Anon 1989) information is presently available. This indicator is relevant to most forests.

Indicator b. Extent of area by forest type and by age class or successional stage.

Information on the extent of Forest Types by age class and successional stage is not available and probably not applicable considering forest disturbance and logging history. Structural groupings are considered more appropriate, both for indicating the stage of stand development and successional stage. Information is not generally available in a standard, accepted system, but this would be of value if developed.

Indicatar c. Extent of area by forest type in protected area categories as defined by IUCN or other classification systems; and

Indicator d. Extent of areas by forest type in protected areas defined by age class or successional state.

These indicators address the degree to which Forest Types are conserved and are valuable at a regional level (or above). They are of limited value at the management unit level alone. To interpret them it is necessary to go beyond management unit boundaries and across tenures.

In the examination of Bago/Maragle State Forests interpretation of these indicators is limited by lack of information. In Table 1 a comparison is provided of Alpine Ash Types in Bago/Maragle State Forests and other land tenures, permitting a regional assessment to be made. Based on this comparison, 74% or 62,000 ha in 83,400 ha of the Alpine Ash Types in New South Wales are found in formal reserve systems. Alpine Ash forests are the main type of commercial forests found in New South Wales.

Indicator e. Fragmentation of forest types.

Estimates of fragmentation are difficult to analyse in these areas as most of the commercial forests are in relatively large blocks. No simple index of fragmentation is immediately available and is probably not applicable to a contiguous block of forest.

CRITERION 2: MAINTENANCE OF PRODUCTIVE CAPACITY OF FOREST ECOSYSTEMS

Indicators

a. Area of forest land and net area of forest land available for timber production.

b. Total growing stock of both merchantable and non-merchantable tree species on forest land available for timber production.

c. The area and growing stock of plantations of native and exotic species.

d. Annual removal of wood products compared to the volume determined to be sustainable.

e. Annual removal of non-timber forest products compared with the level determined to be sustainable.

Discussion

Estimations of these indicators for Bago/Maragle State Forests are presented in Table 3. Details of calculations are presented in Appendix 1 (Hatich *et al.* 1995).

Table 3. Sustainability indicators for Bago/Maragle State Forests.

Descriptor	Area (ha)	Timber volume (m^3 x 1000)	Derived values
Indicator a			
Area available for timber production	23,000		
Total forest area	48,430		
Percentage of area for production			47.5 %
Indicator b			
Total merchantable growing stock		2,645.6*	
Total non-merchantable growing stock		0.0*	
Indicator c			
Average growing stock per productive ha			115 m^3/ha
Indicator d			
Average annual yield		25.0*	
Estimated sustained yield		27.5*	
Average annual yield per ha			1.09 m^3/ha
Yield ÷ sustained yield			0.91
Indicator e			
No information available			

* 1984 estimate (see Hatich *et al.* 1995).

Indicator a. Area of forest land and net area of forest land available for timber production.

The estimation of the area of land available for timber production, and its change over time, is an appropriate broad indicator of sustainability. The definition of what is to be included in such an estimate needs to be clarified to permit comparisons between forests and to take into account changes in the forest over time. The definition would need to consider whether it is the area of production compartments available or the net area with buffer strips and non-productive areas within compartments removed.

The estimate for Bago/Maragle State Forests is 48,430 ha of forest of which 23,000 ha net is considered productive (Table 3), that is 47.5% of the total forest area. At the management unit level, the area available for production and the total area of forest can be affected by tenure (both loss and acquisition) and possibly by silvicultural treatment of what is, at present, non-commercial forest. Hence, changes over time could not be presented as a raw number but would require some interpretation.

Indicator b. Total growing stock of both merchantable and non-merchantable tree species on forest land available for timber production.

Estimates of growing stock indicate, in gross terms, what is being managed, its condition, and possibly the potential for modification. Total growing stock can be estimated and in the case of Bago/Maragle State Forests is estimated as 2,645,000 m^3 of timber.

The estimation of non-merchantable tree species on forest land available for production presents a problem of definition at the management unit level. The definition of merchantability will be market defined and hence may vary over time. If the estimate required is species that are presently non-merchantable in an area used for timber production, it could be reasonably estimated. Similarly if it is the non-merchantable component of merchantable species in those same areas they may be estimated. However, if the estimation is non-merchantable species falling within the boundaries of the forest but not in the production areas, then it is presently a non-merchantable production type and information is not readily available.

The value of such an indicator on a forest basis requires further analysis and if it is to be used requires refinement. To be of value over time, there would need to be indicators on regeneration and structural change, specifically estimates of:

- harvested area with adequate regeneration;
- regeneration growth (e.g. at five years) expressed in comparison to expected value; and
- size class distribution by volume (e.g. as shown in Figures 4 and 5 in Appendix 1).

Indicator c. The area and growing stock of plantations of native and exotic species.

There are no plantations within Bago/Maragle State Forests. The change in area of plantations generally needs to be presented at a regional level. It can be addressed at the management unit level for individual plantations.

Indicator d. Annual removal of wood products compared to the volume determined to be sustainable.

The removal of wood products in relation to their estimated sustained yield is a valuable indicator. Within Bago/Maragle State Forests the annual removal of wood products is approximately 25,000 m^3 per annum (Table 3 and Figure 6 in Appendix 1) and the estimated present sustainable yield is 27,500 m^3 per annum. Data in Figure 6 (Appendix 1) indicate that the estimated sustainable yield has altered on several occasions. This is in part due to changes in productive forest area but also because the forest is still developing after initial clearing, very heavy harvesting and fire. Yield has fluctuated marginally (Appendix 1) but overall does not exceed the estimated sustainable level. The estimate of 1.1 m^3 ha^{-1} average annual yield appears very low considering climatic and soil conditions and considering the average MAI (mean annual increment) of adjacent pine plantations. A comparison of potential and actual productivity or yield may be a valuable indicator of trade-offs for other values.

Indicator e. Annual removal of non-timber forest products (e.g. fur bearers, berries, mushrooms, game) compared to the level determined to be sustainable.

Non-timber products are not included in the present analyses as they are minor and not currently measured.

Recommendations	***Relates to Indicator***
1. The area of land available for timber production is a critical indicator and is calculable at the management unit level. Losses and gains need to be explicitly stated as there may be changes in use within the management unit or changes of tenure.	a
2. The total growing stock should be calculable, although improvements in estimation are required. The distinction between merchantable and non-merchantable tree species will be market affected and therefore comparisons may be difficult.	b

3. Where plantations exist, estimations are valuable and should be at a higher level of precision than in native forests. c

4. Annual removal in relation to sustainable yield is a crucial indicator and should be accurately determined through the marketing system. d

5. Estimation of non-timber products needs further analysis. e

6. Regeneration, size class distribution and product quality are not addressed and are important at the management unit level. -

CRITERION 3: MAINTENANCE OF FOREST ECOSYSTEM HEALTH AND VITALITY

Indicators

a. Area and percent of forest affected by processes or agents beyond the range of historic variation (e.g. by insects, disease, competition from exotic species, fire, storm, land clearance, permanent flooding, salinisation and domestic animals).

b. Area and percent of forest land subject to specific air pollutants (e.g. sulphates, nitrates, ozone) or ultra violet B that may cause negative impacts on the forest ecosystem.

c. Area and percent of forest land with diminished biological components indicative of changes in fundamental ecological processes (e.g. soil, nutrient cycling, seed dispersal, pollination) and/or ecological continuity (monitoring of functionally important species such as nematodes, arboreal epiphytes, beetles, fungi, wasps, etc.).

Discussion

The basis for these indicators and their relevance to Australia has been discussed by Turner *et al.* (1996a).

Indicator a. Area and percent of forest affected by processes or agents beyond the range of historic variation (e.g. by insects, disease, competition from exotic species, fire, storm, land clearance, permanent flooding, salinisation and domestic animals).

The principle behind this indicator is important at the management unit level, but the concept of historic variation reduces its value due to the lack of records. If the concept was to be extended to consider effects by 'processes that are extreme based on experience' that would provide a basis for developing future information. Such an approach would also provide valuable information for forest managers.

Most of the factors listed for this indicator are not issues within Bago/Maragle State Forests. Factors that are likely to have an impact in the future (e.g. storms) will be specifically noted and evaluated. Fire could potentially have a major impact on growing stock and future productivity but the information is not available for collation.

It is recognised that there are a wide range of natural pests which will have an affect on productivity by a variety of processes. Certain levels of these are considered normal although no outbreak level, considered to have a critical impact, has been defined. In Bago State Forest there have been outbreaks of insect pests in the past leading to mortality and loss of increment on remaining trees in the affected areas. One of these outbreaks, specifically the defoliating group of insects, phasmatids, has been studied and documented and these studies reviewed by Eldridge and Cai (1995).

As a result of the phasmatids outbreak in Bago State Forest there was defoliation in some areas over several years. On an area basis, CAI (current annual increment) declined from 10.1 m^3 ha^{-1} $year^{-1}$ to 0.84 m^3 ha^{-1} $year^{-1}$. Reports indicate that in the initial outbreak approximately 95 ha were totally defoliated rising to 400 ha the following year. However, no accurate estimates were made of areas affected according to intensity and the degree of repeated attacks. The impacts of these attacks over a decade (main attacks between 1953-1964) were significant, however, it would be difficult to express that in the form of the indicator as proposed. It is suggested that, based on the information from the *Phasmatid* studies, that an indicator of cumulative impact (over the years of an outbreak) and intensity of impact is required at the management unit level. Based on compartments and Forest Types from Eldridge and Cai (1995) the information may appear as in Table 4. This raises issues concerning the impact of moderate insect infestations and the lack of specialised knowledge necessary for its assessment.

Table 4. Impact of *Phasmatid* attack on the merchantable areas of Bago State Forest.

Year	Area							
	Moderate defoliation		Severe defoliation		Complete defoliation		Total	
	(ha)	(cum)	(ha)	(cum)	(ha)	(cum)	(ha)	(cum)
1952/53	100	100	120	120	95	95	315	315
1953/54	nr	100	nr	120	nr	95	nr	315
1954/55	900	1000	700	820	400	495	2000	2315
1955/56	nr	1000	nr	820	nr	495	nr	2315
1956/57	5600	6600	3200	4020	740	1235	10835	13150
1957/58	nr	6600	nr	4020	nr	1435	nr	13150
1958/59	3350	9950	5600	9620	1100	1535	10050	23200
1959/60	nr	9950	nr	9620	nr	1535	nr	23200
1960/61	9400	19350	nr	9620	nr	1535	9400	32600
1961/62	nr	19350	nr	9620	nr	1535	nr	32600
1962/63	8200	27550	6300	15920	400	1935	14900	47500

nr = no reports (i.e. not surveyed)

The areas affected by *Phasmatid* attacks were not accurately assessed however the estimated areas are considered reasonable and this form of indicator to be of value. It indicates, firstly, that for over a decade there was continued pressure on the productive capacity of the forest, that is, it was subject to widespread and extended high levels of defoliation (the effect of this defoliation on regeneration and other factors was not addressed). Further, when the accumulated effect is considered, an area 2.1* times the area of the productive forest has had at least moderate defoliation. This indicates that some areas were severely affected on a number of occasions. In relation to the estimates of increment loss reported by Eldridge and Cai (1995) this may be considered to be an overall loss of 20% for the period 1951 to 1966.

At the management unit level, site specific indicators and better analysis and reporting may be needed to make this indicator more useful.

* Total cumulative area defoliated (47,500 ha)/productive area (23,000 ha)

Indicator b. Area and percent of forest land subject to specific air pollutants (e.g. sulphates, nitrates, ozone) or ultra violet B that may cause negative impacts on the forest ecosystem.

This indicator is not discussed as it is not relevant at the management unit level (Turner *et al.* 1996a).

Indicator c. Area and percent of forest land with diminished biological components indicative of changes in fundamental ecological processes (e.g. soil, nutrient cycling, seed dispersal, pollination) and/or ecological continuity (monitoring of functionally important species such as nematodes, arboreal epiphytes, beetles, fungi, wasps, etc.).

This indicator is not discussed as it is not considered to be a high priority at the management unit level (Turner *et al.* 1996a).

Recommendations	***Relates to Indicator***
1. The effects of feral animals, such as horses, need consideration.	a
2. Historical information is not generally available and hence impacts beyond a critical level need assessment. Cumulative and longer-term effects need analysis both spatially and in terms of growth.	a
3. Changes in processes need analysis at the research level and in manipulative studies. Unless specific critical processes are defined at the management unit level they cannot be assessed.	a

CRITERION 4: CONSERVATION AND MAINTENANCE OF SOIL AND WATER RESOURCES

Indicators

a. Area and percent of forest land with significant soil erosion.

b. Area and percent of forest land managed primarily for protective functions (e.g. watersheds, riparian zones).

c. Percent of stream kilometres in forested catchments in which streamflow and timing has significantly deviated from the historic range of variation.

d. Area and percent of forest land with significantly diminished soil organic matter and/or changes in other soil chemical properties.

e. Area and percent of forest land with significant compaction or change in soil physical properties resulting from human activities.

f. Percent of water bodies in forest areas (e.g. stream kilometres, lake hectares) with significant variance of biological diversity from the historic range of variability.

g. Percent of water bodies in forest areas (e.g. stream kilometres, lake hectares) with significant variation from the historic range of variability in pH, dissolved oxygen, levels of chemicals (electrical conductivity), sedimentation or temperature change.

h. Area and percent of forest land experiencing an accumulation of persistent toxic substances.

Discussion

Indicator a. Area and percent of forest land with significant soil erosion.

Within Bago/Maragle State Forests the spatial extent of soil erosion is not available. It is considered that soil erosion is mappable but a subjective definition of 'significant' would be required.

Indicator b. Area and percent of forest land managed primarily for protective functions (e.g. watersheds, riparian zones).

The area reserved for protection within a forest can be estimated although it may have multiple functions. This estimate is not available at present.

Indicator c. Percent of stream kilometres in forested catchments in which streamflow and timing has significantly deviated from the historic range of variation.

Stream flow information and historical estimates of variation are not available for Bago/Maragle State Forests.

At the management unit level catchment size is considered to be a potentially valuable indicator. This would be the case for reasonable sized catchments where streams are leaving forests and the level of management within the area is significant enough to alter long-term patterns. In this situation streamflow estimates may need to be based on models. Rather than considering an area such as Bago/Maragle State Forests and other native forests, which are relatively stable in management, plantation areas (including areas being converted to forest from other land uses, such as grassland) would be a higher priority.

Indicator d. Area and percent of forest land with significantly diminished soil organic matter and/or changes in other soil chemical properties.

There is insufficient information on this case study area to estimate areas affected by soil organic matter and soil chemistry changes at this time.

Indicator e. Area and percent of forest land with significant compaction or change in soil physical properties resulting from human activities.

There is insufficient information on this case study area to estimate areas with significant compaction or changes in soil physical properties at this time.

Indicator f. Percent of water bodies in forest areas (e.g. stream kilometres, lake hectares) with significant variance of biological diversity from the historic range of variability.

There is no information on which to base an assessment of short or long-term stream biological diversity changes.

Indicator g. Percent of water bodies in forest areas (e.g. stream kilometres, lake hectares) with significant variation from the historic range of variability in pH, dissolved oxygen, levels of chemicals (electrical conductivity), sedimentation or temperature change.

Spatial assessment of water quality was addressed by Turner *et al.* (1996b) (Appendix 3), however there is no current information on which to address historical changes. It would be valuable to establish baseline information that could be utilised in future comparisons. This would be a useful indicator which could be utilised to manage stream quality within forests. This could be achieved by using short-term intensive sampling to categorise lengths of stream according to water quality. Changes could then be assessed in the future. Tables 5, 6, 7 and 8 provide basic presentations of this type of information.

Table 5. Length of stream determined for turbidity levels (total of 186 km of stream).

	% Stream length					
Land use	**0-1 NTU**	**1-2 NTU**	**2-3 NTU**	**3-4 NTU**	**4-6 NTU**	**>6 NTU**
Hardwood	0	38	43	14	5	0
Pine	0	16	43	22	14	5
Hardwood+ Pine	0	31	44	15	8	2

Table 6. Length of stream determined for conductivity levels (total of 186 km of stream).

	% Stream length					
Land use	**0-8 $\mu s\ cm^{-1}$**	**8-16 $\mu s\ cm^{-1}$**	**16-24 $\mu s\ cm^{-1}$**	**24-32 $\mu s\ cm^{-1}$**	**32-40 $\mu s\ cm^{-1}$**	**>40 $\mu s\ cm^{-1}$**
Hardwood	0	41	55	0	4	0
Pine	0	44	50	6	0	0
Hardwood+ Pine	0	40	55	2	2	0

Table 7. Length of stream determined for total nitrogen concentrations (total of 186 km of stream).

	% Stream length					
Land use	**0-0.2 mg/mL**	**0.2-0.4 mg/mL**	**0.4-0.6 mg/mL**	**0.6-0.8 mg/mL**	**0.8-1.0 mg/mL**	**>1.0 mg/mL**
Hardwood	39	22	35	0	4	0
Pine	0	15	71	0	14	0
Hardwood + Pine	33	18	43	0	6	0

Table 8. Length of stream determined for total phosphorous concentrations (total of 186 km of stream).

	% Stream length					
Land use	**0-0.06 mg/mL**	**0.06-0.12 mg/mL**	**0.12-0.18 mg/mL**	**0.18-0.24 mg/mL**	**0.24-0.3 mg/mL**	**>0.3 mg/mL**
Hardwood	29	65	2	4	0	0
Pine	58	23	0	14	0	5
Hardwood + Pine	39	51	1	7	0	2

Indicator h. Area and percent of forest land experiencing an accumulation of persistent toxic substances.

This indicator is not discussed as it is considered to be more applicable to northern hemisphere forests (Turner *et al.* 1996a).

Recommendations	***Relates to Indicator***
1. Area of forest affected by soil erosion or changes in chemical or physical properties would be of value but difficult to assess. Key, site specific, growth limiting factors need to be determined by research and monitored specifically.	a, d and e
2. Historical changes in any stream characteristics would be difficult to assess. Utilising the percent of affected water bodies in forest areas as an indicator would be worthwhile but requires further evaluation. This type of indicator could be applied at the management unit level and would be useful for amalgamation up to the regional level.	c and g

CRITERION 5: MAINTENANCE OF FOREST CONTRIBUTION TO GLOBAL CARBON CYCLES

Indicators

a. *Total forest ecosystem biomass and carbon pool, and if appropriate by forest type, age class, and successional stages.*

b. *Contribution of forest ecosystems to the total global budget, including absorption and release of carbon (standing biomass, coarse wood debris, peat and soil carbon).*

c. *Contribution of forest products to the global carbon budget.*

Discussion

Indicator a. Total forest ecosystem biomass and carbon pool, and if appropriate by forest type, age class, and successional stages.

This indicator is considered more relevant at the regional level. Estimates of carbon storage can be made at the regional level by amalgamating information from individual forests. At the management unit level carbon storage may be difficult to interpret unless there are very significant changes, as may be expected in newly developed plantation areas.

An initial estimate of carbon storage has been made for Bago State Forest by converting volume to mass on the basis of ratios of biomass to volume. This estimate is provided in Table 9. Tree storage was estimated from Hatich *et al.* (1995) (Appendix 1) and soil from Ryan *et al.* (1995) (Appendix 4). Estimates of litter biomass are not currently available, however, broad estimates of average litter biomass per hectare have been provided.

Indicator b. Contribution of forest ecosystems to the total global budget, including absorption and release of carbon (standing biomass, coarse wood debris, peat and soil carbon).

This indicator is not discussed as it is considered to be more applicable at the national level than at the management unit level (Turner *et al.* 1996a).

Table 9. Accumulation of carbon in Bago State Forest (assuming an area of 46,805 ha).

Component	Tonnes/ha	Tonnes/forest (x 1000)
Tree	111.1	5200
Litter	8.0	374
Soil		
0-200 mm	135.2±62.4	6328
200 -500 mm	81.5±40.5	3815
500-1000 mm	62.3±42.0	2916
Total soil	279.0	13059
Total system	398.1	18633

Notes:
- Mass = (total standing volume x 2.4 x 660 kg/m^3)/1.74/1000 (factor of 2.4 accounts for above merchantable level stem, branch and smaller trees in stand).
- Mean volume for Bago/Maragle State Forests is assumed to be 122 m^3/ha.
- Litter weight assumed from other studies.

Indicator c. Contribution of forest products to the global carbon budget.

This indicator would be difficult to address at anything less than the State level.

Recommendations

	Relates to Indicator
1. The calculation of carbon accumulation and changes needs to be on a regional basis rather than on a forest basis.	a
2. Absorption and release of carbon is difficult to assess at any level.	b

DISCUSSION

A major limitation to the application of indicators of sustainability is the lack of suitable data on State forests at the management unit level. This is particularly the case in terms of spatial information, specifically areas of forest, Forest Type and structure and reserves of various types. This problem is exacerbated when information is required from lands of other tenure (which is generally not available). While not addressed in this report, the lack of information on lands of other tenure is critical in addressing issues of biodiversity.

A further limitation is that many of the terms used in the Santiago Declaration need clear and explicit definitions, especially if comparisons are to be made between forests.

A number of indicators that rely on historical data are contained in the Santiago Declaration. These are not appropriate as historic information generally does not exist. In some cases, using appropriate models, an estimate of the historical position may be developed, particularly at the regional level. However, this is not appropriate at the management unit level. Base conditions need to be set at the present day level or at some other preliminary condition, recognising that they are subjective and will be subject to modification.

In Bago/Maragle State Forests information is available on sustained yields and diameter size classes. More sensitive measures of sustainable production are required, particularly in terms of potential productivity, regeneration and early growth. The quality of timber produced also needs to be considered, since degrade can be induced by management practices.

Bago/Maragle State Forests are periodically affected by natural disturbances, specifically fire and defoliating insects. Together with the maturation of the forest, these disturbances lead to structural change and the modification of processes. This aspect of forest ecosystems is not addressed in the Santiago Declaration with the presumption in many indicators that the ecosystem is static.

The following alternative indicators have been proposed in this report and are considered important at the management unit level.

1. The area of the management unit by Forest Type, structure, productive forest areas and protected or reserve areas *(relates to Criterion 1 and 2)*.
2. Growing stock, rates of increase, level of sustained yield and yield *(relates to Criterion 2)*.
3. Regeneration, growth rates of regeneration, and stand size class distribution *(relates to Criterion 2)*.
4. Estimates of soil disturbance (erosion, movement or compaction) *(relates to Criterion 4)*.
5. Measures of stream health on a spatial basis *(relates to Criterion 4)*.

Many of these indicators are first estimates. Practical methodologies for measurement and interpretation are required to obtain maximum value from them for forest management.

REFERENCES

Anon (1989). Forest Types of New South Wales. *Forestry Commission of New South Wales Research Note No. 17.* 95 pp.

Dalrymple Hay, R. (1915). Forestry Handbook, Part 1. Forest principles and practice. New South Wales Govt Printer. 87 pp.

Doherty, M. (1993). Kosciusko vegetation data: attributes and suitability for analysis modelling. National Parks and Wildlife Service.

Eldridge, R.H. and Cai, S. (1995). Review of *Phasmatid* occurrence and effect on increment in Bago State Forest. State Forests of New South Wales. 11 pp.

Hatich, D., Johnson, I. and Bi, H. (1995). Indicators of sustainable timber yield from Bago/Maragle Hardwood Management Area in New South Wales. 21 pp.

Ryan, P., N. McKenzie, C. Wilkinson and P. Leppert. (1995). Relating native forest productivity to site and soil properties in Bago/Maragle State Forests. First Interim Report. 21 pp.

Turner, J., Pribble, J. and Flinn, D. (1996a). Evaluation of Santiago Declaration indicators of sustainability for Australian commercial forests. State Forests of New South Wales. 81 pp.

Turner, J., Lauck, V. Dawson, J. and Lambert, M.J. (1996b). Water quality monitoring strategies for forest management: a case study at Bago State Forest. *State Forests of New South Wales Technical Paper No. 30.* 25 pp.

APPENDIX 1

INDICATORS OF SUSTAINABLE TIMBER YIELD FROM BAGO/MARAGLE HARDWOOD MANAGEMENT AREA IN NEW SOUTH WALES

by

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INTRODUCTION

In 1992, State Forests of New South Wales stated its intention to manage forests under its control on an ecologically sustainable basis. One objective was to develop a range of performance indicators of ecologically sustainable forest management (ESM) through research and development. It was proposed (Turner 1993) that initially the development of indicators and monitoring procedures should take place in selected areas of forest with a long history of management for timber yield, which would be regarded as case studies in ESM. The first of the selected study areas was the Bago/Maragle Hardwood Management Area (referred to as the Management Area in the following discussion) in south-east New South Wales. This area of two State Forests has been surveyed and data compiled fairly intensively for timber production over many years. It was thus considered that a suitable body of data had already been gathered in this area, probably more than for any other area in New South Wales, for quantifying indicators of sustainable timber yield.

This paper discusses the development and application of a set of indicators to address Criterion 2 from the Santiago Declaration, 'Maintenance of productive capacity of forest ecosystems', as it relates to the Management Area. These indicators are based on three out of the five indicators for Criterion 2, which deal with forest area, Forest Types and the yield of wood products from native forest ecosystems. They are used to show whether the past management of wood production in the Bago/Maragle State Forests has been in accord with the principles of sustainable management.

THE STUDY AREA

1. LOCATION, LANDFORM AND CLIMATE

The area covered by this study comprises essentially the whole of the Bago/Maragle Management Area, consisting of the greater part of Bago and Maragle State Forests, near the towns of Batlow and Tumbarumba on the south-west slopes (Figure 1). The total area is 48,430 ha. It is part of the Cumberland Plateau, with altitudes ranging from about 400 m to 1438 m a.s.l. Tributaries of both the Murray and Murrumbidgee Rivers rise on this plateau, draining to the north and east and the south and west respectively. The Forests are important in protecting soils in high rainfall and high altitude localities within these major catchments.

The Management Area experiences a cool, moist tableland climate, with mild to warm summers and cold to very cold winters. Annual precipitation ranges from about 1100 mm in the lower altitude areas to 1400 mm in the higher central portion of the plateau (mostly 1200-1400 mm), most of which falls in winter and spring. Snow is frequent at the higher elevations, and in some winters may lie for several weeks in sheltered situations. Frosts may be severe at higher altitudes, occurring on more than 100 days per year. The extreme range in mean temperature for Pilot Hill (1200 m) is -1.5°C to 23.5°C, but the lowest and highest recorded there are - 8.9°C and 38.1°C.

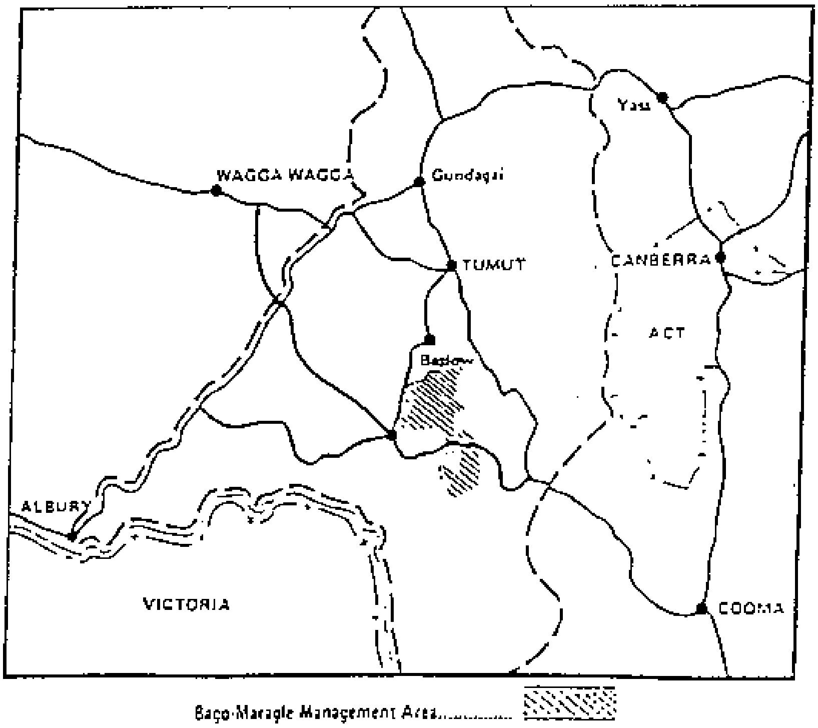

Figure 1. Location of the Bago/Maragle Hardwood Management Area in New South Wales.

2. *GEOLOGY*

The most common rock types in the Bago/Maragle Management Area are Corryong and Green Hills Granodiorite of Silurian age, which give rise to moderately fertile, reddish, clay-rich loams and clay-loams up to 2 m deep. Extensive Tertiary basalt caps occur on ridges in some areas, mostly in the north-eastern and south-eastern parts of Bago State Forest and the northern edge of Maragle State Forest. The soils are generally shallower than those on granodiorite, with brown loam topsoil and reddish-brown clay-loam subsoil. Fairly extensive areas of Ordovician sedimentary lithology are found in the central and south-east portions of Maragle State Forest.

3. *FOREST TYPES*

The Management Area contains 15 Forest Types as defined in Research Note 17 (Anon. 1989), all dominated by single or mixed *Eucalyptus* species. The only non-eucalypt Forest Types present are grassy plains and mossy or tea-tree bogs. The three primary commercial timber species are alpine ash (*E. delegatensis*), mountain gum (*E. dalrympleana*) and narrow-leaved peppermint (*E. radiata* ssp. *robertsonii*), with eurabbie *(E. globulus* ssp. *bicostata*) of secondary importance. These occur primarily in seven Forest Types: 147, 148, 140, 111, 131, 159 and 164 (Table 1), which occupy about 88.6% (42,913 ha) of the total Management Area. Forest Types dominated by alpine ash occur mainly on deeper soils at elevations of 1100 to 1300 m a.s.l., but lower where there is a basalt cap. They form a greater proportion of Bago State Forest (37%) than of Maragle State Forest (12%). Mountain gum has a wider soil and altitude tolerance and occurs with snow gum up to 1400 m and with peppermint lower than 500 m a.s.l. Narrow-leaved peppermint is widespread throughout middle to lower elevations, in pure stands or in association with mountain gum at higher levels and with red stringybark (*E. macrorhyncha*) at the lowest elevations.

Most (8%) of the remaining area contains high altitude Forest Types such as Snow Gum (*E. pauciflora*), Black Sallee (*E. stellulata*) or mixtures, which are non-merchantable, and lower altitude Types including Manna Gum (*E. viminalis*), Apple Box (*E. bridgesiana*) and Red Stringybark. These latter Types occur mainly in Maragle State Forest and are of some, though relatively minor, commercial significance. Treeless areas (mostly grassy plains and bogs), research trials and reserves occupy about 3.4% of the Management Area.

4. *NATURAL DISTURBANCES TO THE FORESTS*

Historically, the main natural disturbances to the forests of the Management Area have been caused by insects and wildfire, although their impacts have tended to diminish in more recent years. Termites and stick insects (phasmatids) are the main insect agents of tree damage and degrade in wood quality. The large termite *Porotermes adamsoni* is the greatest single problem to alpine ash productivity. It attacks single trees, normally gaining entry through a fire scar on the trunk, and doing most damage in the lower section of the bole. The amount of reject volume due to termites has decreased as overmature sections of the forests are cut out and the incidence of severe fires has been reduced.

Defoliation by the stick insect *Didymuria violescens* was a great problem at times in the past. 'Plagues' of this insect normally affect mountain gum and peppermint rather than ash, but ash is also attacked when phasmatid populations are very high. Between 1953 and 1965 attacks occurred every second summer, mostly in the Yellowin area in the north east of Bago State Forest. In severe cases whole stands of ash were killed. Growth increments suffered over the whole forest, with mean diameter yields halved in affected areas for several years. Since 1965 there have been no significant outbreaks of phasmatids.

Table 1. Forest Types present in Bago/Maragle Hardwood Management Area as at 1984, presented for each State Forest separately and the total Management Area. Types based on Research Note 17 (Forestry Commission of New South Wales 1989).

Type No.	Type Description	Bago S. F. (ha)	Bago S. F. (%)	Maragle S. F. (ha)	Maragle S. F. (%)	Total M.A. (ha)	Total M.A. (%)
147	Ash-Pure	7998	25.4	661	3.9	8659	17.9
148	Ash/Gum	3558	11.3	1343	7.9	4901	10.1
140	Snow Gum/Mtn. Gum.	9611	30.5	4097	24.2	13708	28.3
136	Snow Gum/Black Sallee		0.0	2		2	0.0
137	Black Sallee	349	1.1	70	0.4	419	0.9
138	Snow Gum	64	0.2	335	2.0	399	0.8
143	Broadleaved Sallee	276	0.9	114	0.7	390	0.8
111	Peppermint	575	1.8	1238	7.3	1813	3.7
131	P'mint/Mtn Gum/Manna	5027	16.0	6184	36.5	11211	23.1
159	Mtn Gum/Manna Gum	435	1.4	878	5.2	1313	2.7
160	Manna Gum			3		3	0.0
103	Apple Box			11	0.1	11	0.0
124	Red Strngy bark	1176	3.7	1384	8.2	2560	5.3
125	Red St. Bark/Brittle Gum			68	0.4	68	0.1
164	Eurabbie	1308	4.2			1308	2.7
Treeless Types (220, 220c, 224, 231, Roads, Trans. lines)		859	2.7	557	3.3	1416	2.9
Areas not included in Type Areas							
Research Trials		40	0.1			40	0.1
Flora Reserves		209	0.7			209	0.4
Total		31485	100.0	16945	100.0	48430	100.0

Fires of even moderate intensity may be very damaging to alpine ash in particular; young trees can be killed or the cambium damaged on these or larger trees, leading to bark lift and possible insect/disease attack. Information about wildfires prior to 1926 is sketchy. In that year a fire burnt most of Bago State Forest and was especially severe in the southern section. Other severe fires were in 1939 (south-west and northern parts of Bago State Forest), 1943, and 1952 (southern areas of Bago State Forest). Since then, wildfire damage in this forest has been very limited, due no doubt to good road access and advanced fire detection and control organisation. There are no records of wildfire in the Maragle State Forest alpine ash areas. Parts may have been burnt by relatively mild fires lit by cattlemen, sufficient to cause some butt damage but not severe enough to kill extensive areas of mature trees.

Other natural and semi-natural disturbances would include windstorms and grazing. The former are rare and have caused only localised damage by uprooting or breaking of trees. Low intensity grazing by cattle in summer and wild horses (brumbies) occurs over much of the Management Area but its effect on tree growth and regeneration is not known.

5. *FOREST DEDICATION, UTILISATION AND MANAGEMENT HISTORY*

The original dedication of Bago State Forest was as a timber reserve in 1878, and as a State Forest of 28,000 ha in 1917. Additions since then increased the area to 43,000 ha, of which 31,485 ha are in the Management Area. Small portions of the present Maragle State Forest were declared in 1917 and 1919, but most were incorporated in Kosciusko National Park until 1968, when the present 16,945 ha was declared as Maragle State Forest.

There are three main periods in the history of utilisation and management of what now forms the Management Area. The first period, one characterised by no organised forest management, began with gold mining in the 1860s to 1870s, with associated cutting of timber for sluice boxes, and lasted until 1917. Several small sawmills were established on or near the plateau between 1879 and 1928 but most relocated to sites closer to the main towns and a few have survived to the present day. Logging was limited to the more accessible areas and directed mainly by sawmilling interests, leading to the removal of sound, vigorous trees and leaving stands degraded. Between 1917 and 1939 there was a period of limited management of the alpine ash areas, but this was not guided by accurate yield or growth estimates, and logging was largely unregulated. Regeneration treatment over 1200 ha in Bago State Forest in 1917, involving virtual clear-felling, ringbarking of non-merchantable trees, and a hot fire, gave rise to a fine even-aged stand known today as the Regeneration Area. Other smaller areas were similarly treated.

An extensive inventory by A.D. Lindsay in 1939 resulted in a management plan for both forests and ushered in the present phase of organised management, aiming to regulate the yield of alpine ash timber at a sustainable level. Under the 1939 plan a balance was aimed for between the supply of timber and the retention and promotion of vigorously growing trees and regeneration; this resulted in further good pole and spar stands. A further management plan for Bago State Forest in 1954 (Anon. 1954) set a higher annual quota ash log yield, and laid down two silvicultural strategies including group selection in some areas and thinnings to remove larger stems in other areas; also the removal of unmerchantable trees following logging. After 1972, the emphasis in alpine ash logging changed again to favour the retention of all vigorous trees, regardless of size, and the removal of defective and suppressed trees (some of which were of relatively small diameter). This policy has prevailed since 1972, with burning of logging debris in many areas, and local planting of seedling alpine ash to extend the margins of the Alpine Ash Forest Type. Harvesting of 'other hardwoods' (mostly mountain gum and narrow-leaved peppermint) in non-ash Forest Types commenced in Bago State Forest in the late 1960s, aiming to remove all merchantable logs. There were few attempts to deliberately encourage regeneration of these species.

Heavy logging began in Maragle State Forest from 1968, resulting in the removal of the high proportion of mature and 'overmature' trees in the largely virgin alpine ash areas while retaining younger vigorous stems and seed trees. In economically accessible hardwood areas of non-ash Forest Type, merchantable and defective trees have generally been logged or felled to waste.

6. CURRENT CONDITION OF MANAGEMENT AREA

The different Forest Types in the Management Area today display variable structure, reflecting past logging and management history. In Bago State Forest, Alpine Ash Types have five basic stand structures ranging from pure essentially even-aged stands (the 1917 Regeneration Area is the largest example) to limited areas of unlogged old stands in steep country. Most stands contain a mixture of age classes and sizes resulting from the removal of defective and suppressed trees and the opening of gaps of small to moderate size during two or more logging episodes. The bulk of the ash areas in Maragle State Forest contain young pole-sized trees and regeneration, with some older seed trees. Only small areas remain with a full range of tree sizes and ages.

Stands of other commercial eucalypt Types contain mainly non-commercial, 'overmature' trees and younger regeneration, with a minor component of trees 50-60 cm DBHOB (diameter at 1.3 m over-bark) left to grow at the time of logging. In both State Forests there are limited areas of unlogged forest in steep or other less accessible areas and in small reserves. Most of the remaining Forest Types (high and lower altitude) are either unlogged or lightly disturbed by selective logging.

EVALUATION OF AVAILABLE DATA

There have been two distinctly different periods in the long history of commercial use of the Bago/Maragle Management Area: prior to 1939, when deliberate management of timber yield was virtually non-existent, and from 1939 onwards when management aimed to quantify the resource and regulate yield.

Collection of the first complex set of information on the Management Area was organised and supervised by Lindsay in 1939. This survey was very detailed and comprehensive, including mapping of the area, forest typing, standing timber assessment (quantity and stand structure), volume and growth modelling, stand quality indexing, and soil, fauna and vegetation surveys. It resulted in a detailed map of the Management Area as at 1939, a report on growth studies (Lindsay 1939), and the first management plan. Since 1939, the managers of the Management Area have collected vast quantities of data. These consist of spatial data (maps, aerial photographs, satellite images, and GIS data), timber quantification data (growth, inventory and yield), geological and soils data, meteorological data, and ecological (flora and fauna) data.

In this paper, only data concerned with the quantification of timber yield are discussed. These data have been divided into three groups: growth data, inventory or assessment data, and yield or past logging data. The availability of data from these groups varies between the two State Forests in the Management Area, and also among Forest Types (Table 2).

Table 2. Availability of tree growth, inventory and yield data from research trials and other assessments in each Forest Type in the Management Area.

Forest Type No.	Forest Type	Bago S. F.			Maragle S. F.		
		Growth	*Inventory*	*Yield*	*Growth*	*Inventory*	*Yield*
147	Alpine ash-Pure	✓	✓	✓		✓	✓
148	Alpine ash / Mountain gum	✓	✓	✓		✓	✓
140	Snow gum / Mountain gum		✓	✓		✓	✓
136	Snow gum / Black sallee						
137	Black sallee						
138	Snow gum		✓				
143	Broadleaved sallee						
111	Peppermint						
131	Peppermint / Mountain gum / Manna gum	✓	✓	✓			✓
159	Mountain gum / Manna gum	✓		✓			✓
160	Manna gum						
103	Apple box						
124	Red stringy bark						
125	Red stringy bark / Brittle gum						
164	Eurabbie						

Forest Types in the Management Area can be divided into those used for timber production, Types not used for timber production but used for other products (e.g. grazing), and anthropogenic or human-created Forest Types (see Table 1). The five Types used for most of the timber production, that is 147, 148, 140, 131, and 159, have received most attention from management, and consequently the bulk of available data originates from them (see Table 2). Within these Types, three species account for nearly all of the timber production: alpine ash, mountain gum and narrow-leaved peppermint.

The timing of data collection throughout the management period since 1939 is shown in Figure 2 and discussed in detail below.

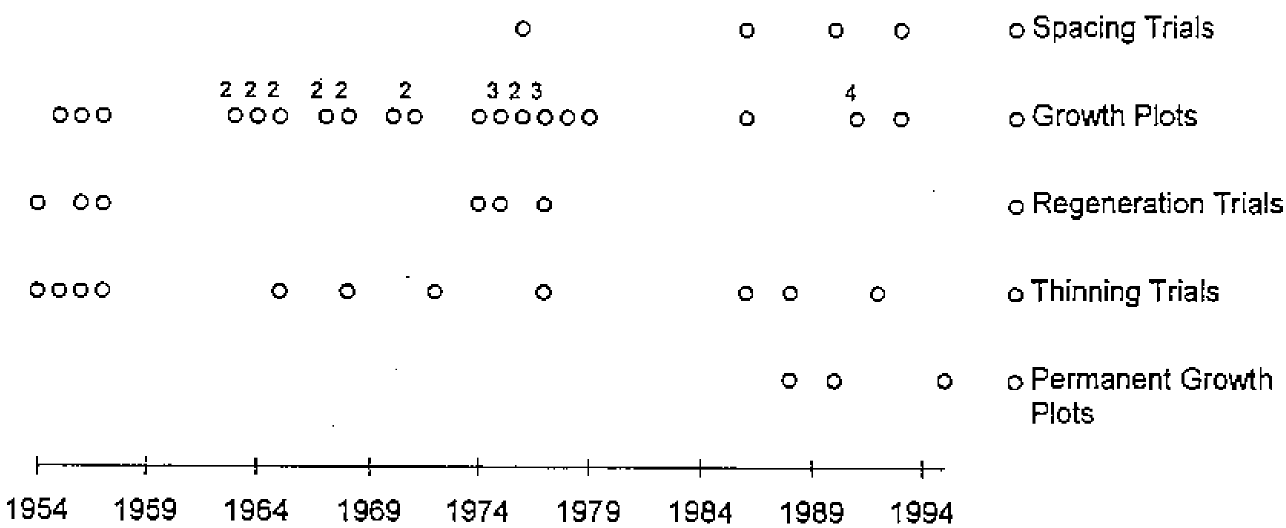

Figure 2. Assessment history of experiments and plots with data suitable for growth analysis. Circles represent years in which trials and plots of various categories were assessed. Small numbers above some of the circles for growth plots show the numbers of experiments measured in that year.

1. GROWTH DATA

Data were collected over many years for use in growth and yield modelling. These may be separated into experimental data from growth plots, thinning plots and regeneration trials, and Permanent Growth Plot (PGP) data from plots established much more recently.

Most growth data came from five experiments which were established between 1954 and 1967, in alpine ash regeneration in Bago State Forest, variously as growth plots, thinning trials and natural regeneration trials. Three of these experiments (growth plots) have only one plot, one has four plots, and one has 20 plots; plot size varies from 0.2 ha to 0.8 ha. Two have different spacing treatments, but only one of these is replicated (five replicates); the others are single plots. These experiments have been measured over varying lengths of time (up to 38 years) and at varying frequency, up to 11 different occasions (Figure 2). The measurement interval averages about three years. The experimental data are of high quality but limited in scope. Parameters measured include DBHOB and dominant height; crown mapping was done in the replicated trial.

A series of five small growth plots and spacing trials using planted ash seedlings were established in Forest Types 148, 131 and 159 of Bago State Forest between 1969 and 1973. The sizes of these plantings were mostly not recorded. They were generally placed in small gaps created by extending snig tracks or log dumps, sometimes in an attempt to extend the Alpine Ash boundary into adjacent

Gum and Peppermint Types. In effect they are small plantations, but could be regarded as enrichment plantings to enhance alpine ash regeneration. Two of these trials employed different spacing or planting treatments; the others were planted at a single spacing. They have only been assessed at fairly irregular intervals averaging 7.5 years, and two have not been measured since 1976-77. Data collected are only DBHOB and/or total height.

PGP plots in the Management Area are small circular plots with an area of 0.1 ha. They are part of the State-wide growth data collection scheme. PGP data were collected on 18 plots established in Bago State Forest in 1988 (six plots) and in 1990 (12 plots), all within Forest Type 147. A second measurement was made in 1995. Trees of all sizes were measured in these plots. The data are of high quality and very wide in scope, and include species, DBHOB, bole height, log length, dominance, merchantability class, crown quality, and timber status code (TSC). Plot location and geology were also detailed.

2. *INVENTORY DATA*

The inventory data come from two sources: Temporary Assessments (TA) and Continuous Forest Inventory (CFI). Three major inventories (TA) were undertaken in 1939, 1966-67 and 1984, covering the whole of the Management Area (as at those times). The 1939 and 1966 (Bago) and the 1967 (Maragle) assessments collected data from only Forest Types 147 and 148, while the 1984 assessment covered Types 147, 148, 140, 138 and 131. Unfortunately, only the data from the two later assessments have survived to the present time. These data are of fairly high quality and moderately wide in scope. .

In the 1966-67 assessment, 174 random temporary plots for the purposes of volume calculation were established in Bago State Forest, and 70 plots in Maragle State Forest. The plots were 302 m long x 20 m wide (0.6 ha), generally running east-west from randomly determined starting points. Each was divided into three subplots. In the two end subplots data were recorded only for merchantable alpine ash over 50 cm DBHOB; in the middle subplot (0.2 ha) data were recorded for all eucalypt trees present. Data were recorded for species, merchantability class, DBHOB, log length, crown class and dominance. The 1984 assessment employed 134 plots in Bago and 20 plots in Maragle, on a systematic grid. Parameters measured were as for the earlier assessment, with the addition of stump height, crown quality and Timber Status Code.

CFI plots were established in 1957, in the Regeneration Area, and in 1958 in the alpine ash section of Bago State Forest, designed to serve similar purposes to that of the more recently established PGP plots. There were 166 plots in two strata on a systematic 400 m grid. Plots were 100 m x 20 m, oriented east-west. Trees within 10 m of the centre line of each plot were considered for assessment. Data are of questionable quality but moderately wide in scope. Measurements taken included: DBHOB of trees over 20 cm; log height for trees over 30 cm DBH; dominance; stem form (class); crown form; recording of any other notable features such as phasmatid attack.

After the initial assessment, these plots were remeasured twice more, in 1963 and 1971. They sampled only the most productive parts of Forest Types 147 and 148 and were abandoned because of doubts about their representativeness. Original data from these plots are only available from the 1963 measurement, with plot-level summaries for the 1957-58 measurement.

3. *YIELD DATA*

Historical yield data were artificially separated into two groups, 'pre-1972' and 'post-1972', based on differences in the scope of the available data. Data originating from before 1972 are available on an annual basis but limited to alpine ash and hardwood (mountain gum and peppermint) sawlog data.

There is no exact indication of the origins of these logs (e.g. compartment and/or Forest Type); the source area is only broadly specified as 'mainly Management Area' (Anon. 1986). The post-1972 data group forms a detailed account of yield from the Management Area, containing quantitative and spatial data. Timber types are still separated only into alpine ash and hardwood. Data recorded each year and for each compartment operated in included: log sizes (in four classes), log numbers, and gross and net volumes and values, along with defect volume.

APPLICATION OF INDICATORS FOR CRITERION 2 TO BAGO/MARAGLE MANAGEMENT AREA

Criterion 2 from the Santiago Declaration is the 'Maintenance of productive capacity of forest ecosystems'. Five indicators are suggested, of which three (a, b, and d) are relevant for investigating this criterion in the case of Bago/Maragle Management Area (Canadian Forest Service 1995). These indicators, as worded, were each applied using relevant available data for the Management Area, to assess their suitability as measures of the criterion in this case.

Indicator a. Area of forest land and net area of forest land available for timber production.

The area of dedicated State Forest in the Management Area increased slowly from 1917 (28,000 ha) to 1970, in which year the dedication of most of Maragle State Forest (ex Kosciusko National Park) raised it to 43,343 ha. Subsequent small additions have brought the Management Area to 48,430 ha.

Before 1984, only the Forest Types containing alpine ash (147 and 148) were regarded as important productive areas for the purposes of yield management and stand treatment. Timber was, naturally, taken from other Types, but on a more-or-less opportunistic basis. The 1984 Management Plan specified a productive area consisting of seven Forest Types (the two Ash Types plus 111, 131, 140, 159 and 164). Using this definition, the net area available for timber production has increased from 35,208 ha in 1939 to 42,913 ha currently, an increase of 7705 ha (Figure 3). Both measurements of this indicator thus show a positive trend for Criterion 2 as applied to the Management Area.

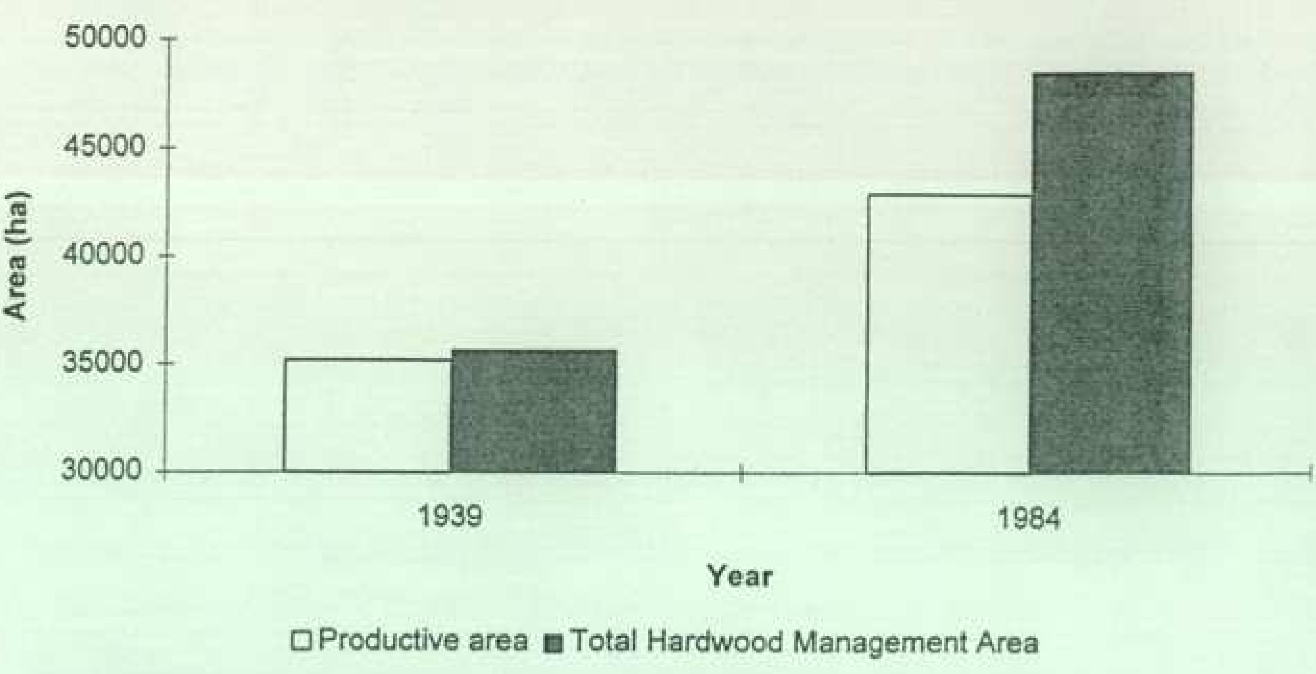

Figure 3. Total Hardwood Management Area and the area of Forest Types regarded as comprising the productive area (Types 147, 148, 140, 131, 159, 111 and 164) in 1939 and 1984.

Indicator b. Total growing stock of both merchantable and non-merchantable tree species on forest land available for timber production.

Due to differences in the approach to forest management in the Management Area over its history, data on growing stock have been collected and analysed over a range of different land management units. In this paper, the Forest Type is regarded as the basic management unit and the basis for the presentation and interpretation of data. Within the seven Forest Types regarded as comprising the productive area (see above), the commercial tree species are alpine ash, mountain gum, narrow-leaf peppermint, manna gum and eurabbie. The only non-commercial species likely to be encountored is snow gum.

The total growing stock in this case is best determined from temporary assessment data collected in 1966-67 and CFI data from 1963. Between them, these data represent all of Forest Types 147 and 148, which are the most productive portion of the Management Area though by no means the whole productive area. Data from the 1984 temporary assessment are more indicative of the growing stock in the productive area, as they were collected over four Forest Types (147, 148, 140, and 131). However, there are no comparable earlier data which can be used in conjunction with these to fully evaluate changes in growing stock over time.

Summary information from the 1963 CFI plots in Bago State Forest and the two temporary assessments in Bago State Forest is shown in Table 3 and in Figures 4 and 5. Data from the 1967 assessment of Maragle State Forest is shown in Table 4. This information includes data for stand density, basal area and volume for each of the Forest Types in which plots were established on these occasions and, for Bago State Forest, also a breakdown of data by tree diameter classes and species.

Table 3. Statistics for stocking, basal area, and volume per hectare for different Forest Types in Bago State Forest, from temporary assessments and inventories in 1963, 1966 and 1984.

Forest Type	No of Plots	No of trees / ha				Basal Area / ha				Volume / ha			
		Mean	STD	Max	Min	Mean	STD	Max	Min	Mean	STD	Max	Min
Year	*1963+1966*												
147/148	304	144	89	558	5	17.9	11.9	72.9	0.3	71.9	47.2	310.2	0.6
Year	*1984*												
131	6	273	255	767	63	16.9	6.0	24.2	7.7	89.8	39.1	145.2	36.6
140	10	235	120	452	60	19.0	8.3	33.2	7.7	109.7	50.9	194.2	33.5
147	89	235	130	703	40	24.8	8.3	44.4	5.6	141.7	59.4	296.2	14.5
148	27	226	166	632	12	20.1	8.9	41.5	5.7	112.0	51.0	271.2	41.3

Table 4. Statistics for stocking, basal area, and volume per hectare for different Forest Types in Maragle State Forest, from temporary assessments in 1967 and 1984.

Forest Type	No of Plots	No of trees / ha				Basal Area / ha				Volume / ha			
		Mean	STD	Max	Min	Mean	STD	Max	Min	Mean	STD	Max	Min
Year	*1967*												
147/148	70	85	73	465	12	21.5	10.4	56.4	1.8	102	58.6	287.3	9.8
Year	*1984*												
140	1	313				16.5				97.6			
147	15	275	218	857	22	16.7	13	54.2	5.2	98.9	87.3	365.3	28.6
148	4	249	165	402	23	15.1	5	21.9	10.8	73.1	34.3	123.5	47.5

SUMMARY OF RESULTS - BAGO STATE FOREST

A total of 304 plots were measured in 1963 and 1966 assessments. These were all located in Forest Types 147 and 148 (Alpine Ash Types), but details of their exact locations have been lost over time. Because of this, summary results for these Forest Types were analysed as a single entity. The 1984 assessment data cover four Forest Types (Table 3). All three of the growing stock parameters for Types 147 and 148 showed a considerable increase in mean value between 1966 and 1984, being greatest for volume/ha (increase of 76%). Basal area (BA) and volume figures were also less variable between plots in 1984. Stands in these two Forest Types had become denser and potentially more productive over 18 years. Forest Types 131 and 140 had a slightly higher mean density but considerably lower BA and volume than the Ash Types in 1984.

Data presented in Figure 4 represent diameter distributions from assessment and inventory plots only in Forest Types 147 and 148 in Bago State Forest. Stocking in the smaller DBHOB classes particularly (under 40 cm) increased between 1966 and 1984, indicating successful regeneration and growth of pole-sized trees. Both basal area and volume distributions in 1984 generally displayed a bimodal distribution, with peaks in the 30-40 cm class and the larger (60+ cm) classes. The beginning of a trend towards a more normal distribution is evident in the 1984 data, which could be expected to develop as more trees grow into the 30-60 cm classes and larger stems are removed in logging. Overall, these parameters clearly show an increase with time in the availability of timber over all diameter classes, especially the larger classes, as well as increased amounts of regeneration in the smallest diameter class (10-20 cm).

Figure 5 shows changes in stocking, basal area and volume for four species in the same plots as used to compile Figure 4. The commercial species are alpine ash, mountain gum and narrow-leaf peppermint; snow gum is non-commercial. Alpine ash displayed large increases for all parameters between 1966 and 1984, especially in total volume per ha which more than doubled. This indicates the success of management aimed at increasing the number and volume of ash trees in Bago State Forest. Stocking of mountain gum increased over time, but both BA and volume declined, probably due to the removal of larger individuals by logging and regeneration treatments aimed at increasing the stocking of ash. Peppermint showed large declines for all parameters, due to removal in logging and an apparent inability, compared with the former two species, to regenerate successfully in these Forest Types under the prevailing management regimes. Snow gum declined only slightly in stocking and volume in the 18 years, probably due to some deliberate removal to stimulate ash regeneration.

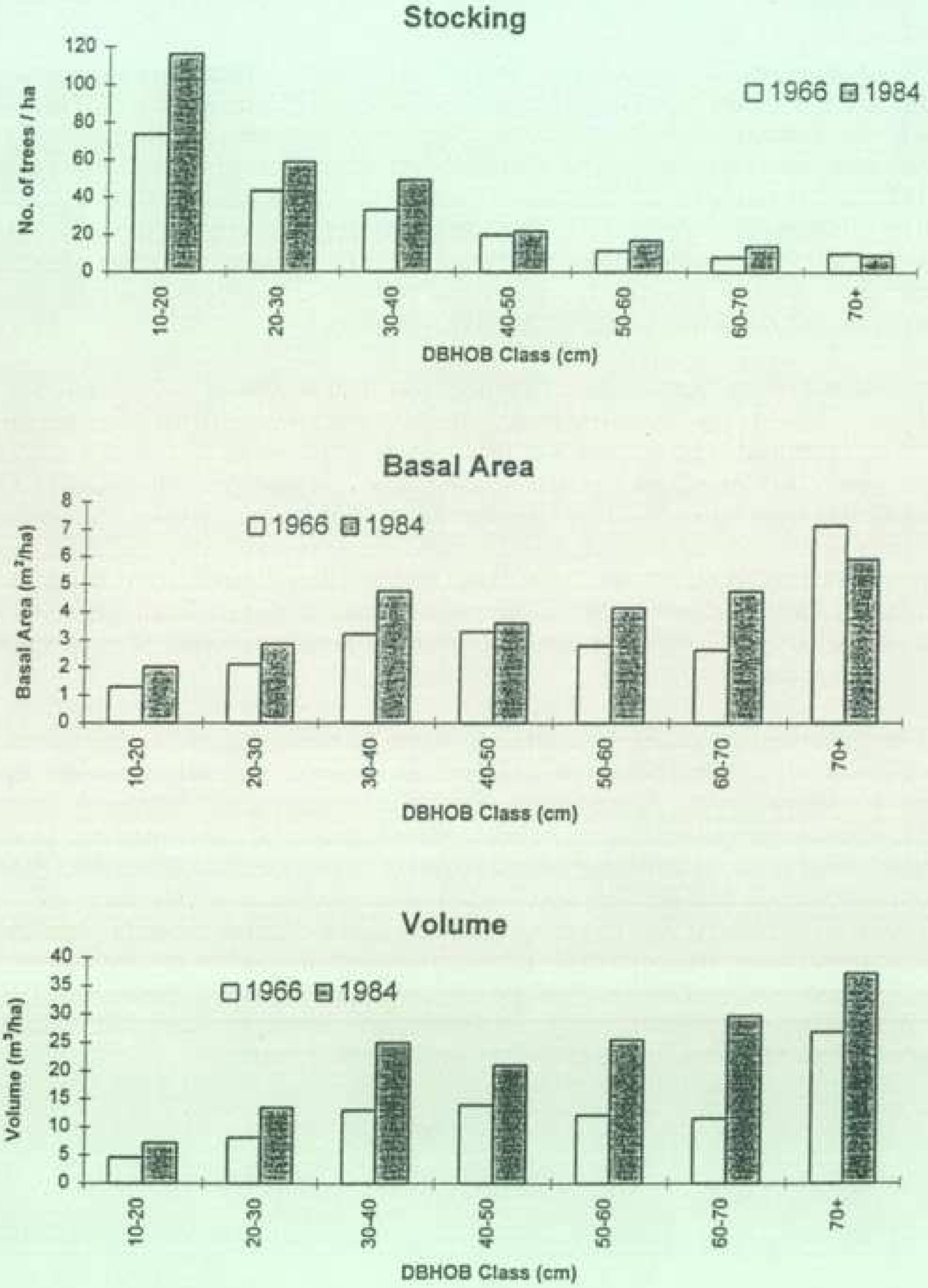

Figure 4. Distribution of stocking, basal area and stand volume over diameter classes in Forest Types 147 and 148, Bago State Forest. Data derived from inventories and temporary assessments in 1963, 1966 and 1984 (all species combined).

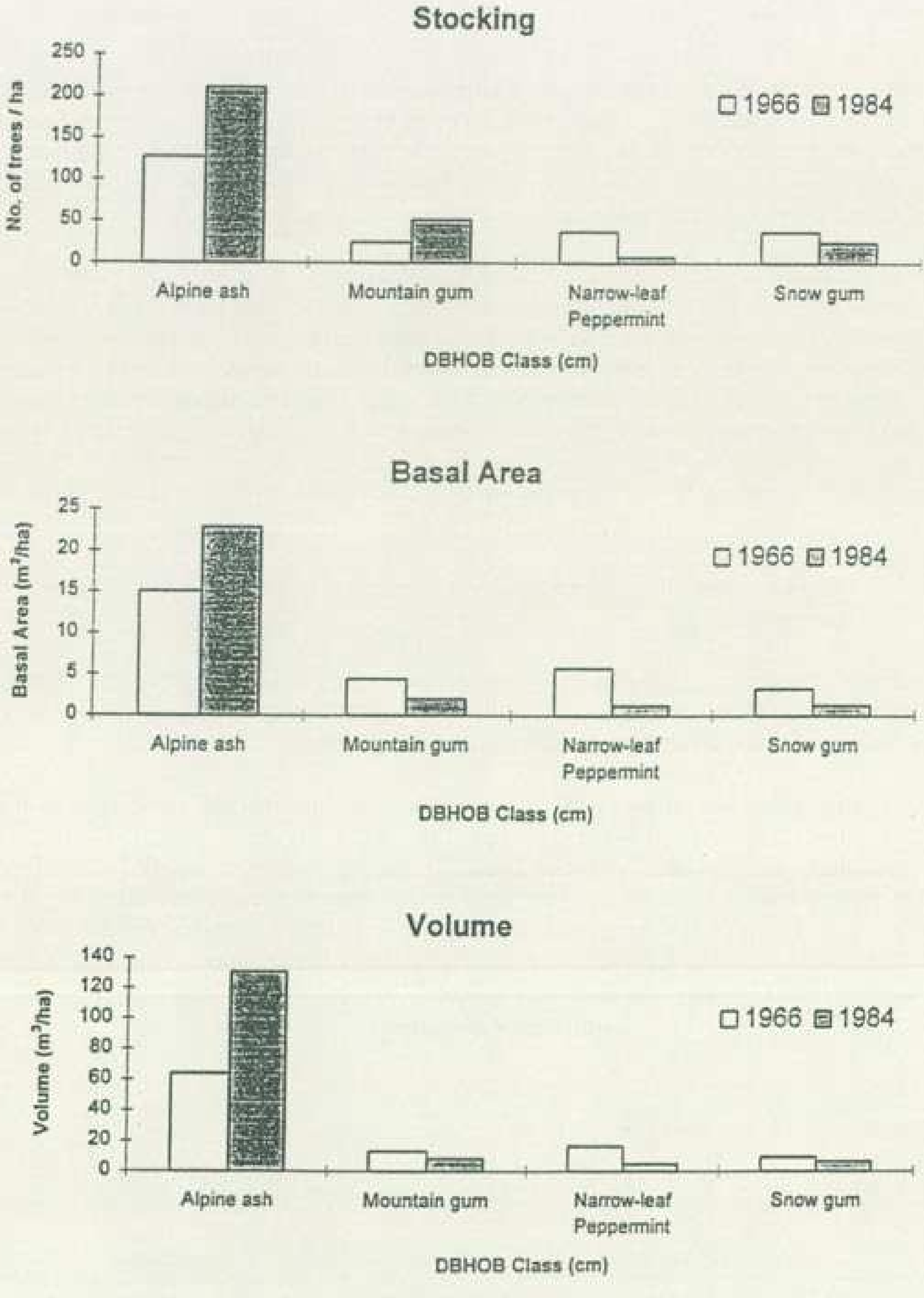

Figure 5. Stocking, basal area and stand volume for different tree species in Forest Types 147 and 148, Bago State Forest. Data derived from inventories and temporary assessments in 1963, 1966 and 1984.

Data for Maragle State Forest (Table 4) show a large increase in stocking density in Forest Types 147 and 148 between 1966 and 1984. This was accompanied by a decrease in BA ha^{-1} (particularly) and volume/ha, consistent with the management regime in Maragle State Forest over this period. This involved the removal of larger trees in logging, stimulating the development of large amounts of regeneration and growth of established younger trees retained in logging.

The results presented above show an increase in total growing stock over 18 years for which comparable data were available, albeit for a limited number of Forest Types and species. The amount and type of data available were able to indicate successful growth and regeneration of the prime commercial species, alpine ash, generally at the expense of other commercial and non-commercial species. There are insufficient data at the present time to carry out similar comparisons in the other, commercially less important, Forest Types in the Management Area. Indicator (b), as stated, is capable of evaluation using data of the type we have used. More wide-ranging and comprehensive inventories would be required, across all Forest Types and repeated at least twice over several decades, to achieve this fully.

Indicator d. Annual removal of wood products compared to the volume determined to be sustainable.

Actual volumes of alpine ash and other hardwood species sawlogs cut annually over the Management Area from 1940 until 1994, are shown as solid lines in Figures 6 and 7. The data were taken from Management Plan records, which detail annual yields of wood products.

Planned yields for alpine ash sawlogs from trees of 40 cm or greater DBHOB were set in each of the Management Plans, published in 1940, 1954, 1968, 1980, and 1986 (Anon 1940; 1954; 1968; 1980; 1986). Equivalent yields for other hardwood species, pooled together, were specified in the 1968 and 1986 Management Plans. These figures were derived from growth rates determined firstly from the 1939 survey and later from CFI plots, and used in yield modelling undertaken for the Plans. The planned yields may be taken to represent what was regarded by forest planners as sustainable levels of wood extraction from 1940 up to the present. They are shown by dAshed lines in Figures 6 and 7.

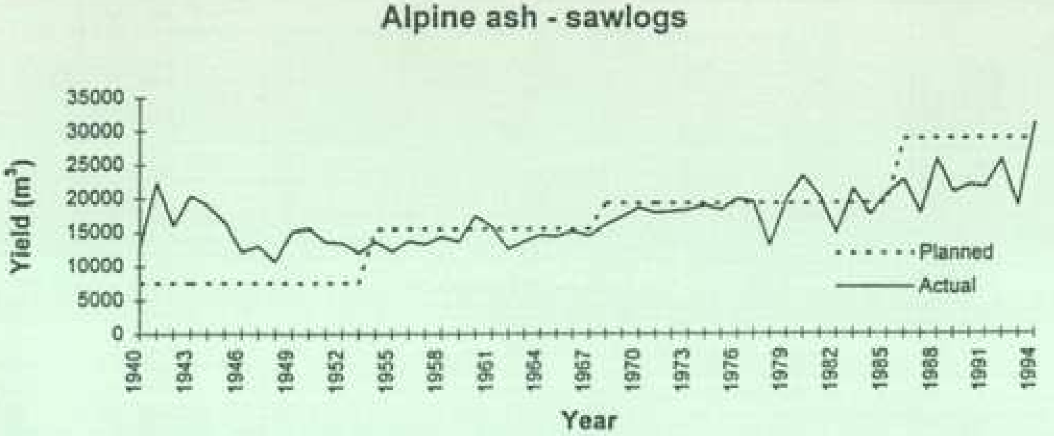

Figure 6. Actual annual yields of alpine ash sawlogs from the Management Area, 1940-1994, and planned yields based on 1939 growth studies (Lindsay) and 1954, 1968 and 1986 Bago/Maragle Management Plans.

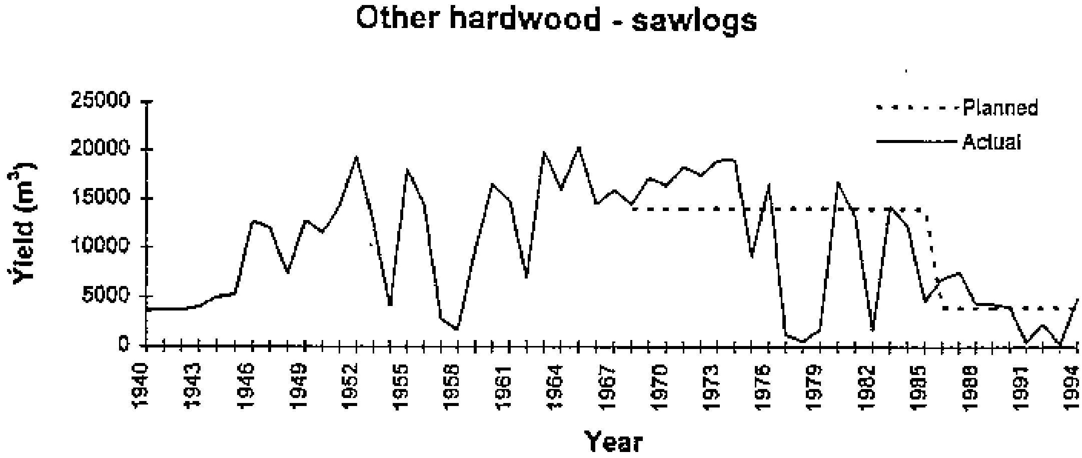

Figure 7. Actual annual yields of other hardwoods sawlogs from the Management Area, 1940-1994, and planned yields based on 1968 and 1986 Bago/Maragle Management Plans.

A comparison of the actual and planned yields as displayed in Figures 6 and 7 is one method of evaluating Indicator (d). In the case of alpine ash sawlogs (Figure 6), yields closely matched the calculated sustainable levels or remained below them during most of the 1954-1994 period. From 1940 to 1953, there appears to have been substantial overcutting, but this may be an artefact caused by setting an over-conservative planned annual yield of about 7,500 m^3/yr. The fact that annual yields of usually twice this size or greater were supported after 1954 suggests this was the case. Overall, these measurements of Indicator (d) suggest that ash sawlog extraction has been at or below sustainable levels for several decades, and further, that the resource available for harvesting has increased as a result of management over this period.

A similar analysis for non-ash sawlogs from the Management Area (Figure 7) shows much greater fluctuations in annual cuts throughout the whole 54 years. Since planned annual yields were set (1968), actual yields have mostly been either considerably higher or lower. The available resource and actual yield appear to have declined since the early 1970s, particularly after 1984. This reflects management policies which were to remove all merchantable trees and to encourage the extension of ash at the expense of mountain gum.

Another method of evaluating this indicator is through the specially derived Growth-minus-Yield Line. An example is shown in Figure 8, for alpine ash sawlogs in Forest Types 147 and 148 in Bago and Maragle State Forests between 1966 and 1984. Data used to construct this chart were standing volume calculated from assessments and inventories for the initial and final years, past yields, and calculated growth rates. The standing volumes are shown as two constants across the whole period, although in reality they are only single points at the beginning and end of the period. The points on the ascending line between the two constants were derived for each year as:

a = 1966 standing volume + (growth - yield) 1967
b = a + (growth - yield) 1968
c = b + (growth - yield) 1969 etc.

Growth (Mean Annual Increment, or MAI) was assumed to be constant across the period.

The Growth-minus-Yield Line is interpreted as follows:

- When horizontal, growth and yield are in balance, i.e. all available increment is harvested.
- When ascending, growth outweighs yield, i.e. standing volume increases progressively.
- When descending, yield outweighs growth, i.e. the standing volume is being progressively decreased.

It is considered that in multi-aged forests managed by selection methods, yield should not exceed growth if it is to be sustainable over a period (Potocic 1987).

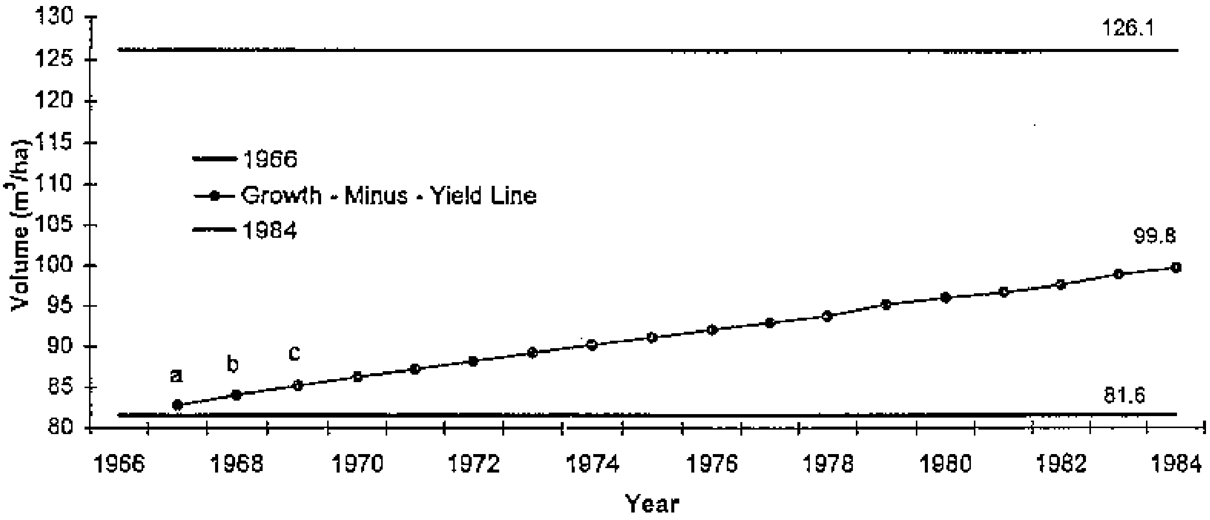

Figure 8. Growth-minus-Yield Line for alpine ash sawlogs in Forest Types 147 and 148, Bago State Forest, from 1966 to 1984. Standing volumes calculated from inventory and temporary assessment data in 1963-66 and 1984 are shown as solid horizontal lines. Annual values on the ascending line are calculated as explained in the text.

The Growth-minus-Yield Line is one measure of the net growth of the forest between two assessment events, based on assumed annual growth rates. It was not possible to calculate these rates from the available 1963-1966/67 and 1984 inventories because, for accurate estimation, one would need annual data for tree ingrowth, removals in logging, and mortality over the intervening years. In this case such data were not available so annual increments for alpine ash and mountain gum were taken from the 1986 Management Plan, calculated from CFI data collected up to 1971 from plots established in 1958. MAI per hectare for alpine ash was assumed to be 2.428 m^3 ha^{-1}, over an 'average hectare' of Forest Types 147/148. This increment, and the two standing volume estimates, were calculated using an alpine ash volume model developed in 1985 (Anon. 1986).

The value reached by the Growth-minus-Yield Line by 1984 was 99.8 m^3 ha^{-1}, an increase of 18.2 m^3 ha^{-1} over the 1966 standing volume. This is still considerably below the 1984 calculated standing volume (126.1 m^3 ha^{-1}); the simulated growth underestimated the 'true' situation in 1984 as determined by the temporary assessment. This may be due to a number of causes, such as poor precision in volume models (including the use of the alpine ash model for other species), inaccurately defined growth rates etc. It is also likely that the large amount of regeneration and advance growth of ash that had accumulated in Bago State Forest by 1966 grew faster than expected from calculations based on the 1958 CFI plots, since it was not subjected to heavy logging over much of the 1966-84 period. Most of the annual ash volume between 1968 and 1984 was taken from Maragle State Forest.

If it is accepted that sustainability of yield at the level of a whole forest area is being achieved if the annual removal of wood products does not exceed the annual wood growth increment, the Growth-minus-Yield Line data (Figure 8) show that sustainable yield was certainly achieved in the area studied. This measurement of Indicator (d) demonstrates this clearly, despite the apparent discrepancy in 1966 and 1984 standing volumes. If anything, the data probably underestimated the annual surplus of increment over removals in logging. Extending this methodology to accurately investigate the balance between timber growth and yield in other Forest Types is not possible at present because volume functions for species other than alpine ash have not yet been calculated, and accurate inventories of Forest Types other than 147 and 148 have not been carried out. Also, there is no record of yield by individual species other than alpine ash; yields are bulked under the description 'hardwood'.

CONCLUSIONS

1. Data available for forest areas, Types, and timber yields were generally sufficient for developing each of the three indicators (a, b and d) relevant to wood production, to evaluate Criterion 2 of the Santiago Declaration (Maintenance of productive capacity of forest ecosystems) with respect to Bago/Maragle Hardwood Management Area. The sufficiency and usefulness of the data varied somewhat depending on the indicator being quantified. In general, it is expected that lack of suitable existing data would be the greatest obstacle to fully quantifying indicators and exploring criteria of sustainable management in most forest areas.

2. The land base for timber production, in terms of total and productive area, has clearly increased over the history of forest management in the Bago/Maragle State Forests. Available data were sufficient to quantify this indicator, Indicator (a), to a large extent.

3. Deficiencies in available data, due to insufficient sampling and poor book-keeping historically, allowed growing stock, Indicator (b), to be quantified for only a portion of the productive area, namely Forest Types 147 and 148. However, these include the most productive Types and the prime commercial species (alpine ash) in the Management Area. The data indicated successful regeneration and growth of the potential resource of alpine ash in response to management, although often at the expense of other eucalypt species. To use this indicator fully one would need reliable volume models for all tree species.

4. The two methods used to quantify and present Indicator (d) (annual removal of wood compared with sustainable volume) were successful in portraying maintenance of the productive capacity of alpine ash in the Management Area over several years. The situation for other hardwood species appeared to be quite different. Accurate quantification of this indicator was hampered by a lack of accurate timber source data and by not having accurate growth rate data for any individual species.

REFERENCES

Anon. (1940). Bago Management Plan - ash forest: regulation of the cut and cutting programme. Forestry Commission of New South Wales. 20 pp. plus appendices.

Anon. (1954). Bago State Forest 560 Management Plan. Forestry Commission of New South Wales. 30 pp. plus appendices.

Anon. (1968). Eucalypt Working Plan - Bago-New Maragle area 1969. Forestry Commission of New South Wales. 17 pp. plus appendices.

Anon. (1980). Management Plan for Bago/Maragle Hardwood, July 1980 to June 1985. Forestry Commission of New South Wales. 33 pp. plus appendices.

Anon. (1986). Management Plan for the Bago/Maragle Management Area. Forestry Commission of New South Wales. 65 pp plus appendices.

Anon. (1989). Forest Types in New South Wales. *Forestry Commission of New South Wales Research Note 17*. 95 pp.

Canadian Forest Service (1995). Criteria and indicators for the conservation and sustainable management of temperate and boreal forests. The Montreal Process. 27 pp.

Lindsay, A.D. (1939). Report on growth studies - alpine ash. Volume 1. Forestry Commission of New South Wales. 165 pp.

Potocic, Z. (ed.) (1987). Encyclopaedia of Forestry, pp. 528-530. Jugoslovenski Leksikografski Zavod, Zagreb.

Turner, J. (1993). Research and ecologically sustainable forest management - a discussion paper. *State Forests of New South Wales Technical Paper No. 61*. 26 pp.

APPENDIX 2

REVIEW OF PHASMATID OCCURRENCE AND EFFECT ON INCREMENT IN BAGO STATE FOREST

by

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CONTENTS

SUMMARY

Since the early 1950s there has been a build up of large populations of the phasmatid *Didymuria violescens*, a serious insect defoliator of eucalypts in south-eastern Australia. In Bago State Forest outbreaks of the pest occurred in the 1950s and early 1960s. Defoliation by the phasmatid during that period greatly decreased both diameter and volume increment. Since the 1960s no significant outbreaks have occurred. The history of defoliation can be detected by examining growth rings.

INTRODUCTION

Most species of the Phasmatodea usually occur in low numbers, but some species have occurred in plague proportions. In such instances serious defoliation of trees has resulted. *Eucalyptus* forests in the highlands of south-eastern Australia have been extensively defoliated over a number of years (Readshaw 1965). At Bago State Forest the first known case of severe defoliation occurred in January 1953 (Shepherd 1957). Further defoliation occurred every second summer until 1965, with 1959 being the worst year (Readshaw 1965, 1969, 1990). Since then there have been no significant phasmatid outbreaks in the Bago area (Carter 1978). In 1988 defoliation around the Yarrangobilly area was evident and quite extensive but no damage could be discerned at Bago State Forest to the west (Readshaw 1990).

Three species of phasmatids occur in plague numbers in Australia, these are *Podacanthus wilkinsoni* Macl., *Didymuria violescens* (Leach) and *Ctenomorphodes tessulatus* (Gray) (Campbell 1967). The phasmatid involved in the defoliation in Bago State Forest is *D. violescens* (Shepherd 1957).

Briefly, the biology of *D. violescens* is as follows. *D. violescens* eggs hatch in spring and early summer (October-December) with young nymphs climbing and settling on the nearest eucalypts. Five nymphal instars occur, each lasting from one to three weeks, depending on temperature conditions. Adults appear between January and March; each female laying about 200 eggs which drop one at a time to the forest floor. A few eggs hatch during the following spring and early summer but most remain in the litter until about eighteen months later when hatching occurs. This long period between the laying and hatching of eggs is responsible for the biennial nature of the plagues. The hatching of eggs in very high and very low numbers in alternate years results in marked defoliation every second year and little defoliation in the intervening year. Phasmatid outbreaks and defoliation have occurred in Bago State Forest in odd calendar years (e.g. 1955, 1957, 1959) with no defoliation occurring in even years (Readshaw 1965).

Most species of *Eucalyptus* are defoliated by *D. violescens*. The severely defoliated species of *Eucalyptus* at Bago State Forest are *E. delegatensis* (alpine ash) (Shepherd 1957). Other favoured species first to be defoliated are the narrow-leafed peppermints *E. radiata* Sieb. and *E. robertsoni* Blakely, the broad-leafed peppermint *E. dives* Schauer and the gums *E. viminalis* Labill., *E. huberiana* Naud., *E. dalrympleana* Maiden, *E. mannifera* (A. Cunn. Herb.) Mudie, *E. stellulata* Sieb., *E. pauciflora* Sieb. and *E. bicostata* Maiden, Blakely and Simmonds. Other species known to have been severely defoliated are *E. laevopinea* E. T. Baker, *E. obliqua* L'Herit., *E. delegatensis* R. T. Baker, and *E. fastigata* Deane and Maiden, though these appear to be less favoured than the former groups (Campbell 1960).

PHASMATID OCCURRENCE AT BAGO STATE FOREST

The first reported outbreak of phasmatids in Bago State Forest was during the 1952/53 season, resulting in the complete defoliation of approximately two hundred acres in two adjoining compartments (126 and 131) in the alpine ash belt (Shepherd 1957). The compartments* defoliated during the 1952/53 and 1954/55 attacks, according to Shepherd's work, are listed in Table 1.

Table 1. Compartments defoliated during the 1952/53 and 1954/55 attacks.

1952/53	1954/55
126***	19**
131***	25**
	34*
	36**
	131**

*** complete defoliation
** severe defoliation
* moderate defoliation.

The original attack within the ash belt was on the boundary of Compartments 126 and 131 in 1952/53. During 1954/55 the attacked areas spread outward considerably and several new centres of concentrated attack were developed. The worst of the new attack centres was within the regeneration area, an area of alpine ash (Anon 1955). In the 1956/57 season there were large numbers of phasmatids in all parts of Bago State Forest with severe defoliation caused in regeneration near the Granite Mountain in Compartment 169. The order of working had to be altered in the alpine ash section due to severe damage in Compartments 41 and 42 (Anon 1957). Although the defoliation was severe in 1958/59 the extent of damage and the ash area infested were not known accurately (Anon 1959). Widespread defoliation over the altitudinal range of Bago State Forest was obvious in the 1960/61 plague season. However, alpine ash suffered much less than other hardwood species. There was no complete defoliation in ash areas, but large tracts of gum/messmate were completely defoliated (Anon 1961). A major plague was experienced during 1962/63, but no complete defoliation occurred (Anon 1963). During 1964/1965 relatively few phasmatids hatched out and of these not many survived to the adult stage. Areas of pure alpine ash experienced the greater numbers and areas of mixed hardwoods had virtually no phasmatids. In 1965 CSIRO forecast that the bad plagues of phasmatids were over (Anon 1965).

In the 1960-61 and 1962-63 seasons an aerial reconnaissance of defoliation in Bago State Forest was carried out by the Division of Entomology, CSIRO. Extensive patches of severe defoliation were observed in the 1960/61 season, but there were only a few rather diffuse patches of light to medium defoliation near Pilot Hill, Scotchmans Creek, Buddong Falls and Brabins Road in the 1962/63 season (Readshaw 1964).

From 1960 to 1964 field observations were also made at 33 sites every year in Bago State Forest, investigating the severity of defoliation and the density of healthy eggs (Readshaw 1964). Site positions are shown in Figure 1 and data are summarised in Table 2. Defoliation and the density of

* A specified area of land within a State forest defined for management purposes and generally based on clear geographic boundaries defined by geographic features (creeks, ridges, road lines). Average compartment size is around 200 ha.

healthy eggs had decreased markedly at nearly all sites since 1960/61. No serious defoliation occurred in 1962/63 and 1964/65.

Table 2. Defoliation and egg density in infestation of *D. violescens* at Bago State Forest (CSIRO Site 1-33, 1960-64)

Site	1960-61		1961-62		1962-63		1963-64	
	Defoliation*	Eggs**	Defoliation	Eggs	Defoliation	Eggs	Defoliation	Eggs
1	++	0.82	--	0.16	+	2.16	--	0.33
2	+++	6.17	--	0.50	++	2.00	--	1.33
3	++	1.00	--	--	+	0.66	--	--
4	+	1.33	--	0.16	+	0.50	--	--
5	--	--	--	--	--	--	--	--
6	+++	20.50	--	10.66	++	5.49	--	0.33
7	+	2.50	--	0.33	--	0.66	--	--
8	+	1.49	--	3.16	+	8.00	--	4.50
9	++	2.50	--	0.83	--	--	--	0.17
10	+	3.00	--	0.33	--	--	--	--
11	++	9.50	--	1.75	--	0.16	--	--
12	+	1,50	--	--	--	--	--	--
13	++	13.33	--	5.66	+	3.50	--	0.83
14	+	1.33	--	0.83	--	1.16	--	0.33
15	+	3.16	--	1.49	--	1.16	--	--
16	+	--	--	--	--	0.16	--	--
17	++	10.16	--	1.33	+	2.50	--	0.17
18	+	3.83	--	1.50	--	0.16	--	--
19	+	3.00	--	3.16	--	0.16	--	--
20	+	0.83	--	0.16	--	0.16	--	--
21	+++	11.33	--	2.49	--	0.49	--	--
22	++	0.66	--	0.50	--	--	--	--
23	+++	13.83	--	1.16	+	0.16	--	0.17
24	+++	4.40	--	2.82	+	0.50	--	--
25	+	0.49	--	--	--	--	--	--
26	+	15.33	--	4.16	--	0.33	--	--
27	+	0.16	--	0.50	--	--	--	--
28	+	8.66	--	--	--	--	--	--
29	--	--	--	--	--	--	--	--
30	++	3.16	--	0.33	+	7.50	--	1.17
31	+++	3.33	--	0.83	+	2.67	--	2.17
32	+	5.83	--	0.66	--	0.17	--	0.17
33	+	4.66	--	0.49	--	--	--	--
	Totals	157.87		45.95		40.41		11.67
	Means	4.78		1.39		1.22		0.35

* no defoliation
\+ light defoliation
++ medium defoliation
+++ heavy defoliation
** mean number of healthy eggs per 5 min. search in winter

Since the outbreaks of phasmatids in the 1950s and early 1960s there have been no significant phasmatid outbreaks in the Bago area. To understand the potential presence of phasmatids in the Bago ash forest, eggs were sampled on 15 November 1978 in Compartments 27, 81 and 83 (Carter 1978). Egg sampling was also conducted on 5 October 1979, in Compartments 16, 27, 35, 45, 81 and 82 (Carter 1979). Unfortunately, the timing of these samplings was so late that only empty shells were collected and it was not possible to estimate the phasmatid population on the basis of these. However, the number of empty shells gave cause for alarm at the build-up of phasmatids.

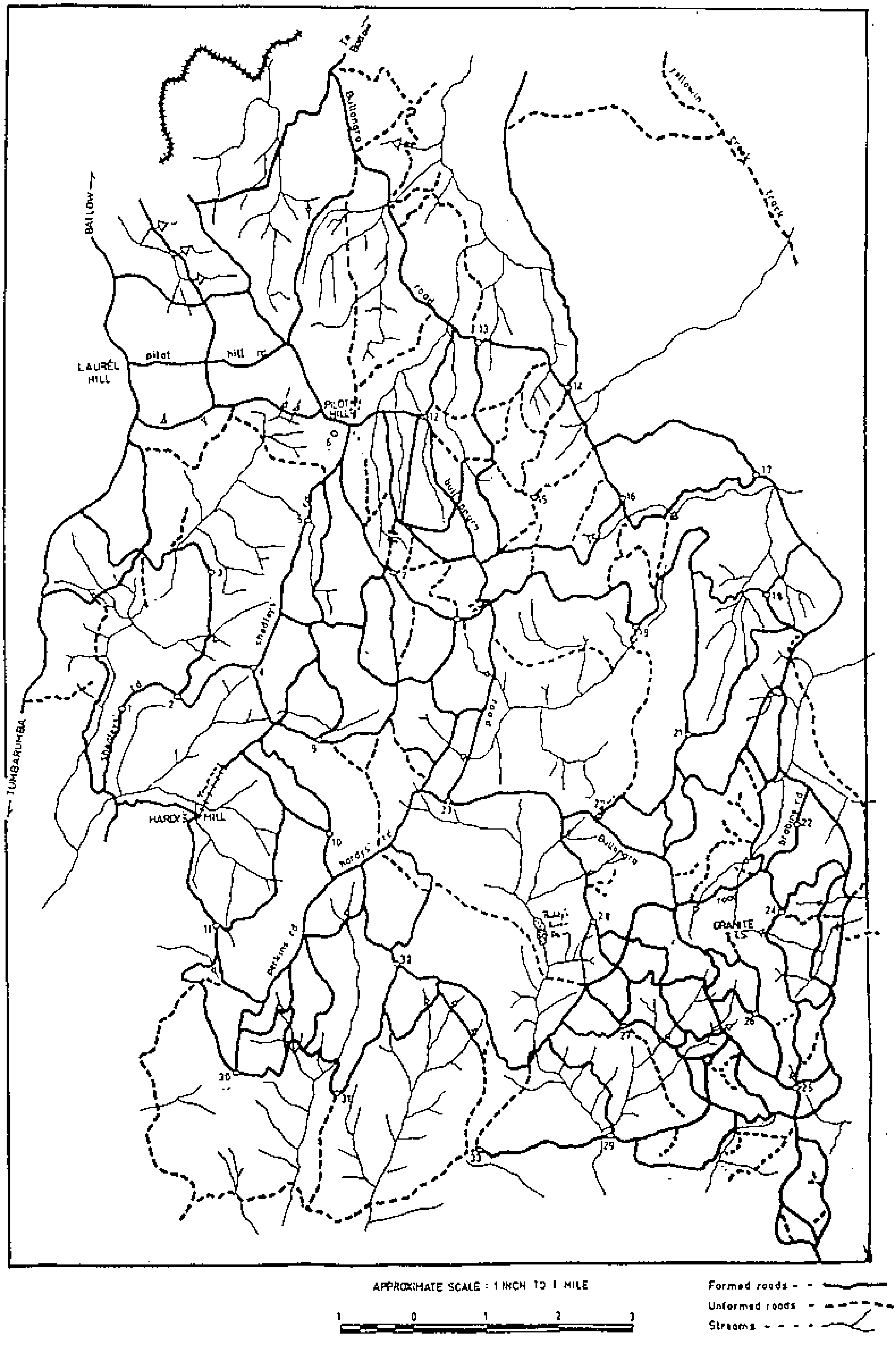

Figure 1. Positions of 33 sites at Bago State Forest where field observations were made of severity of defoliation and density of healthy eggs.

Phasmatid occurrence in Bago State Forest is summarised in Table 3, according to information extracted from Annual Reports of the Forest Commission of New South Wales (Anon. 1951-1965) and the *Bago State Forest 560--Management Plan* (Anon. 1955-1965).

Table 3. Phasmatid occurrence in Bago State Forest.

Year (summer)	Severity of defoliation	Area defoliated	Area sprayed
52/53	Complete	81 ha	-
53/54*	Few phasmatids	No	-
54/55	Severe	Extensive	121 ha**
55/56*	Few phasmatids	No	-
56/57	Severe	All parts of the forest	284 ha***
57/58*	Few phasmatids	No	-
58/59	Severe	Extensive	-
59/60*	Very few phasmatids	No	-
60/61	Moderate	All parts of the forest	-
61/62*	Very few phasmatids	No	-
62/63	Light	Partial	-
63/64*	Very few phasmatids	No	-
64/65	Very few phasmatids	No	-
65/66*	Very few phasmatids	No	-

* " off year " of the outbreaks due to the two year life cycle of the pest
** chemical used was dieldrin
*** half with dieldrin and half with benzene hexachloride

D. violescens has also caused significant defoliation in a number of areas in Victoria. The first outbreak of *D. violescens* in Victoria was ascertained during the summer of 1960/61 in 800 ha of mixed *E. regnans* and *E. obliqua* forest near the headwaters of the Bunyip and Tarago rivers south of Powelltown in the Upper Yarra and Neerim Forest Districts. In the following two years phasmatids were also found in about 850 ha of pure *E. regnans* regrowth forest further north at Britannia Range and Dee River. The original outbreak in the Bunyip and Tarago River area also spread to about 1365 ha in 1963/64. From that time the infestations occurred every two years until the early 1970s, the most widespread infestation being in 1971, when about 6400 ha of forest were affected (Neumann *et al.* 1977). *E. regnans* forest areas that were defoliated and aerially sprayed with insecticide in the central highlands of Victoria are shown in Table 4.

THE EFFECT OF DEFOLIATION ON INCREMENT

No figures for diameter or volume increment for defoliated areas are available prior to 1954 when Shepherd established thinning and increment plots in areas which had been moderately defoliated (Shepherd 1957). DBHOB (diameter at 1.3 m over-bark) measurements were recorded for 200 sample trees which were completely defoliated and located at Compartments 19, 25, 36 and 131 in Bago State Forest. During the period 1 November 1955 to 31 March 1957, covering two growing seasons, five diameter classes gave positive increment, 25 gave negative increment, while two showed 100% mortality. From these results it can be seen that complete defoliation causes loss of increment for a period of at least two years.

Table 4. *E. regnans* forests defoliated by *D. violescens* and sprayed with malathion insecticide within the central highlands of Victoria.

Year (summer)	Forest district	Total forest area defoliated (ha)	Forest district	Total forest area sprayed (ha)
60/61	Upper Yarra Neerim	679	-	-
61/62*	-	-	-	-
62/63	Upper Yarra Neerim	790	-	-
63/64*	-	-	-	-
64/65	Upper Yarra	16	Upper Yarra Neerim	1083
65/66*	-	-	Upper Yarra	81
66/67	Upper Yarra	120	Upper Yarra	121
67/68*	-	-	Upper Yarra	191
68/69	Upper Yarra Neerim	897	Upper Yarra	2186
69/70*	-	-	Upper Yarra Neerim	1968
70/71	Upper Yarra Neerim	790	Upper Yarra Neerim Broadford	6660
71/72*	-	-	Upper Yarra Neerim	1593
72/73	Erica	808	Upper Yarra Neerim	3523
73/74*	-	-	Upper Yarra Neerim Erica	335

* " off year " of the plague

Table 4. (cont.)

Year (summer)	Forest district	Total forest area defoliated (ha)	Forest district	Total forest area sprayed (ha)
74/75	Upper Yarra Neerim Erica	0	Upper Yarra Neerim Erica	1070
75/76*	-		Upper Yarra Neerim Erica	531
76/77			-	0

* " off year " of the plague

In February 1955 Shepherd established two acre yield plots in 1917 regeneration for successive yield measurements of defoliated trees. At the time of establishment there was little evidence of defoliation in these areas. The treatment plot was situated in Compartment 34 and the control plot in Compartment 25, results are shown in Tables 5 and 6.

Table 5. Yield Plot 1 Compartment 34, Bago State Forest.

Parameter	February 1955	February 1956	March 1957
Age-years	38	39	40
Stocking ha^{-1}	185	185	180
DBHOB (cm)	44.6	44.9	45.6
MAI	1.17	1.14	1.14
CAI	----	0.23	0.79
Basal area (m^2 ha^{-1} $year^{-1}$)	30.6	30.9	31.1
MAI	0.80	0.79	0.78
CAI	----	0.33	0.16
Volume (m^3 ha^{-1} $year^{-1}$) true	304.4	308.5	309.3
MAI	10.1	7.9	7.8
CAI	----	4.1	0.84

Note: Basal area loss due to deaths = 0.16 m^2
Volume per ha loss = 11.12 m^3

Table 6. Control Plot 2, Compartment 25, Bago State Forest.

Parameter	February 1956	March 1957
Volume (m^3 ha^{-1} $year^{-1}$) true	310.5	320.5
MAI	7.98	8.05
CAI		10.1

General growth studies in alpine ash indicated that CAI (Cumulative Annual Increment) should be greater than MAI (Mean Annual Increment) at the age of 39-40 years. Therefore from the above results it was concluded that moderate defoliation caused a greatly reduced increment. The increment dropped from an expected 9.8 m^3 to 4.1 m^3 and then to 0.84 m^3.

Consecutive remeasurements of the above yield plots revealed a surprising loss of increment, even in the stands subjected to very mild attack. In the case of yield plot 1 the loss of CAI diameter was 40% per year for six years and the initial loss of increment immediately after severe defoliation was in the vicinity of 75%. The basal area increment percentage for those six years was only 50% of that expected for ash. In yield plot 2, which had never been severely defoliated, only experiencing minor attack, the loss of CAI diameter was 16% per year for five years, with a 20% loss of the basal area increment for a period of five years (Anon. 1961, Anon. 1961a).

Mazanec (1966, 1968) developed a method for detecting the occurreuce and severity of phasmatid attack in the growth rings of alpine ash (*E. delegatensis* R. T. Baker) in the Mount Pinnibar area of north-eastern Victoria. In his 1966 paper he described the effects of moderate defoliation of alpine ash by *D. violescens* on the diameter growth of pole-sized trees, and the effect of different intensities of artificial defoliation on the survival of saplings. He found that during the period of late wood production in the autumn and winter following the summer 1962-63 attack the diameter increment was only 11% of that in controls. Good recovery of crowns occurred the following summer (1963-64), when phasmatids were scarce, but diameter increment was reduced by 50%. He also studied (1968) the influence of defoliation by phasmatids on the seasonal trends of diameter growth and described how inspection of the growth rings may be used to determine the history of alpine ash with regard to the past defoliation. He concluded that in *E. delegatensis* each defoliation altered the proportion of late wood in the two adjacent growth rings and thus produced a characteristic pattern of narrow and wide bands of late wood. In this pattern the actual years of defoliation corresponded to the years with narrow bands of late wood. The severity of defoliation can be assessed from the width of late wood produced during the year of defoliation and the width of the succeeding early wood produced in the year of recovery. A heavy defoliation reduced the widths of both bands to the limits of visibility, while a light defoliation reduced the late wood, without appreciably affecting the succeeding early wood.

Readshaw and Mazanec (1969) used the method developed by Mazanec (1966, 1968) to determine the extent of previous defoliation in about 25,000 acres of alpine ash in Bago State Forest. Details of the studies follow.

157 sample trees were located throughout the forest (their positions can be located according to the map found in that paper). Three discs were cut from each tree; one at breast height, one at half height and one immediately below the crown. Growth rings were then examined under a binocular microscope, four categories of defoliation being recognised.

- Nil: late wood and early wood not noticeably reduced.
- Light: late wood reduced, early wood apparently normal.
- Moderate: late wood and early wood both much reduced.
- Severe: late wood reduced, little or no early wood such that the two rings almost fuse into one.

From the studies of the growth rings of 157 sample trees Readshaw found that the earliest defoliation in Bago State Forest was in 1951, earlier than stated by Shepherd. This was detected in the growth rings in four trees in Compartment 126 in the Yellowin Hut locality. After subsequent attacks by phasmatids the defoliation extended to most of the alpine ash area, reaching a maximum of 141 of the 157 samples in 1961. It then declined and in 1965 only 18 trees in the sample had been attacked. The severity of the defoliation is shown in Table 7. It can be seen that the heaviest defoliation occurred in 1959, with 9, 73 and 34 trees ranked respectively as light, moderate and severe.

Table 7. Classification of the 157 sample trees according to the degree of defoliation detected in the growth rings.

Degree of defoliation	1951	1953	1955	1957	1959	1961	1963	1965
Nil	153	142	107	59	41	16	105	139
Light	0	8	20	16	9	35	44	18
Moderate	4	6	22	73	73	98	8	0
Severe	0	1	8	9	34	8	0	0
Total defoliated	4	15	50	98	116	141	52	18

Note: Numbers indicate the number of trees defoliated each year.

From Table 8 it can be seen that many trees were defoliated several times during the course of the outbreak.

Table 8. Number of trees defoliated.

Frequency of defoliation	0	1	2	3	4	5	6	7	8	**Total**
Number of trees	14	17	22	40	28	24	3	8	1	157

The average radial increment of trees was estimated by measuring the widths of ten pairs of rings in the year of defoliation and in the year of recovery. The width of each ring was measured along four radii at three levels in the bole. The results are shown in Table 9.

Table 9. Widths of growth rings in years of defoliation and years of recovery of ten pairs of rings in each of the four categories of defoliation.

Class of defoliation	**Year of defoliation Mean ring width (mm)**	**Year of recovery Mean ring width (mm)**
Nil	4.0	4.0
Light	2.6	2.7
Moderate	2.1	1.4
Severe	2.1	1.0

The average annual increment of the 157 sample trees was calculated by multiplying the number of trees in each defoliation class (Table 7) by the appropriate mean width of ring (Table 9) and for each year adding the resulting four products. The percentage reduction in increment for each year was estimated as $100\text{-}100t\ T^{-1}$, where t is the annual increment of the sample and T the increment that would have accrued if there had been no defoliation. Results are provided in Table 10.

Table 10. Percentage reduction in annual increment of alpine ash at Bago State Forest between 1951 and 1966 based on the sample of 157 trees.

Year	**Actual increment (t) (mm)**	**Potential increment (T) (mm)**	**Reduction percent ($100\text{-}100t\ T^{-1}$)**
1951	620.3	628.0	1
1952	617.8	628.0	2
1953*	603.0	628.0	4
1954	599.2	628.0	5
1955*	541.6	628.0	14
1956	521.8	628.0	17
1957*	447.5	628.0	29
1958	393.3	628.0	37
1959*	409.6	628.0	35
1960	326.2	628.0	48
1961*	332.5	628.0	47
1962	279.2	628.0	56
1963*	549.3	628.0	13
1964	391.2	628.0	13
1965*	602.1	628.0	4
1966	605.0	628.0	4
Mean	499.8	628.0	20

* years of defoliation

Note: The above tables are extracted from Readshaw (1969).

It can be seen that the effect of defoliation on the current annual radial increment ranged from an estimated reduction of 1% in 1951 to 56% in 1962, an average of 20% over the outbreak period of 16 years.

REFERENCES

Anon. (1951-1965). Annual Reports of Forest Commission of New South Wales.

Anon. (1955). Bago State Forest 560--Management Plan, 1954/55 Annual Report.

Anon. (1956). Bago State Forest 560--Management Plan, 1955/56 Annual Report.

Anon. (1957). Bago State Forest 560--Management Plan, 1956/57 Annual Report.

Anon. (1958). Bago State Forest 560--Management Plan, 1957/58 Annual Report.

Anon. (1959). Bago State Forest 560--Management Plan, 1958/59 Annual Report.

Anon. (1960). Bago State Forest 560--Management Plan, 1959/60 Annual Report.

Anon. (1961). Bago State Forest 560--Management Plan, 1960/61 Annual Report.

Anon. (1961a). Phasmatid Investigation, Yield Plots -- Bago State Forest 560. Report, The District Forester, Tumut.

Anon. (1962). Bago State Forest 560--Management Plan, 1961/62 Annual Report.

Anon. (1963). Bago State Forest 560--Management Plan, 1962/63 Annual Report.

Anon. (1964). Bago State Forest 560--Management Plan, 1963/64 Annual Report.

Anon. (1965). Bago State Forest 560--Management Plan, 1964/65 Annual Report.

Campbell, K. G. (1960). Preliminary studies in population estimation of two species of stick insects (Phasmatidae: Phasmatodea) occurring in plague numbers in highland forest areas of southeastern Australia. Proceedings of the Linnean Society of New South Wales, 85: 121-141.

Campbell, K. G. and Hadlington, P. (1967). The biology of three species of phasmatids (Phasmatodea) which occur in plague numbers in forests of south-eastern Australia. *Forestry Commission of New South Wales, Research Note No. 20*, 38pp.

Carter, P. R. (1978). Phasmatid pilot study--Bago State Forest, Tumut. *Forestry Commission of New South Wales, Research Report VI/1.61*.

Carter, P. R. (1979). Phasmatid egg collection, Bago State Forest, Tumut. *Forestry Commission of New South Wales, Research Report VI/1.61*.

Mazanec, Z. (1966). The effect of defoliation by *Didymuria violescens* (Phasmatidae) on the growth of alpine ash. *Australian Forestry*, 30: 125-130.

Mazanec, Z. (1968). Influence of defoliation by *Didymuria violescens* on seasonal diameter growth and the pattern of growth rings in alpine ash. *Australian Forestry*, 32: 3-14.

Neumann, F. G., Harris, J. A. and Wood, C. H. (1977). The phasmatid problem in mountain ash forests of the central highlands of Victoria. Forestry Commission of Victoria, Bulletin 25, 43pp.

Readshaw, J. L. (1964). Observations of *Didymuria violescens* infestation at Bago (1960-1964). A report to the Forest Commission of New South Wales.

Readshaw, J. L. (1965). A theory of phasmatid outbreak release. *Australian Journal of Zoology*, 13: 475-490.

Readshaw, J. L. and Mazanec, Z. (1969). Use of growth rings to determine past phasmatid defoliation of alpine ash forests. *Australian Forestry*, 33: 29-36.

Readshaw, J. L. (1990). Phasmatid outbreak revisiting? *Australian Journal of Zoology*, 38: 343-346.

Shepherd, K. R. (1957). Defoliation of alpine ash *Eucalyptus delegatensis* by phasmatids. Paper presented at the 7th British Commonwealth Forestry Conference, Australia and New Zealand, 14 pp.

APPENDIX 3

WATER QUALITY MONITORING STRATEGIES FOR FOREST MANAGEMENT: A CASE STUDY AT BAGO STATE FOREST

Available as Research Paper No. 30,
State Forests of New South Wales

by

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Sustainable forest management requires development and utilisation of indicators of performance. Water quality is a broad area requiring monitoring, but there are a number of differing objectives, and to fulfil these, a range of methodologies and strategies are required. The main sampling method presently used for water chemistry assessment in New South Wales has been the use of relatively few fixed point automatic water samplers providing information on temporal change. The interpretation of these for routine forest management practice is limited because of the methods, short periods of calibration, control requirements and spatial representation.

One alternative or enhancement, involves analyses from a large number of sampling points sampled over a short time period within a managed forest. This can provide relative information on land use, geology and disturbance and establishment of standardised sites allows revisitation of the area and comparison of results through indexation. The methodology has been tested within Bago State Forest and initial results have been reported both in tabular form and in relation to length of stream represented. The method can be integrated within an overall strategy of sampling providing sound information for forest managers. Resources required are much less than alternatives, hence providing efficiency and value.

INTRODUCTION

State Forests of New South Wales has requirements for water quality monitoring in forest management as a method of demonstrating sound forest practice, providing information for improving activities in the future, and complying with regulations specifically aimed at protecting the aquatic environment. That is, water quality monitoring fulfils several objectives. Possible alternative methods to efficiently and effectively fulfil these objectives need evaluation, and information is needed for such evaluations.

Water sampling in forests and interpretation raise a number of issues relating to pollution resulting from non-point sources of sediments or chemicals. While the protection of the aquatic environment is a major issue and maintenance of water quality is required at a high level, water quality measurements have often been used as surrogates for other aspects such as measurements of levels of soil erosion. That is, stream quality has been used as an indicator of terrestrial disturbance rather than an indicator of stream health itself. In doing so, the specific focus and value of water quality assessment has been lost.

Water quality monitoring is often developed as an extension of existing research programs and hence is carried out in a comparable manner. Long terms studies overseas have influenced these approaches (Likens *et al.* 1977, Johnson and Van Hook 1989, Swank and Crossley 1988, Manderscheid *et al.* 1995). Research projects in forest hydrology are often undertaken in small paired catchments with highly controlled forest management operations involved. The calibration periods are reasonably long term (8-10 years) with the post treatment analysis extending over an equivalent time. Water quantity is accurately assessed using a calibrated weir allowing for loadings to be determined. Such systems are valuable as they allow for development of models and can be important in the understanding of processes. They are, however, expensive to set up and there is a substantial cost in subsequent maintenance with a high risk of data loss or failure. Monitoring systems extending this approach recognise that most chemical and sediment movement results from events and attempt to measure movement at such times. However, to reduce costs and to bring the analyses into a management or regulatory time frame, the infra-structure and calibration periods tend to be short. The result is that comparative accuracy and precision are also greatly reduced, especially if the control and treated catchments respond in a significantly different manner or the pre-and post-treatment climatic conditions are greatly different. Further, as the catchments are generally in the headwaters and relatively small in size, they are 'flashy' in response and may not relate to water quality in the larger streams.

Low intensity, periodic grab sampling of streams at different times is a lower cost system and will provide some relative water quality information, especially where a large impact is expected, however, lack of information on the relative flows of creeks, the sampling position on the hydrograph or the lack of flow information for a given sampling point means it is difficult to use such results in any spatial or temporal context. This form of sampling is valuable for short term monitoring when chemicals such as fertilisers, weedicides or insecticides have been applied or some other specific management operation has been carried out such as road building. Modification of this sampling in an intensive spatial context, may be of value.

This report considers specific requirements of forest managers when sampling water quality and assesses alternatives for providing required information.

1. *WATER MONITORING PROGRAM*

A critical factor in the design and implementation of water quality monitoring is the clear definition of objectives. General water monitoring programs have been proposed for non-point source pollution in areas of the United States (for example, Boynton 1972, MacDonald *et al.* 1991, Spooner and Line 1993). MacDonald *et al.* (1991) proposed guidelines for forestry activities in the Pacific Northwest and these are on a broad regional approach. In that document, the authors identified seven types of monitoring which were listed as:

- Trend
- Baseline
- Implementation
- Effectiveness
- Project
- Compliance
- Validation

being distinguished by the purpose of the monitoring and use of the data rather than the specific data collected. They also established criteria for developing an effective program for monitoring. Boynton (1972), proposed a systematic procedure to ensure the programs were cost effective:

1. Establish objectives.
2. Review existing data.
3. Establish statistical utilisation and interpretation of data.
4. Select water quality characteristics.
5. Establish sampling frequency.
6. Locate stations.
7. Determine cost of surveillance.
8. Evaluate the ongoing program.

The major requirements of monitoring programs are statements of objectives, assessment of methods to ensure fulfilment of objectives, and cost effectiveness.

2. *OBJECTIVES OF WATER QUALITY MONITORING*

The objectives of water quality monitoring will determine the type of sampling required and the subsequent analysis and reporting. The monitoring requirements for managed forests include:

- Assessment of specific treatment (fertiliser application, need to assess concentration of specific applied nutrient). Operational monitoring.

- Monitoring after harvesting operation (multiple facets). Examples are:

    1. Ascertain if integrity of buffer strips is held.
    2. Change in stream bank stability.
    3. Nutrient losses.

- Assessment of stream status (stream health) through instantaneous sampling

3. *MONITORING METHODOLOGIES AND REPORTING*

The range of objectives and requirements lead to a range of considerations of methodologies and reporting. The types of data may be considered and include:

(a) Stream loading

Stream loading is the quantity of material moving past the sample point per unit time (e.g. kg, or kg/ha. for the catchment). The requirements for estimations include a need for calibrated weir and water sampling equipment over a long enough period to ascertain seasonal and annual variation (ten years). This approach is proposed for some larger catchments, particularly at points where land use changes (for example leaving forest) with reporting on progressive changes over time.

(b) Concentration change

This approach considers the changes in components of water quality over time after a treatment or disturbance. The sample techniques could include an automatic sampler or regular manual sampling. This requires regular sampling over a period until water quality returns back to equilibrium. There is a requirement of a control situation for comparison, such as in adjacent unaffected streams. Period to be considered is weeks to three years or longer in specific situations (see Cornish and Binns 1987).

(c) Grab sampling

For specific purposes, point sampling on some basis for analysis, management treatment, or general comparisons. Little sensitivity to pick up true minor changes in quality.

(d) Relative spatial variation

This involves intensive manual sampling of a large number of points in a short space of time. It provides spatial variation (termed instantaneous spatial assessment) in a short time frame with opportunity to revisit and consider changes. Concentrations can be converted to relative units and reported according to lengths of creeks that the sampling points represent.

(e) Observational assessment

Assesses streams for problem areas and reasons (roads, stream bank collapse) and could include surveys for bed load movement and cross sectional surveys. This is primarily in the form of audit and compliance or explanation of changes (e.g. stream bank collapse, road building).

(f) Specific surveys

In addition to water quality sampling, assessment of stream health may include periodic measurements of stream bank, bed load movement, riparian zone vegetation health, invertebrate analysis etc., these fulfilling specifically stated objectives.

4. *SAMPLING STRATEGIES*

An optimum system for sampling for an organisation could be hierarchical (Figure 1).

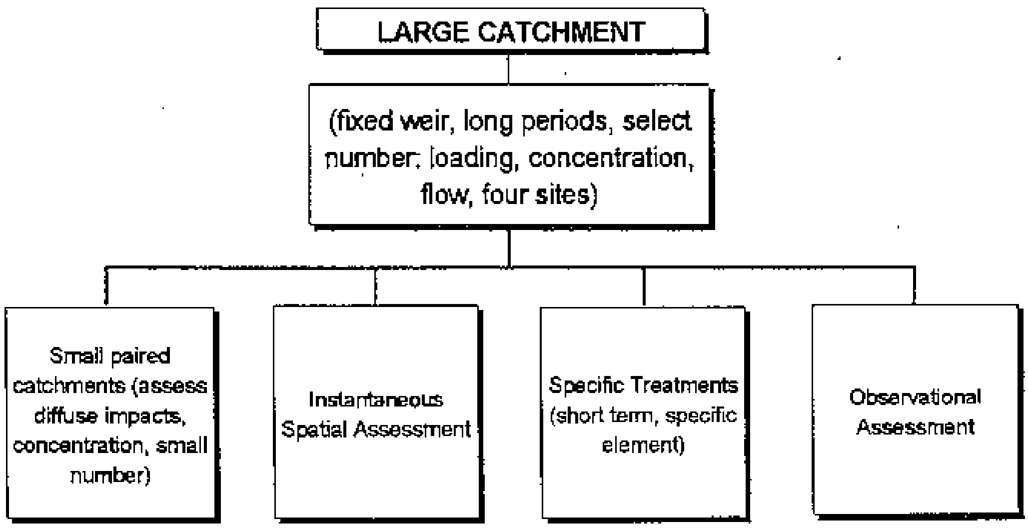


Figure 1. Hierarchical system of water quality sampling for the Management Unit level with forests.

Such an example may be in a forest of 50,000 ha. One or two sites may be located with fixed weirs used for long term assessment. These would be set on catchments of 2000-5000 ha. size and be at a point near where streams leave the forest. There may be one pair of small (100 ha) catchments addressing specific issues such as harvesting or grazing but focus would be on concentration (flow is not a primary measure except when specified). Depending on types of operations there would be periodic operational monitoring (e.g. over periods when fertilisers are applied). Over the total forest, a spatial assessment would be carried out every two-three years at 70-100 relocatable points.

The main focus of this paper is the value of instantaneous spatial assessments.

5. *CURRENT MONITORING PROGRAMS (STATE FORESTS OF NEW SOUTH WALES)*

At present, State Forests undertakes several types of water quality monitoring, in addition to specific research programs. As a component of Environmental Protection Authority harvesting licences, a program in two components has been established. The first component focuses on native forests and uses small paired catchments (Figure 1). Monitoring is aimed at determining changes in water quality, specifically due to harvesting operations. The sites are established with automatic water samplers, but do not have calibrated weirs. The reporting of results considers concentration changes.

Calibration periods will be short as will subsequent assessments. Sites are located on a matrix defined with respect to annual rainfall, slope and broadscale geology (Table 1).

Table 1. Matrix of sampling sites for fixed point water quality monitoring with existence of at least one site marked (*). Each site consists of a pair of catchments with automatic water samplers, but not with weir construction.

	Mean slope					
	<12°		12-18°		>18°	
Rainfall (mm)	Sediment	Igneous	Sediment	Igneous	Sediment	Igneous
<900	-	*	-	*	*	-
900-1200	-	-	*	*	*	*
>1200	-	**	*	*	*	-

The intensity of sampling sites is low, but the cost is high. While providing feedback on effects of specific operations, past research would indicate that the monitoring considers only a minor component of effects of forestry operations on water quality (i.e. harvesting) and is therefore technically inefficient.

In pine plantations, the identification of small paired catchments in which one would be routinely harvested and the other retained as a control was found to be artificial, considering age class distributions and frequency of operations (i.e. it would be extremely difficult to locate two catchments with a single, comparable age class and for which one could be harvested, such that any changes in water quality could be attributed to that operation). While such a study could be established, it would become a research experiment not monitoring routine operations as required by EPA licensing. The alternative was to monitor larger catchments (as in Figure 1) over a longer period of time and use observation and short term grab sampling to identify sources of sediment within the catchment. Such points have been set up in pine plantations in Carabost and Gurnang State Forests.

In addition to the monitoring requirements for EPA harvesting licences, a series of grab sample sites have been monitored over an extended period of time and these have provided broad information on water quality in catchments.

The existing monitoring systems provide little information which indicate the general health of the aquatic environment within forests or its spatial variation. Nor do they indicate the main areas for needing improvement within the forest. To address these requirements, a system of 'instantaneous spatial assessment' is proposed.

6. *INSTANTANEOUS SPATIAL ASSESSMENT*

The objectives of this form of sampling are to provide an assessment of water quality from a relatively large number of points and streams in a forest area in a period of time short enough that flow changes do not cause an impact on quality (for further reference see Meybeck *et al.* 1992, National Rivers Authority 1994). The practical component of the method involves:

1. Locate specific number of potential stream sampling points (stream junctions, roads, above and below operations, changes in geology) which are accessible.

2. Estimate length of creek represented by that point (i.e. length above it either to the source of the stream or to the next up-stream sampling point).

3. Estimate total length of creek stratified according to forest characteristics (native, plantation etc.).

4. Sample in a short period of time in a standard manner so that changes in flow between sample sites are not a factor. Preferably repeated sampling will be carried out and analyses will be in a short enough time frame to assess apparent aberrations and take new points where problems arise.

5. Water samples to be analysed in field for :
   pH
   conductivity
   turbidity
   temperature

   and for chemical analyses in the laboratory (Ca, Mg, K, Na, total N and total P).

6. Data to be compared in absolute terms to standards (e.g. five NTU's for turbidity).

7. The select permanent station will, for the period of the study, have the mean and median standardised (i.e. for turbidity, pH and conductivity).

   Turbidity will be standardised at 2 units
   Conductivity at 16 units

   The relationship between the standard and the mean will be used to adjust all mean and median values for all sites for subsequent sampling periods, (i.e. mean value is 2.2 for standard site so each site to be adjusted by 2/2.2 or 0.9).

8. The comparisons for tubidity will then be made on a linear scale:

<1	
1-2	very good
2-3	
3-4	
4-5	
>5	concern

The alternative would be a logarithmic or modified scale which takes into account the relationship of flow and suspended sediment or other chemicals. However, in these initial stages it was considered that insufficient information existed to allow such analyses to be made.

MATERIALS AND METHODS

1. CASE STUDY FOR SPATIAL ANALYSIS - BAGO STATE FOREST

A case study on spatial analyses of water quality was carried out in and around Bago State Forest in November 1995. The focus of the study was in hardwood forest dominated by alpine ash *(Eucalyptus delegatensis)*, and was extended into adjacent pine plantations and cleared leasehold land.

Eighty six sampling sites were established in an attempt to obtain broad coverage of creeks. The location of further sites was limited by access (roads, blackberries) and lack of continuous streamflow. Sampling points were located to take into account disturbance from roading, and any stream that may be affected by operations. Geology was only considered at the broadest level as mapping was insufficiently refined (1:1,000,000 scale) to allow for accurate inclusion, although broad estimates were used in data analysis. Locations of the sampling sites are shown in Figure 2.

Each site was marked prior to sampling with a steel peg and flagging including its site number. The site location was mapped. Information on predominant land use and other factors was noted (see Appendix 1). A total of 186 km of streams (up to second order streams only) was identified within the forest. The area of hardwood represented by the sampling was 31,500 ha. This consisted of 126.7 km of stream resulting in a stream density of 0.004 stream km/ha. The pine plantations represented a total area of 18,800 ha and 59.6 km of stream resulting in a stream density of 0.003 stream km/ha. Information for private land was not available in such detail. Sampling was at an intensity of one sampling point for each 3.7 km of stream within both hardwood (34 sites, 126.7 km) and pine (16 sites, 59.5 km) areas. This intensity can be compared to that of fixed point samplers discussed previously. The fixed point samplers within the forest are at a higher intensity than in any other State Forest because of other existing studies. Fixed point samplers are located at an intensity of one for each 46 km of stream.

On the sampling days, crews were allocated points to be sampled and methodologies were standardised. At each site the water sample, and stream and air temperatures were taken. A temporary laboratory was set up on site and samples were returned and immediately analysed for conductivity, turbidity and pH. Over a four-day period, each site was sampled six times to provide an estimate of site variation in the first study. Data were stored in Excel and summarised on site. Where discrepancies appeared (e.g. apparent high contamination) the sites were either re-analysed or transcription was checked. The summary data for each site are included in Appendix 1. Appendix 2 shows a plot of stream height and cumulative rainfall at the automatically sampled site 21. Sampling took place from 30th October to 2nd November.

The results were analysed in relation to site variability, comparison between individual sites, and lengths of creek affected.

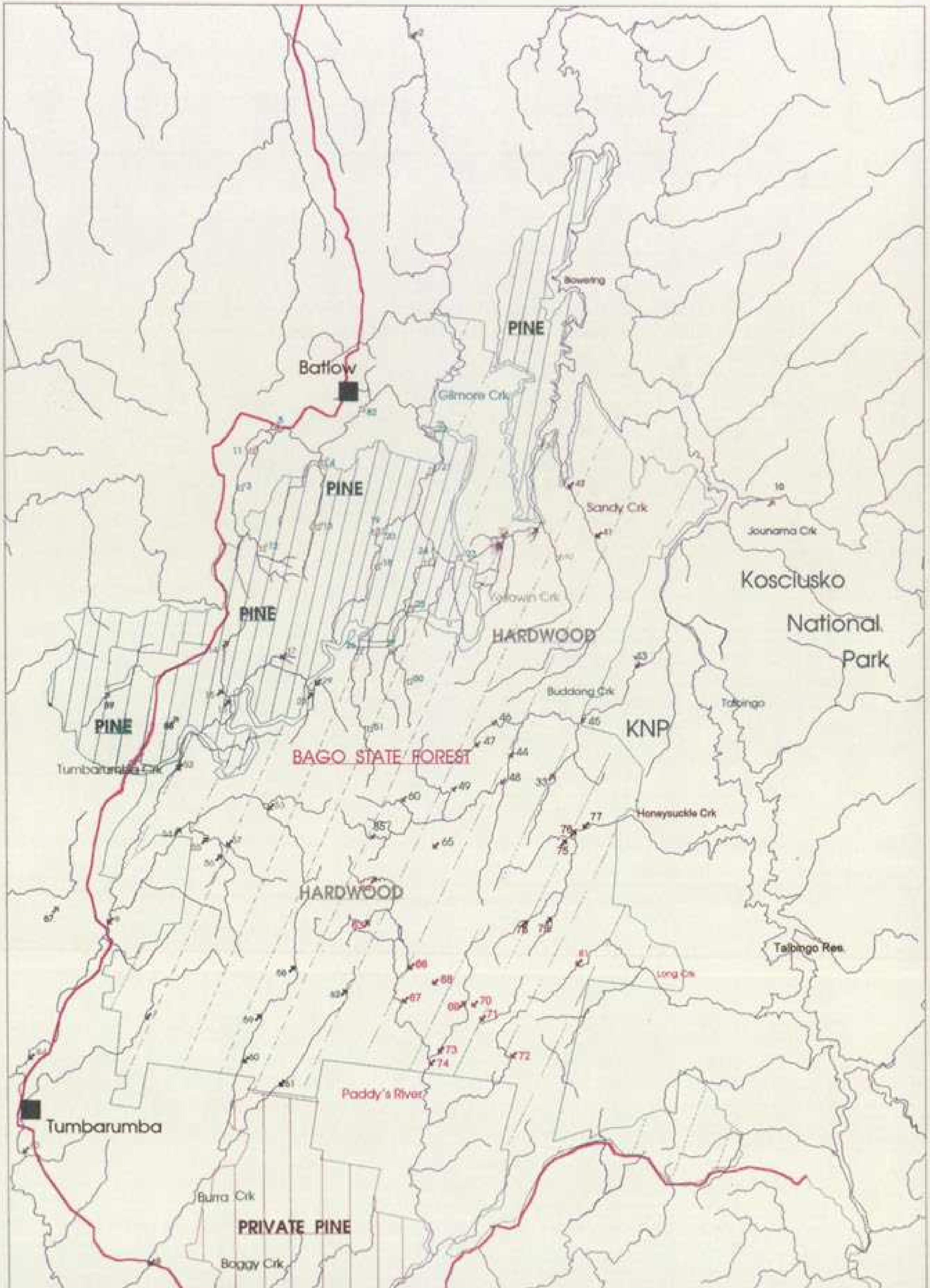
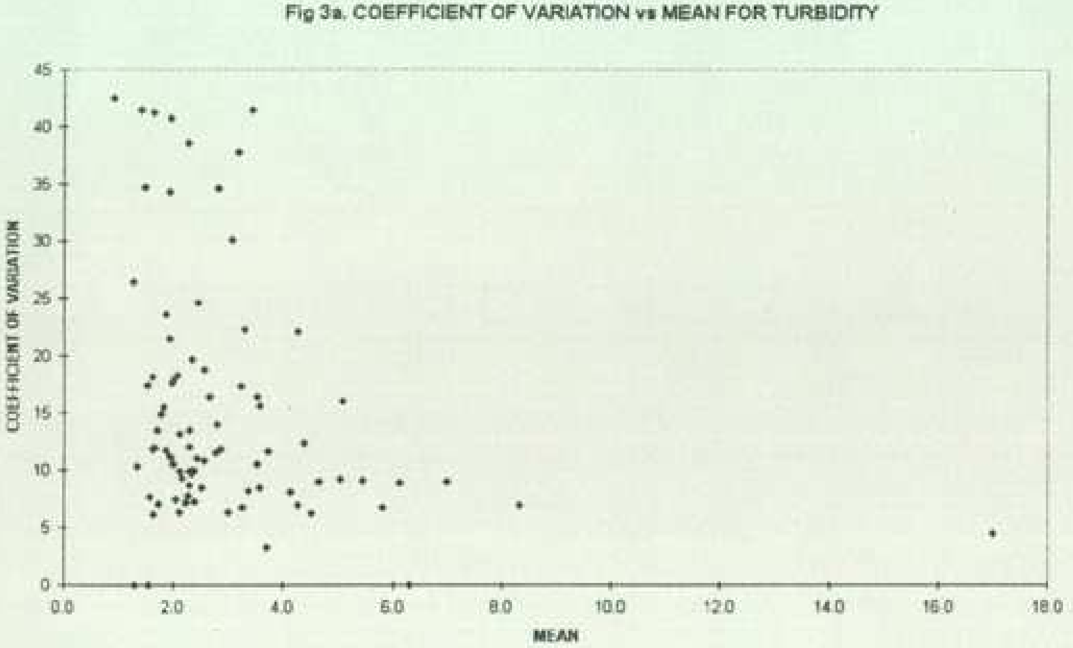


Figure 2. Locations of sampling sites

RESULTS

1. The within-site variation analyses for conductivity and turbidity showed low variations (Figure 3, Appendix 1) and it was assumed that this also relates to the chemical elements (total N, total P, Ca, Mg, K, Na).



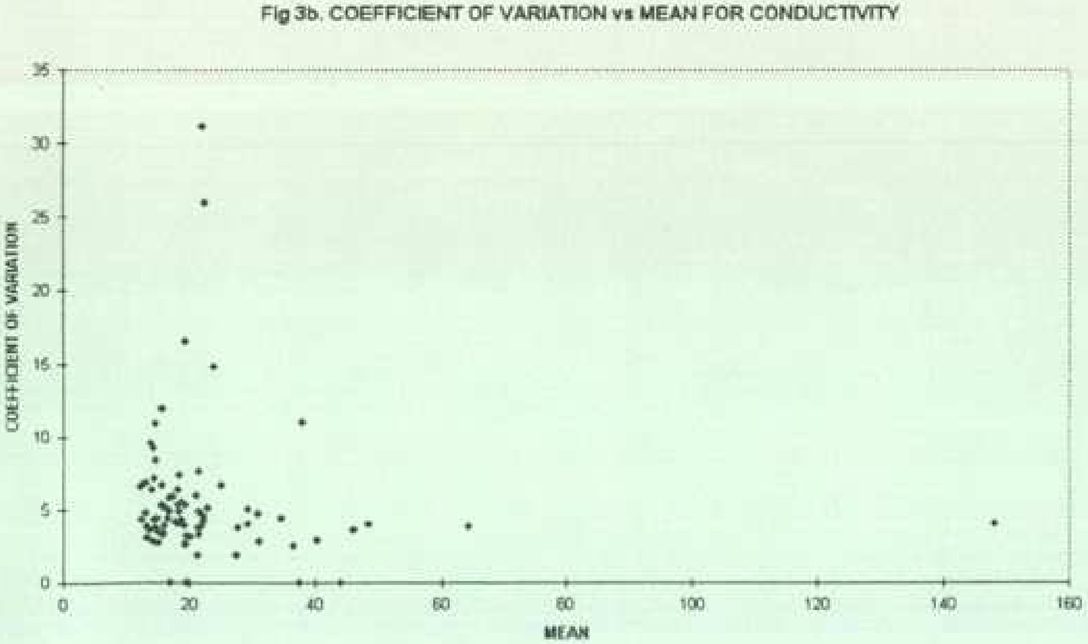


Figure 3. Within-site variation for turbidity (Fig 3a) and conductivity (Fig 3b).

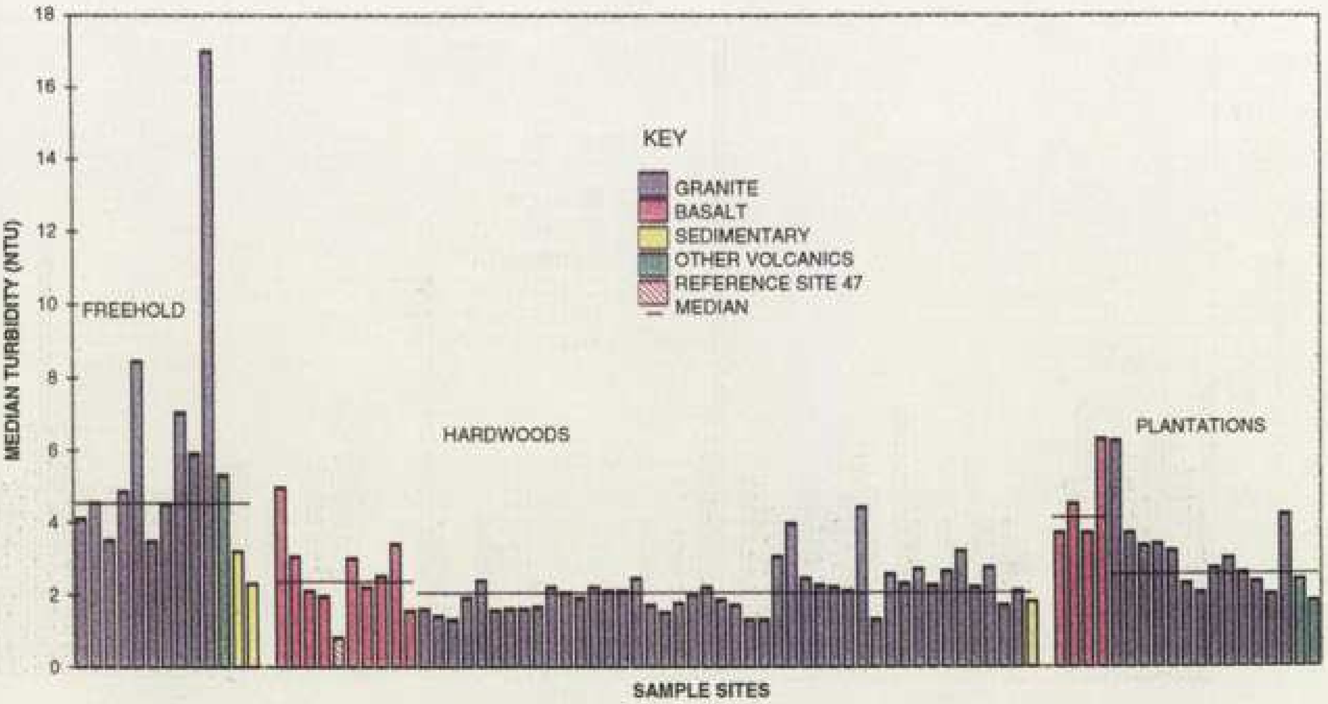


Figure 4. Median turbidity at individual sample sites sorted with respect to landuse and broad geological groupings

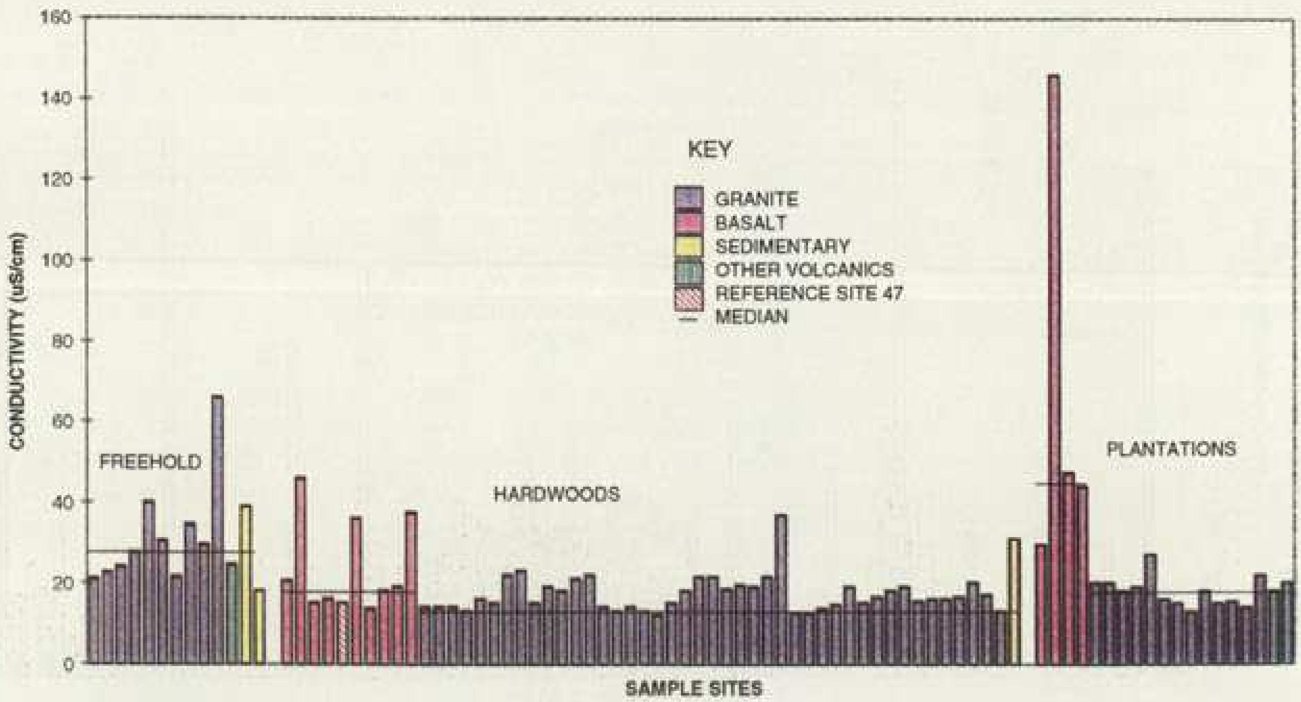


Figure 5. Median conductivity at individual sampling sites sorted with respect to landuse and broad geological groupings

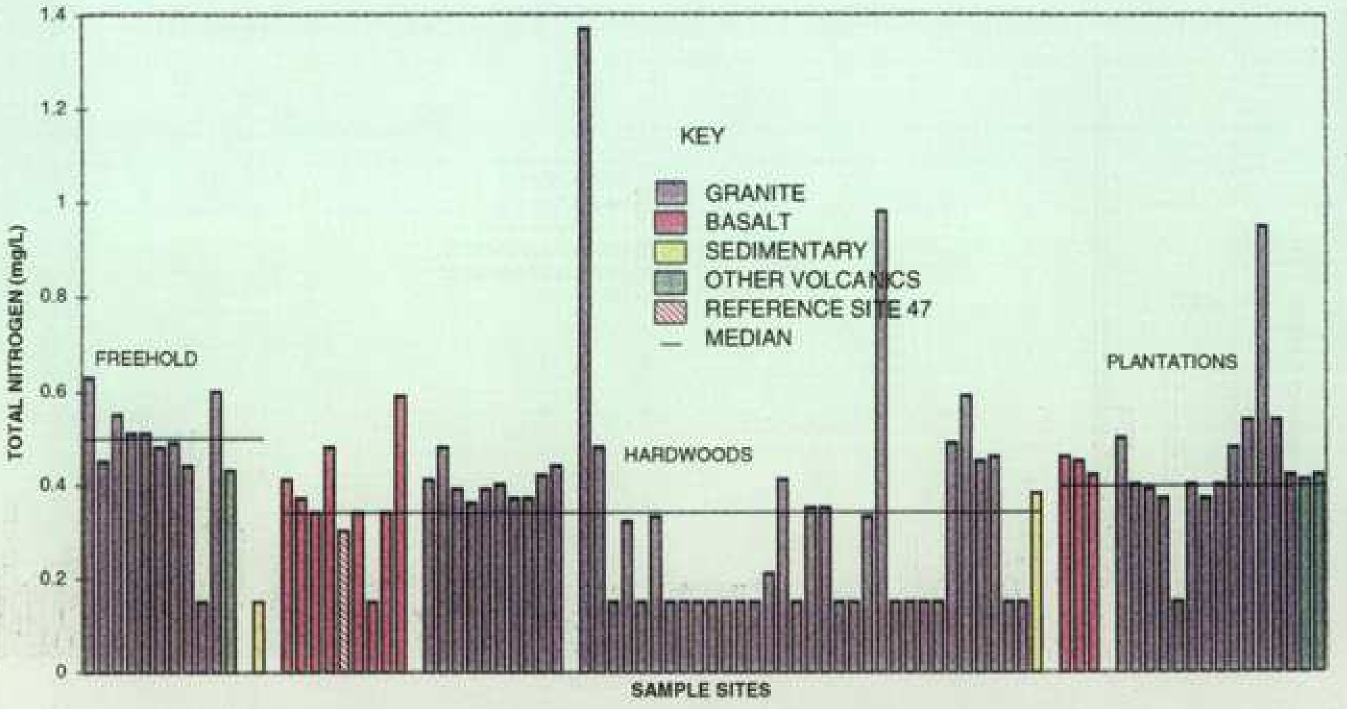


Figure 6. Total nitrogen at individual sampling sites sorted with respect to landuse and broad geological groupings

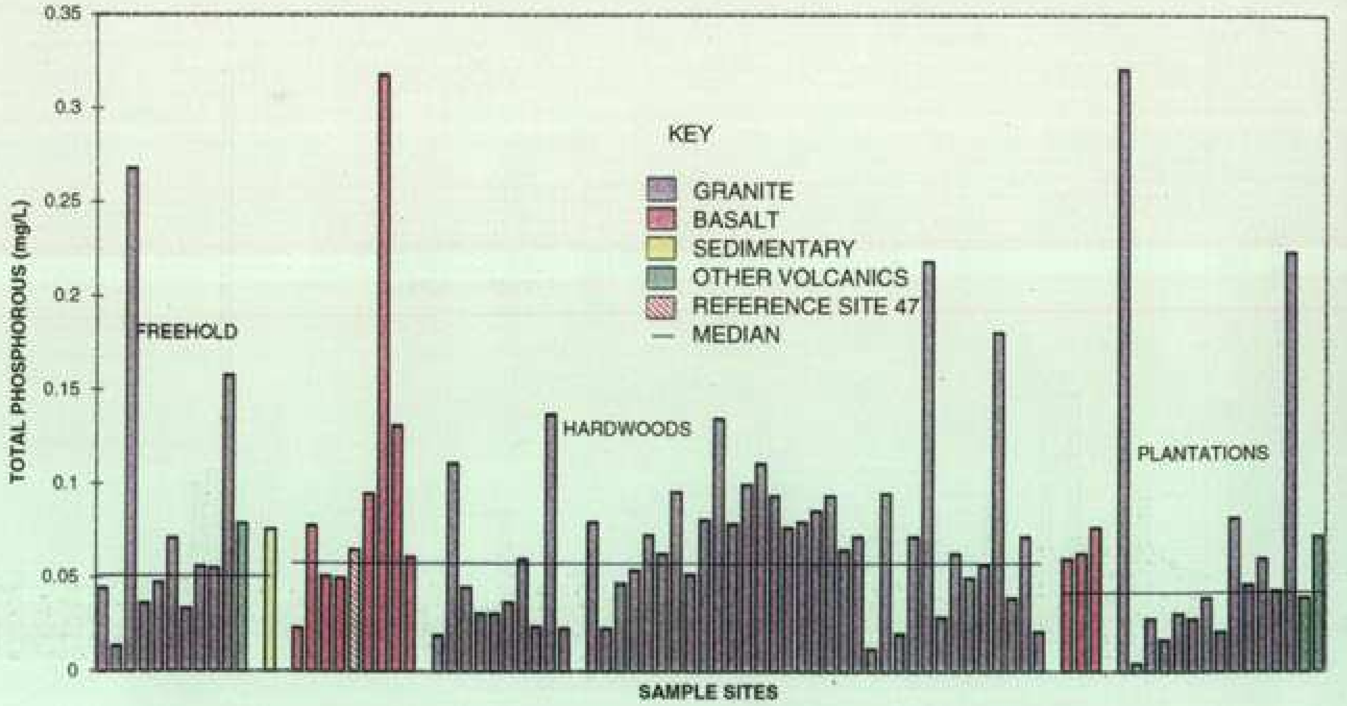


Figure 7. Total phosphorous concentrations at individual sampling sites sorted with respect to landusse and broad geological groupings

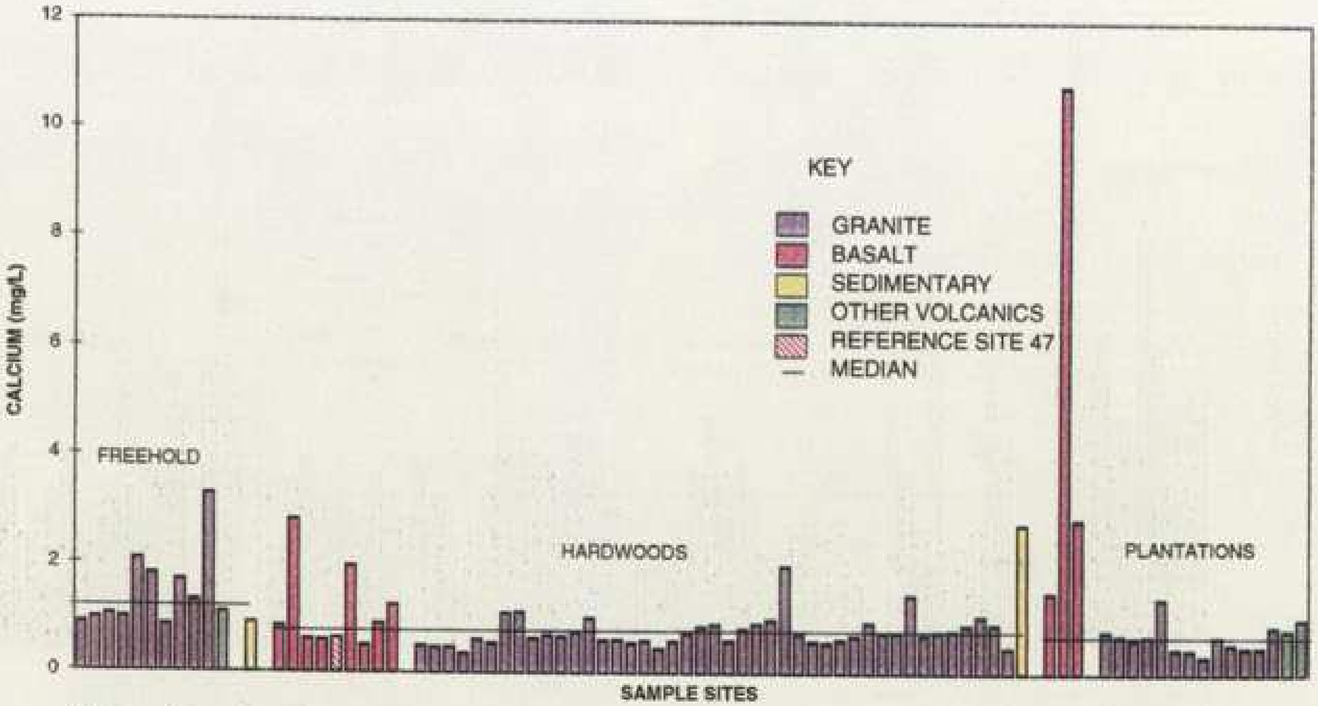


Figure 8. Calcium concentrations at individual sampling sites sorted with respect to landuse and broad geological groupings

Figure 9. Magnesium concentrations at individual sampling sites sorted with respect to landuse and broad geological groupings

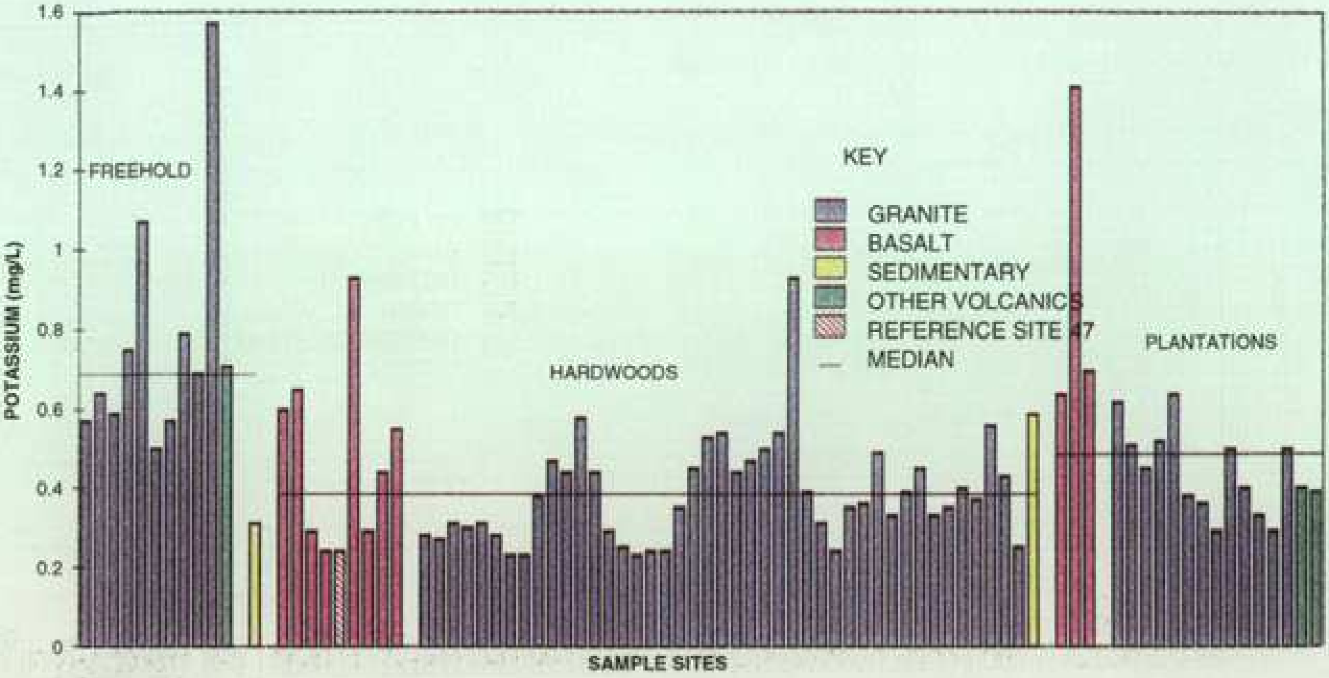


Figure 10. Potassium concentrations at induvidual sampling sites sorted with respect to landuse and broad geological groupings

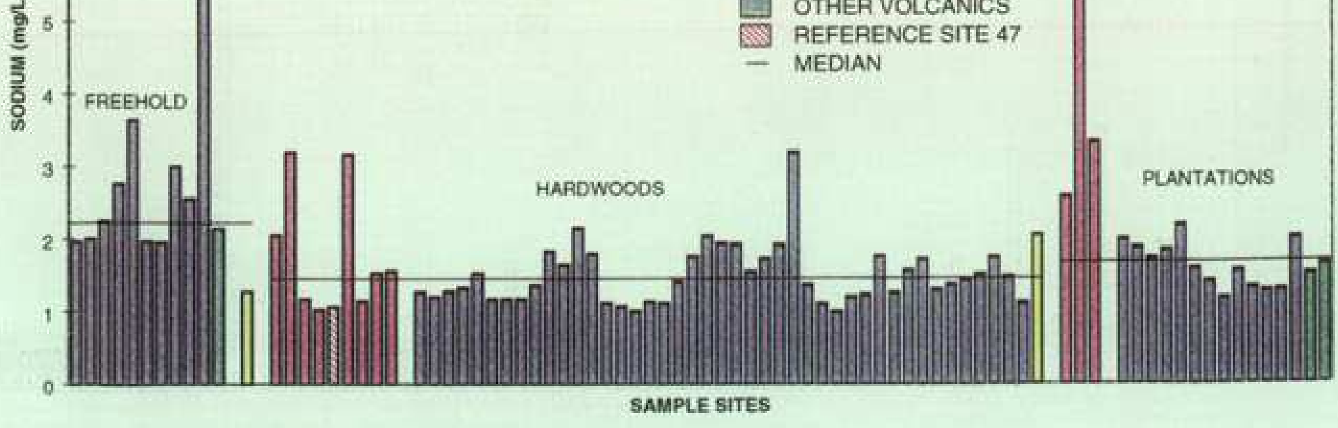


Figure 11. Sodium concentrations at individual sampling sites sorted with respect to landuse and broad geological groupings

2. Variations between sites are presented in Figures 4 to 11 for turbidity, conductivity, total N, total P, Ca, Mg, K and Na respectively. The data were sorted according to primary land use, with secondary sorting according to geology. The analyses indicate:

a) Turbidity (Figure 4) varied significantly according to land use, and within those land uses according to geology (Table 2).

Table 2. Median turbidity (NTU) according to land use and broad geological groupings.

Land use	NTU
Hardwood	
- All sites	2.1
- Basalt sites	2.4
- Other geologies	2.0
Pine plantations	
- All sites	3.2
- Basalt sites	4.1
- Other geologies	2.7
Freehold cleared	4.9

b) Conductivity was differentiated according to land use together with a very strong effect of geology (Figure 5) (Table 3).

Table 3. Median conductivity (µs/cm) according to land use and broad geological groupings.

Land use	NTU
Hardwood	
- All sites	16.5
- Basalt sites	18.5
- Other geologies	16.3
Pine plantations	
- All sites	19.0
- Basalt sites	45.8
- Other geologies	18.0
Freehold cleared	27.5

c) Total nitrogen (Figure 6) tended to be lower on hardwood areas than either freehold or pine. Most levels are low with only four points above 0.6 mg/L.

d) Total phosphorus (Figure 7) was low over all land uses with geology having a greater effect than land use. No general conclusions can be drawn.

e) Cations (Figures 8-11) appeared to be closely associated with geology. There was no apparent relationship with respect to land use for the individual cations. The relationship (as expected) between conductivity and sum of cations indicated that conductivity was a reasonable initial indicator of chemical concentrations (Figure 12).

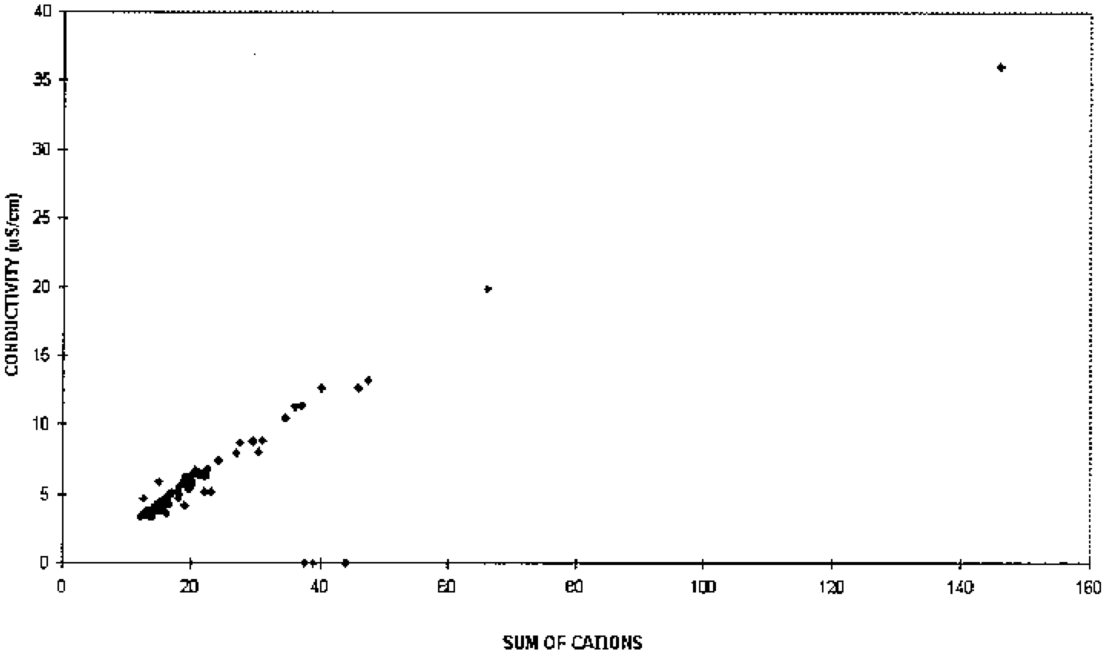


Figure 12. Sum of cations vs conductivity.

3. Stream length analyses were carried out for those sample points falling within State Forests only. Freehold land was not included in the stream length because the lower intensity of sampling per length of stream would result in biased consequences. Most conductivity data for freehold land were found to be above 24 µs/cm. Raw data for conductivity in the managed forest area have been presented in divisions of 8 µs/cm (Table 4) and results showed that 95% of the total forest stream length (186 km) had conductivity values less than 24 µs/cm.

Table 4. Conductivity (µs/cm) in relation to length of stream based on raw data.

	% Stream length					
Land use	**0-8 µS/cm**	**8-16 µS/cm**	**16-24 µS/cm**	**24-32 µS/cm**	**32-40 µS/cm**	**>40 µS/cm**
Hardwood	0	41	55	0	4	0
Pine	0	44	50	6	0	0
Hardwood + Pine	0	40	55	2	2	0

Turbidity was analysed in a similar manner (Table 5). Ninety percent of all streams were found to be below four NTU. Ninety five percent of stream length within hardwood forest were found to be below four NTU in comparison to only 79% for the plantation area. Most data for freehold land was found to be above three NTU.

Table 5. Turbidity (NTU) in relation to length of stream based on raw data.

	% Stream length					
Land use	**0-1 NTU**	**1-2 NTU**	**2-3 NTU**	**3-4 NTU**	**4-6 NTU**	**>6 NTU**
Hardwood	0	38	43	14	5	0
Pine	0	16	43	22	14	5
Hardwood+ Pine	0	31	44	15	8	2

Analyses of raw data for nitrogen and stream length indicated that most streams have low total nitrogen concentrations, but they are higher in pine plantations. Stream length analysis for phosphorus also showed low concentrations. Phosphorus concentrations in pine tended to be very low with some limited sections of streams with higher concentrations.

Table 6. Total nitrogen (mg/mL) in relation to length of stream based on raw data.

	% Stream length					
Land use	**0-0.2 mg/mL**	**0.2-0.4 mg/mL**	**0.4-0.6 mg/mL**	**0.6-0.8 mg/mL**	**0.8-1.0 mg/mL**	**>1.0 mg/mL**
Hardwood	39	22	35	0	4	0
Pine	0	15	71	0	14	0
Hardwood + Pine	33	18	43	0	6	0

Table 7. Total phosphorous (mg/mL) in relation to length of stream based on raw data.

	% Stream length					
Land use	**0-0.06 mg/mL**	**0.06-0.12 mg/mL**	**0.12-0.18 mg/mL**	**0.18-0.24 mg/mL**	**0.24-0.3 mg/mL**	**>0.3 mg/mL**
Hardwood	29	65	2	4	0	0
Pine	58	23	0	14	0	5
Hardwood + Pine	39	51	1	7	0	2

DISCUSSION

Spatial analyses of forest streams provide indicators of stream health. Presentation of results is possible in terms of direct site comparisons or as percentages of stream length with varying water quality. The results from the lower density fixed point sampling sites can be provided as a tabular analysis representing water quality over an extended period (Table 8).

Table 8. Water analyses from Bago State Forest permanent site B2.

	Turbidity	Conductivity	pH
No. samples	35	35	35
Mean	3.17	22.17	N.A.
Medium	2.6	22	6.8
90th%	5.0	24.6	N.A.
Maximum	8.8	31	7.2
Minimum	1.2	18	6.4
St Dev	1.80	2.8	N.A.

Difficulties arise with interpretation of changes in water quality from summary information such as that provided in Table 8. Comparisons of data with other sites are also problematic, especially when sample numbers are low. These two problems are linked as they relate to where the sites fit on the stream hydrograph. Consider the median turbidity of 2.6 NTU for Bago B2. This is slightly higher than the median turbidity for hardwoods in the present study. The range, however, was 1.2 - 8.8 and this in itself makes the interpretation of any changes in water quality difficult where no long term calibration period is involved.

However, the data provided from the permanent station provide information on the variations in water quality to be expected at a site. This enables the design of a more specific sampling strategy.

CONCLUSIONS

The objectives of water quality monitoring programs can be diverse and to be effective need to be very clearly stated.

Where the objective is to maintain a high level of aquatic ecosystem health, and is to be done by minimising sediment and eutrophying chemical inputs to the streams, monitoring needs to provide overall levels of stream health and to identify hazard areas. In addition, water quality information for the next user is needed.

A strategy to do this using a low density of automatic samplers matched with high intensity spatial sampling is provided. The spatial sampling can be adjusted to allow for future resampling and subsequent temporal water quality comparisons. Such information is suitable for reporting on stream health and is compatible with proposed international sustainability indicators.

Where fixed point samplers are to be located within a forest, it would be appropriate to carry out the spatial analyses initially to determine typicality of potential permanent sites.

ACKNOWLEDGEMENTS

The work by Jeff Whiting, Tablelands Research and John Burns, Currumbene Hydrological in locating the sites, planning and co-ordinating the sampling program is sincerely appreciated. Col Wilkinson, Ian Hides, Geoff Heagney, Brad Jarrett, David Bell, Andrea Noble, Geoff Hampstead and Glen Rivers from Tablelands Research undertook the field sampling program and their efforts are appreciated together with those of Val Bowman and Nancy Kwan, Research Division and Shirley McCormack, Currumbene Hydrological in analysing the samples and processing the data.

REFERENCES

Abrahams, A.D. (1972). Drainage densities and sediment yields in Eastern Australia. *Aust. Geog. Studies* 10: 19-41.

Boynton, J.L. (1972). Managing for quality - a plan for developing water quality surveillance programs on national forest in California. *In* Watersheds in transition; proceedings of a symposium 'Water quality in transition'. (Ed. S. Csallany). Fort Collins. pp 84-90.

Cornish, P.M. (1980). Water qualify studies in New South Wales State Forests. 2. A south coast forest of mixed eucalypts near Bega. *Aust. For.* 44: 109-117.

Cornish, P.M. and Binns, D. (1987). Streamwater quality following logging and wildfire in a dry sclerophyll forest in Southeastern Australia. *For. Ecol. and Manage.* 22: 1-28.

Dillon, P.J. and Kirchner, W.B. (1975). The effects of geology and land use on the export of phosphorus from watersheds. *Water Research* 9: 135-148.

Johnson, D.W. and Van Hook, R.I. (1989). Analyses of biogeochemical cycling processes in Walker Branch Watershed. Springer Verlag, NY. 401 pp.

Likens, G.E., Bormann, R.S., Pierce, R.S., Eaton, J.S. and Johnson, N.M. (1977). Biogeochemistry of a forested ecosystem. Springer Verlag, N.Y. 146 pp.

Manderscheid, B., Matzner, E., Meiwes, K.J. and Xu, Y. (1995). Long-term development of element budgets in a Norway Spruce *(Picea abies)* (L. Karst.) Forest of the German Solling Area. Water, Air and Soil Pollution 79: 3-18. *In* Biogeochemical Monitoring in small catchments. Kluwer. (Eds. J. Cerny *et al.*)

MacDonald, L.H., Smart, A. and Wissmanr, R.C. (1991). Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. EPA/910/9-91-001, NPS Section, US EPA Region 10, Seattle, WA. 166 pp.

Meybeck, M., Friedrich, G and Thomas, R. (1992). Rivers. *In* Water Quality Assessments. (Ed. D. Chapman). Chapman and Hall, Great Britain.

National Rivers Authority (1994). The quality of rivers and canals in England and Wales (1990 to 1992). *Water Quality Series No. 19.* AP13 Process Print Ltd., England.

Spooner, J. and Line, D.E. (1993). Effective monitoring strategies for demonstrating water quality changes from nonpoint source controls on a watershed scale. *Wat. Sci. Tech.* 28: 143-148.

Swank, W.T. and Crossley, D.A. (1988). Forest hydrology and ecology at Coweeta. Springer Verlag, N.Y. 469pp.

APPENDIX 1

SUMMARY DATA USED IN THE STUDY

Site	Side creek	Order	Land use	Geo.	Mean turb.	Med. turb.	Stdev. turb	Mean EC	Med. EC	Stdev. EC	Ca	K	Mg	Na	N	P
2	Gilmore	6	FH	S	3.2	3.2	0.2	37.8	39.0	4.2						
3	Little Gilmore	2	FH	G	4.1	4.1	0.3	21.2	21.0	0.4	0.89	0.57	0.5	1.96	0.63	0.044
4	Clear	2	P	G	6.1	6.3	0.5	19.3	20.0	3.2	0.77	0.62	0.46	1.98	0.5	0.321
5	Little Gilmore	4	FH	G	4.5	4.5	0.3	23.8	22.5	3.5	0.97	0.64	0.54	2	0.45	0.013
6	Tumbarumba	4	FH	G	3.5	3.5	0.4	25.0	24.0	1.7	1.05	0.59	0.69	2.24	0.55	0.268
7	Pound	1	FH	G	5.1	4.9	0.8	27.5	27.5	1.0	0.99	0.75	0.63	2.76	0.51	0.036
8	Burra	1	FH	G	8.3	8.5	0.6	40.2	40.0	1.2	2.07	1.07	1.18	3.63	0.51	0.047
9	Paddys	5	FH	G	3.5	3.5	0.6	30.8	30.5	1.5	1.8	0.5	1.32	1.96	0.48	0.071
10	Jounama	1	HW	S	1.9	1.8	0.2	31.0	31.0	0.9	2.74	0.59	0.88	2.04	0.38	0.021
11	Little Gilmore	3	FH	G	4.6	4.5	0.4	21.7	21.5	0.8	0.86	0.57	0.5	1.95	0.49	0.033
12	Little Gilmore	1	P	G	3.7	3.7	0.1	22.5	20.0	5.9	0.69	0.51	0.41	1.87	0.4	0.004
13	Clear	1	P	G	3.3	3.3	0.3	17.8	18.0	0.8	0.64	0.45	0.39	1.72	0.39	0.028
14	Brennans Gully	1	P	G	3.6	3.4	0.6	22.0	19.0	6.9	0.68	0.52	0.4	1.83	0.37	0.017
15	Brennans Gully	2	P	G	3.2	3.2	0.6	27.3	27.0	0.5	1.37	0.64	0.93	2.17	0.15	0.031
16	Tumbarumba	2	P	G	2.3	2.3	0.3	15.7	16.0	0.5	0.45	0.38	0.3	1.57	0.4	0.028
17	Johnsons Gully	1	P	G	2.1	2.1	0.2	15.5	15.0	1.9	0.43	0.36	0.28	1.4	0.37	0.039
18	Walkers	1	P	G	2.8	2.7	0.3	13.2	13.0	0.4	0.32	0.29	0.3	1.17	0.4	0.021
19	Boggy Crk2	1	P	G	3.0	3.0	0.2	18.2	18.0	0.8	0.67	0.5	0.49	1.54	0.48	0.082
20	Boggy Crk2	2	P	G	2.8	2.6	1.0	14.9	15.0	0.4	0.54	0.4	0.37	1.31	0.54	0.046
21	Gilmore	4	P	OV	2.4	2.4	0.2	18.3	18.0	1.4	0.8	0.4	0.49	1.49	0.41	0.039
22	Gilmore	5	P	OV	1.9	1.8	0.4	19.5	20.0	0.6	1	0.39	0.57	1.62	0.42	0.072
23	Snubba	1	P	G	2.3	2.4	0.2	15.5	15.5	1.0	0.48	0.33	0.37	1.26	0.95	0.06

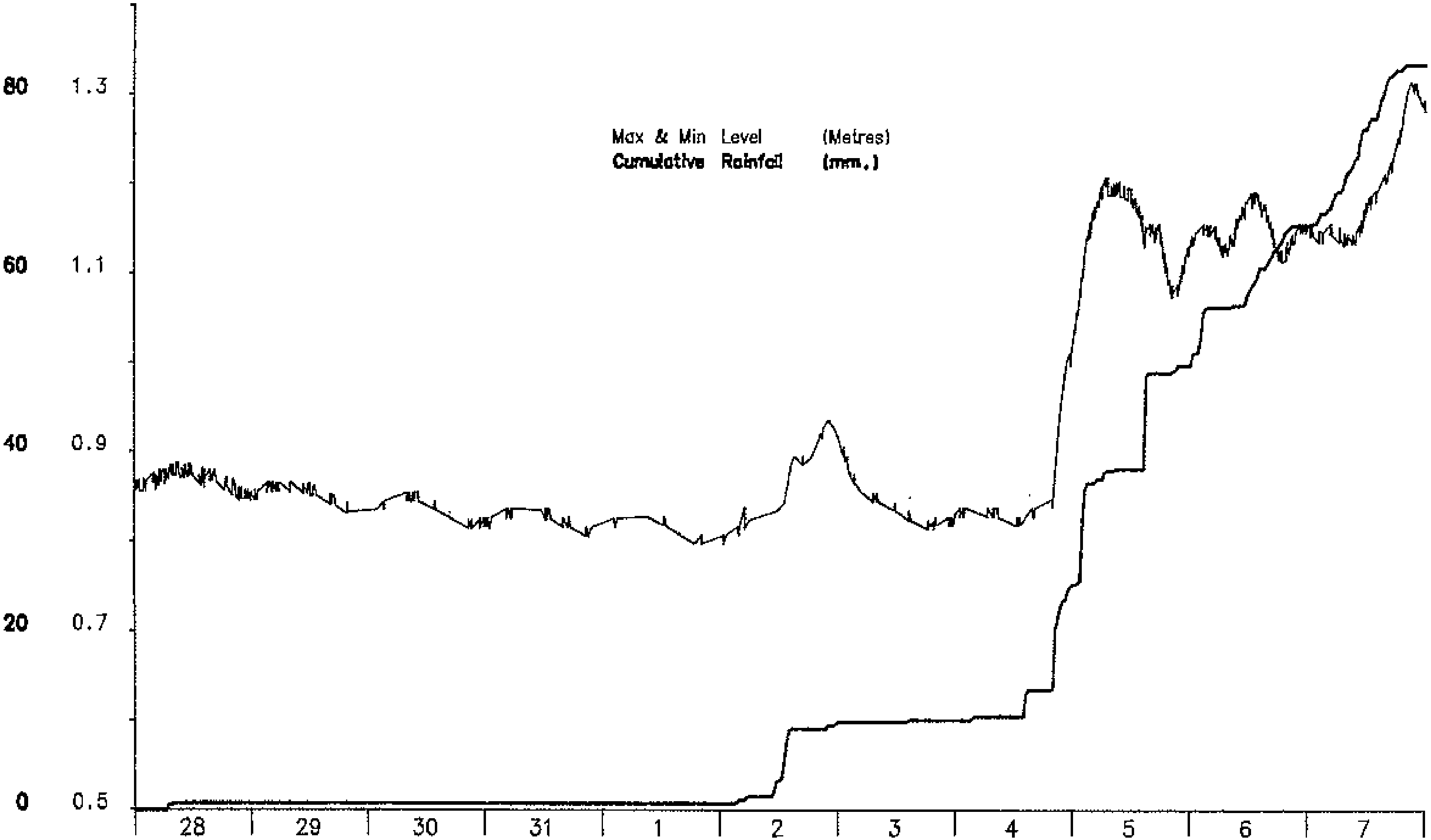
Site	Side creek	Order	Land use	Geo.	Mean turb.	Med. turb.	Stdev. turb	Mean EC	Med. EC	Stdev. EC	Ca	K	Mg	Na	N	P
24	Gilmore	3	P	G	1.9	2.0	0.7	14.3	14.0	0.6	0.48	0.29	0.34	1.27	0.54	0.043
25	Mandys	2	HW	G	1.6	1.6	0.3	14.3	14.0	1.0	0.48	0.28	0.36	1.26	0.41	0.019
26	Gilmore	2	HW	G	1.5	1.4	0.5	13.6	14.0	0.5	0.46	0.27	0.28	1.2	0.48	0.111
27	Clydes	1	HW	G	1.3	1.3	0.1	14.2	14.0	0.4	0.46	0.31	0.34	1.27	0.39	0.045
28	Tumbarumba	1	HW	G	1.9	1.9	0.2	13.8	13.0	1.3	0.34	0.3	0.25	1.32	0.36	0.031
29	Frikes	1	HW	G	2.4	2.4	0.3	16.5	16.0	0.8	0.6	0.31	0.33	1.52	0.39	0.031
30	Mandys	1	HW	G	1.6	1.6	0.1	14.5	15.0	1.2	0.53	0.28	0.39	1.17	0.4	0.037
31	Wilkinson	1	HW	G	1.6	1.6	0.2	22.3	22.0	1.0	1.09	0.23	1.27	1.17	0.37	0.06
32	Wilkinson	2	HW	G	1.6	1.6	0.1	22.8	23.0	1.2	1.11	0.23	1.27	1.17	0.37	0.024
33	Stockmans	1	HW	G	1.8	1.7	0.3	15.5	15.0	0.8	0.62	0.38	0.36	1.35	0.42	0.137
34	Wilkinson	4	P	B	3.7	3.7	0.4	29.2	29.5	1.5	1.47	0.64	0.95	2.57	0.46	0.06
35	Unnamed	1	P	B	4.4	4.5	0.5	148.2	146.0	6.0	10.8	1.41	5.64	8.45	0.45	0.063
36	Unnamed	1	HW	B	5.0	5.0	0.5	21.0	20.5	1.3	0.85	0.6	0.52	2.05	0.41	0.023
37	Unnamed	1	HW	G	2.3	2.2	0.2	19.2	19.0	0.8	0.68	0.47	0.42	1.82	0.44	0.023
38	Unnamed	1	HW	G	2.0	2.1	0.2	18.2	18.0	1.2	0.66	0.44	0.42	1.63		
39	Unnamed	1	HW	G	2.0	1.9	0.3	21.5	21.0	1.6	0.74	0.58	0.45	2.14	1.37	0.08
40	Wilkinson	3	HW	G	2.3	2.2	0.9	22.2	22.0	0.9	1	0.44	0.78	1.79	0.48	0.023
41	Sandy	1	HW	B	2.9	3.1	0.3	45.9	46.0	1.7	2.81	0.65	2.18	3.19	0.37	0.078
42	Sandy	2	P	B	3.6	3.7	0.3	48.3	47.5	2.0	2.82	0.7	2.31	3.32	0.42	0.077
43	Buddong	5	FH	S	2.4	2.3	0.2	18.2	18.0	1.0	0.91	0.31	0.63	1.27	0.15	0.076
44	Buddong	3	HW	G	2.1	2.1	0.3	14.2	14.0	1.3	0.59	0.29	0.32	1.11	0.15	0.047
45	Buddong	4	HW	B	2.0	2.1	0.4	14.6	15.0	0.5	0.61	0.29	0.4	1.17	0.34	0.051
46	Sheepyard	2	HW	B	2.0	2.0	0.8	15.7	16.0	0.6	0.59	0.24	0.53	1.02	0.48	0.05
47	Sheepyard	1	HW	B	0.9	0.8	0.4	14.8	15.0	0.7	0.63	0.24	0.55	1.06	0.3	0.065
48	Buddong	2	HW	G	2.1	2.1	0.4	13.0	13.0	0.9	0.6	0.25	0.3	1.06	0.32	0.054
49	Clear	1	HW	G	2.6	2.5	0.5	14.0	14.0	0.9	0.54	0.23	0.35	1	0.15	0.073
50	Dog	1	HW	G	1.7	1.7	0.2	13.0	13.0	0.6	0.58	0.24	0.26	1.13	0.33	0.063
51	Gilmore	1	HW	G	1.5	1.5	0.3	12.5	12.0	0.8	0.44	0.24	0.23	1.11	0.15	0.096
52	Tumbarumba	3	P	G	4.3	4.2	0.9	21.9	22.0	0.9	0.86	0.5	0.61	1.99	0.42	0.224
53	Back	1	HW	G	1.8	1.8	0.3	15.3	15.0	0.5	0.57	0.35	0.32	1.41	0.15	0.052

Site	Side creek	Order	Land use	Geo.	Mean turb.	Med. turb.	Stdev. turb	Mean EC	Med. EC	Stdev. EC	Ca	K	Mg	Na	N	P
54	Back	2	HW	G	1.9	2.0	0.2	18.2	18.0	0.8	0.72	0.45	0.41	1.75	0.15	0.081
55	Scotchmans	2	HW	G	2.3	2.2	0.5	21.5	21.5	1.0	0.84	0.53	0.52	2.03	0.15	0.135
56	Scotchmans	1	HW	G	1.9	1.9	0.4	21.3	21.5	0.8	0.89	0.54	0.53	1.93	0.15	0.079
57	Cockneys	1	HW	G	1.7	1.7	0.1	18.7	18.5	0.8	0.58	0.44	0.4	1.92	0.15	0.1
58	BurraWest	1	HW	G	1.3	1.3	NA	19.5	19.5	NA	0.8	0.47	0.49	1.54	0.15	0.111
59	BurraWest	2	HW	G	1.4	1.3	0.6	19.4	19.0	0.5	0.9	0.5	0.5	1.72	0.21	0.094
60	BurraWest	3	HW	G	3.1	3.1	0.9	21.5	21.5	0.7	0.97	0.54	0.53	1.91	0.41	0.077
61	BurraEast	2	HW	B	3.4	3.0	1.4	36.4	36.0	0.9	1.96	0.93	1.18	3.16	0.34	0.095
62	BurraEast	1	HW	G	1.6	4.0	0.7	17.0	37.0	0.0	1.96	0.93	1.17	3.18	0.15	0.08
63	Spencers	1	HW	G	2.3	2.5	0.2	12.3	12.5	0.8	0.71	0.39	0.49	1.36	0.35	0.086
64	Paddys	1	HW	G	2.4	2.3	0.2	12.5	12.5	0.5	0.57	0.31	0.24	1.1	0.35	0.094
65	Parsons Gully	1	HW	B	2.3	2.2	0.3	14.0	13.5	1.3	0.49	0.29	0.25	1.14	0.15	0.318
66	Paddys	3	HW	G	2.3	2.2	0.2	14.5	13.5	1.6	0.55	0.24	0.36	0.99	0.15	0.065
67	Paddys	3	HW	G	2.1	2.1	0.2	14.5	14.5	0.5	0.61	0.35	0.29	1.19	0.15	0.072
68	Ash	1	HW	G	4.3	4.4	0.3	19.3	19	1.0	0.67	0.36	0.32	1.22	0.33	0.012
69	Bull & Damper	3	HW	G	1.3	1.3	0.3	15.5	15	0.8	0.92	0.49	0.46	1.75	0.98	0.095
70	Bull & Damper	2	HW	G	2.7	2.6	0.4	16.7	16.5	0.8	0.74	0.33	0.37	1.25	0.15	0.02
71	Bull & Damper	1	HW	G	2.3	2.3	0.2	17.8	18.0	0.8	0.74	0.39	0.32	1.55	0.15	0.072
72	Two Mile	1	HW	G	2.5	2.7	0.6	19.3	19.0	0.5	1.43	0.45	0.5	1.71	0.15	0.219
73	Bull & Damper	4	HW	B	2.5	2.5	0.2	18.7	18.0	1.0	0.9	0.44	0.5	1.53	0.34	0.131
74	Paddys	4	HW	B	3.3	3.4	0.7	18.4	19.0	0.9	1.24	0.55	0.49	1.55	0.59	0.061
75	Foxes	1	HW	G	2.2	2.3	0.2	15.7	15.5	0.8	0.7	0.33	0.34	1.29	0.15	0.029
76	Honeysuckle	2	HW	G	2.6	2.6	0.3	16.0	16.0	0.6	0.76	0.35	0.37	1.36	0.49	0.063
77	Honeysuckle	3	HW	G	3.2	3.2	1.2	16.5	16.0	0.7	0.77	0.4	0.4	1.43	0.59	0.05
78	Honeysuckle	1	HW	G	2.2	2.2	0.2	16.8	16.5	1.0	0.87	0.37	0.33	1.5	0.45	0.057
79	Broadhursts	1	HW	G	2.8	2.8	0.4	20.0	20.0	0.6	1.04	0.56	0.45	1.74	0.46	0.181
81	Long	1	HW	G	1.7	1.7	0.2	17.3	17.0	1.0	0.89	0.43	0.4	1.47	0.15	0.039

Site	Side creek	Order	Land use	Geo.	Mean turb.	Med. turb.	Stdev. turb	Mean EC	Med. EC	Stdev. EC	Ca	K	Mg	Na	N	P
82	Little Gilmore	5	FH	OV	5.4	5.3	0.5	14.5	24.5	0.5	1.1	0.71	0.63	2.14	0.43	0.079
83	Tumbarumba	6	FH	G	7.0	7.0	0.6	34.5	34.5	1.5	1.69	0.79	1.17	3	0.44	0.056
84	Tumbarumba	5	FH	G	5.8	5.9	0.4	29.2	29.5	1.2	1.31	0.69	0.91	2.56	0.15	0.055
85	Buddong	1	HW	G	2.1	2.1	0.1	13.3	13.0	0.5	0.46	0.25	0.24	1.11	0.15	0.072
86	Boggy Crk1	1	FH	G	17.0	17.0	0.8	64.2	66.0	2.5	3.28	1.57	2.38	5.55	0.6	0.158
88	PatrickGully	1	P	B	6.3	6.3	NA	44.0	44.0	NA						
89	Laurel Hill	2	HW	B	1.6	1.6	NA	37.5	37.5	NA						

APPENDIX 2

STREAM HEIGHT AND CUMULATIVE RAINFALL AT THE AUTOMATICALLY SAMPLED SITE 21



APPENDIX 4

Relating Native Forest Productivity to Site and Soil Properties in Bago/Maragle State Forests

FIRST INTERIM REPORT

by

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INTRODUCTION

As part of the proposal by the CSIRO to State Forests of New South Wales on "Forest Soil Research in the Bago/Maragle ESM Program" the following objectives were stated.

1. Ascertain whether relationships between forest productivity measured at research growth plots (RGPs) and Permanent Growth Plots (PGPs) and soil/site properties can be developed into sustainability indices.
2. Do preliminary site and soil descriptions for all RGPs and PGPs within the ESM area (mostly all alpine ash forest type).

This report presents the results of the first stage of the program.

SITE SELECTION

Discussions with the State Forests of New South Wales Research Division (Dalibor Hatich), Tablelands Research Centre (Col Wilkinson) and Tumbarumba District (Bob Gay) concerning available RGPs and PGPs across Bago and Maragle State Forests led to the lists presented in Tables 1 and 2. A total of 11 RGPs and 18 PGPs were chosen and of these all were used except for one PGP which was impossible to access due to blackberry infestation.

FIELD METHODS

At very accessible sites the field procedure outlined below was followed.

1. A soil pit was dug to 1 m. At the RGPs, this pit was adjacent to but outside the plot and in a "mid-slope" topographic position in relation to the variation across the experiment. At the PGPs, the pit was adjacent to the plot centre peg and therefore inside the plot.
2. Location of the soil pit was determined by differential Global Positioning System (GPS) (± 5 m horizontal).
3. The soil pit was augured beyond 1 m to a maximum depth of 4 m (limit for auger) or until an impeding layer (mostly rock) was encountered.
4. Site and profile were described using New South Wales Soil Data Cards and protocols (Abraham and Abraham 1992).
5. Disturbed, bulked soil samples of the major soil horizons plus two standard depths of 0 - 0.075 m and 0.3 - 0.38 m were collected for laboratory analysis.
6. Intact cores were taken within the soil horizons exposed in the soil pit, transferred to jars and sealed. Jars were weighed the night after being sampled. From these cores both bulk density and field moisture content were determined.
7. Field aggregate stability was determined using two techniques:
   - Soil Conservation Service of New South Wales, Field Emerson Aggregate Test; and
   - NSW Department of Agriculture and Fisheries, SOILPAK Dispersion Test.
8. Earthworm and other large soil macrofauna were collected when practicable.
9. Photographs of the soil profile and site were taken.

Table 1. RGP sites in Bago and Maragle State Forests.

RGP	FRED	Name	Cpt	Geology	Location	Plant. date	Est. date
VI/1.11		Alpine Ash Thinning/Growth Study Plots	24	Sgg	1925 Regen Area, Kopsens Track, Bago S.F.		1954
VI/1.13		Alpine Ash Growth Plot	66	Sgg	Bull and Dampier Rd, Bago State Forest		1967
VI/1.14	TH0001	Alpine Ash Growth Plot No. 1	21	Tb	1917 Regen Area, Bago State Forest		1955
VI/1.15		Alpine Ash Growth Plot No. 2	4	Sgg	Pilot Hill Arboretum, Bago State Forest		1956
VI/1.16		Alpine Ash Growth Plots (Open Rooted)	16	Tb	DeBeauzevilles Rd, Bago State Forest	1973	1974
VI/1.17		Alpine Ash Spacing Trial	107	Sgg	Bannons Rd, Bago State Forest	1972	1972
VI/1.18	TH0005	Alpine Ash "off site" Spacing Trial	9	Sgg	Browns Rd, Bago State Forest	1973	1973
VI/1.437	TH0003	Alpine Ash Growth Plot	24	Sgg	Kopsen's Track, Bago State Forest	1969	1975
VI/1.44	TH0004	Alpine Ash Growth Plot	24	Sgg	Hides Old Rd, Bago State Forest	1969	1969
VI/1.46	TH0002	Open Rooted Alpine Ash Planting	3	Sgg	Blackjack Rd, Maragle State Forest	1973	1976
VI/1.81		CSIRO Alpine Ash Provenance Trial	9	Sgg	Brown's Rd, Bago State Forest	1978	1978

Table 2. PGPs from Bago and Maragle State Forests. Data are from State Forests of New South Wales PGP database.

Plot No	Cpt	Northings	Eastings	Slope	Aspect	Altitude	Rainfall	For Type	Site Hgt	Geology	Soil	Rock Cov
1	4	6056000	604100	8	2	1180	1350	147	60	5	1	0
2	10	6056100	606600	13	1	1200	1350	147	60	5	1	0
3	16	6056200	609100	7	3	1170	1350	147	50	4	1	0
4	29	6053700	609100	3	3	1180	1350	147	60	4	1	0
5	38	6053600	604200	0	9	1220	1350	147	50	4	1	0
6	27	6053700	606500	3	6	1210	1350	147	60	4	1	0
7	40	6053600	601600	1	5	1210	1350	147	50	4	1	10
8	3	6058500	604100	1	3	1080	1350	147	50	4	1	10
9	45	6051200	601500	2	1	1150	1350	147	40	4	1	
10	47	6051100	604200		9	1170	1350	147	50	4	1	10
11	34	6051100	609200	10	2	1180	1350	147	40	4	1	
12	54	6048700	609200	5	2	1300	1350	147	45	4	1	
13	45	6048600	601700	6	2	1240	1350	147	40	4	1	10
14	106	6046000	599200	8	2	1230	1350	147	40	4	1	
15	81	6046300	601700	12	3	1140	1350	147	40	4	1	5
16	62	6046100	609100	20	1	1300	1350	147	40	4	1	
17	61	6046200	611700	12	3	1210	1350	147	40	4	1	
18	94	6043800	611800	15	3	1190	1350	147	40	4	1	

LABORATORY ANALYSES

Disturbed soil layer samples were transported to the laboratory where they were air-dried, ground and passed through a 2 mm sieve. The gravel fractions were weighed and then discarded. The fine earth fractions were stored in plastic vials for further analysis. A subsample of the fine earth fraction was ground to less than 500 nm for exchangeable cation analysis.

The following soil chemical analyses were determined on each soil layer sampled:

- total nitrogen; kjeldahl acid digest (Heffernan 1985);
- total phosphorus; kjeldahl acid digest (Heffernan 1985);
- total carbon; Leco CHN-1000 Elemental Analyser;
- exchangeable cations (Ca, Mg, K, Na, Al and H); $BaCl_2$ elution at field pH (Khanna *et al.* 1986); and
- pH (1:5 soil- distilled water and 1:5 soil 0.01 M $CaCl_2$ suspensions) (Jackson 1958).

RESULTS

A total of 28 soil profiles were described and sampled between December 1994 and May 1995. Errors were found in the PGP locations obtained from the database (Table 2). The updated information in Table 3 has been sent to Tumbarumba District Office and State Forests of New South Wales Head Office (David Dore).

1. LOCATION

The distribution of RGP and PGP sites (hereafter referred to as the "productivity sites") is shown in Figure 1. On this map are preliminary geological boundaries, Bago and Maragle State Forests hardwood boundaries (pine plantation area excluded) and soil profile locations numbered BM01-BM28. There is a strong geographic bias of the productivity sites to the north of Bago State Forest with only one site in Maragle State Forest (V1/1.46, BM11). The PGPs were distributed originally in Forest Type 147 (alpine ash) on an approximate 1700 m grid. All 28 productivity sites have alpine ash (*Eucalyptus delegetensis*) as the dominant overstorey species although some RGPs have alpine ash planted in non-ash sites.

2. GEOLOGY AND TERRAIN

The current geology map compiled across the Yarrangobilly 1:100,000 sheet by Australian Geological Survey Organisation (AGSO) covers the hardwood forest area of Bago and Maragle State Forests. Within Bago State Forest the topography is predominantly that of an undulating plateau demarcated on the eastern side by the shear-fault escarpment of the Tumut Trough and encroached on the western side by various tributaries of the Murray-Darling River system. Basalt eruptions flowed down drainage lines in what was probably an old land-surface even in pre-Tertiary times. The Kosciusko Uplift caused further peneplaination of the old pre-Tertiary surface and produced relief-inversion of some of these basalt flows resulting in them now being residual high-points within a granodiorite plateau. This geomorphology is especially evident in northern Bago State Forest. In southern Bago and Maragle State Forests the basalt flows are more extensive and have less relief inversion.

The large area of Green Hills Granodiorite is deceptive. There probably is more than one granitoid body within this batholith but further discrimination will have to await completion of the AGSO geological mapping program.

Most of the productivity sites (23) are on Green Hills Granodiorite (Sgg) three are on Tertiary basalt (Tb) and one has basalt colluvium over granodiorite substrate.

3. SOIL MORPHOLOGY AND CLASSIFICATION

Sites were numbered consecutively based on the Soil Data Cards profile numbers (survey title was "Bago/Maragle ESM") with a "BM" prefix. A summary table including site IDs, GPS locations and soil classifications is given in Table 3.

Most of these soils could be colloquially referred to as "deep red acid soils". In fact, the soil depth classes shown in Table 4 are quite remarkable for forest soils with 60% of the profiles more than 2 m and 32% more than 3 m in depth.

Table 3. Summary of soil classification and location data for the RGP and PGP sites in Bago/Maragle State Forests.

			Soil Classification								
Profile	**RGP**	**PGP**	**PPF[A]**	**GSG[B]**	**ASC[C]**	**Map Sheet**	**Zone**	**Eastings**	**Northings**	**ADH[D]**	**Compt**
BM01	V1/1.15		Gn2.21	RE	KA AA DB AI B E M O X	8526-4-N	55	603472	6057245	1109	'4H'
BM02	V1/1.44		Gn3.11	NSG	DE AA DB AI A E O O X	8526-4-S	55	603033	6056544	1145	'24H'
BM03	V1/1.437		Gn2.11	RE	KA AA DB AI B E O O X	8526-4-S	55	602759	6055924	1142	'24H'
BM04	V1/1.11		Gn2.11	RE	KA AA DB AI A F M O X	8526-4-S	55	602307	6054682	1163	'24H'
BM05	V1/1.81		Gn2.24	RP	KA AA AG AI B F M O X	8526-4-N	55	607032	6058586	1031	'9H'
BM06	V1/1.18		Uf6.21	RE	KA AA DB AI A F M O X	8526-4-N	55	607582	6058559	1104	'11H'
BM07	V1/1.14		Uf6.31	K	FE AA DB GY A E O O X	8526-4-S	55	606824	6055054	1259	'21H'
BM08	V1/1.13		Gn2.41	BRE	KA AB DB AI B E L M X	8526-4-S	55	607318	6047038	1242	'66H'
BM09	V1/1.17		Um7.11	RE	KA AA DB [GY] A E M M W	8526-4-S	55	598679	6044736	1210	'107H'
BM10	V1/1.16		Gn3.11	C	FE AA DB AI B F L O W	8526-4-S	55	609259	6056417	1057	'16H'
BM11	V1/1.46		Gn1.21	NSG	KA AA [AF] AI B F M O X	8526-2-N	55	617204	6037540	1179	'3H'
BM12		PAB108	Gn2.11	RE	KA AA DB AI A F M O X	8526-4-N	55	604059	6058506	1086	3EH
BM13		PAB102	Um7.11	RE	KA AA DB AI B F M O X	8526-4-S	55	606569	6056107	1214	10H
BM14		PAB106	Um7.11	RE?	KA AA AF [GY] B F M M X	8526-4-S	55	606574	6053624	1225	27H
BM15		PAB101	Um7.11	RE	KA AA DB AI A E M O X	8526-4-S	55	604130	6056246	1157	4H
BM16		PAB105	Gn2.11	RE	KA AA DB AI B E O O X	8526-4-S	55	604139	6053727	1223	38H
BM17		PAB107	Um7.11	RE	KA AA DB AI B E L M X	8526-4-S	55	601568	6053619	1218	40H
BM18		PAB110	Um7.11	RE	KA AA DB AI B E M M X	8526-4-S	55	604373	6050916	1223	47H
BM19		PAB109	Gn2.11	RE	KA AA DB AI B E M O X	8526-4-S	55	601685	6051007	1165	45H
BM20		PAB104	Gn3.11	K	FE AA AG GY B E M O X	8526-4-S	55	609177	6053686	1173	29H
BM21		PAB111	Gn2.41	BRE	KA AB DB AI B E M O X	8526-4-S	55	609084	6051087	1191	34H
BM22		PAB112	Um6.13	NSG	KA AA DB DG B E M M X	8526-4-S	55	609183	6048605	1303	54H
BM23		PAB116	Gn2.41	BRE	KA AB DB AI B E L O X	8526-4-S	55	609114	6046175	1347	62H
BM24		PAB117	Gn3.11	NSG	DE AA AG AI B E O O X	8526-4-S	55	611663	6046247	1217	61H
BM25		PAB118	Gn2.11	RE	KA AA DB AI B E O O X	8526-4-S	55	611736	6043735	1193	94H
BM26		PAB114	Gn2.11	RE	KA AA DB AI B F O O X	8526-4-S	55	599214	6046015	1240	106H
BM27		PAB115	Gn2.11	RE	KA AA DB AI B F M O X	8526-4-S	55	601207	6046488	1236	81H
BM28		PAB113	Gn2.11	RE	KA AA DB AI B E M O X	8526-4-S	55	601835	6048590	1227	45H

[A] PPF: Principal Profile Form (Northcote 1979)
[B] GSG: Great Soil Group (Stace *et al.* 1968)
[C] ASC: Australian Soil Classification (Isbell 1993)
[D] ADH: Australian Datum Height (m)

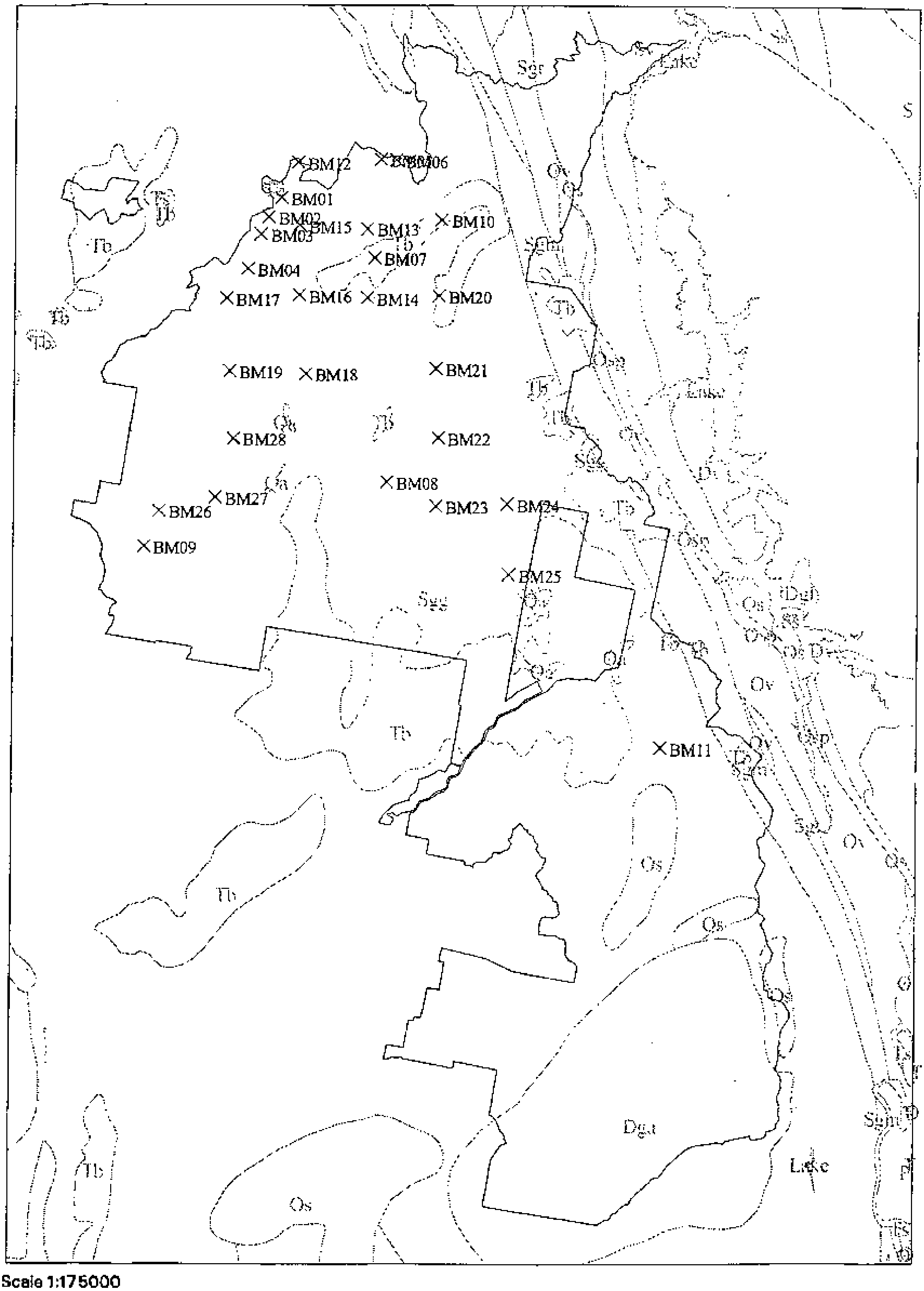


Figure 1. Map of Bago/Maragle State Forests with underlying geological boundaries from the preliminary Yarrangobilly 1:100,000 geological sheet and soil profiles locations.

Table 4. Soil depth classes for the 28 productivity sites.

0 - 1 m	1 - 2 m	2 - 3 m	>3 m
0	11 (39%)	8 (29%)	9 (32%)

The other distinctive feature of all these soils was their texture. Both the granodiorite and basalt soil have field textures of clay loam to light or light-medium clay in the A and B horizons. While this would be expected for the basalt soils it was peculiar that the granodiorite soils had such heavy textures with only a minor sand fraction. It was only in the C horizons that the sand fraction became obvious for many of the deep granodiorite soils.

The two basaltic soils with deep, pedal, non-gravelly profiles (BM07 and BM20) were interesting in that they showed evidence of varying parent material with depth. At BM20, basalt parent material went to 2.7 m and then changed to a tuffaceous or trachyte material with phenocrysts of felspar and vesicles. At BM07 the basalt parent material went to 0.74 m then a coarse lapilli tuff became evident and continued with an increasing amount of gleyed mottling to 2.5 m where there was a distinct change to a more trachyte-like material to 3.1 m. At this depth a perched water table was encountered and there was an abrupt change to coarse sandy material to 3.4 m. Below this saturated sand was a layer of finely layered silty clay loam sediment to 4.10 m where the auger finished. The latter two layers could represent Tertiary sediments below the basalt flow which had initial eruptions of tuff or trachyte. The other interesting feature of these two profiles is that they indicate that the basalt flow in north-east Bago State Forest which displays classic relief inversion is relatively shallow.

The profiles were classified using Great Soil Groups (Stace *et al.* 1968) (see GSG column in Table 3), *A factual key for the recognition of Australian soils* (Northcote 1979) (see PPF column in Table 3), and the new provisional Australian soil classification system (Isbell 1993) (see ASC column in Table 3). The latter classification required laboratory data.

The Great Soil Groups (Table 5) were predominantly red earths on granodiorite and krasnozems on basalt. There was difficulty however with the granodiorite soils in that they all had at least moderate pedality in the A horizons which often extended into the B horizons. This meant that the latter could not really fit into the red earth class but the pedality in the B horizons was not a high enough grade to allow classification as krasnozems (although they were other limitations to this classification). Only one profile showed signs of a pale A2 horizon and sufficient texture change to be classified as a red podzolic. This is the reason there are four profiles for which there was no suitable group. The pedality in the upper granodiorite soil layers is believed to be mostly due to earthworm casting, which had important effects on the aggregate stability results discussed below. The shallower granodiorite soils were generally less red, had little pedality, coarser textures and were classified as brown earths.

Table 5. Classification of the productivity sites by Great Soil Groups.

Brown Earth (BRE)	Red Earth (RE)	Red Podzolic (RP)	Chocolate (C)	Krasnozem (K)	No Suitable Group (NSG)
3	17	1	1	2	4

The Northcote key classified most of the profiles as either uniform or gradational red soils (Table 6). The clay loam to light clay texture range for a number of the granodiorite soils made it difficult in choosing between Um and Uf classes. For this study they were placed in the Um class. There were no duplex soils.

Table 6. Northcote Factual Key Principal Profile Forms (PPF) for the productivity sites.

Um6.13	Um7.11	Uf6.21	Uf6.31	Gn1.21	Gn2.11	Gn2.21	Gn2.24	Gn2.41	Gn3.11
1	6	1	1	1	9	1	1	3	4

In the new Australian Soil Classification (ASC) productivity sites were classified to the family level (Table 3 presents the ASC as 2 character codes for order, suborder, great group, subgroup and family) but can be summarised to the sub-order level in Table 7 as being in four main classes. The dominant order was Kandosol, similar to the old red earth class but allowing some pedality in the B horizons. Dermosols have at least moderate grade structure B horizons while Ferrosols are structured and Fe-rich. All the basalt soils were classed as Ferrosols although this requires laboratory verification of free iron-oxide concentrations. Another interesting feature of the ASC is that at the great group level the majority of the Kandosols and the Dermosols were classified as "magnesic" (DB); that is, the B2 horizons had exchangeable Ca to Mg ratios of less than 1. This will be discussed further below.

Table 7. Australian Soil Classification to suborder for the productivity sites.

Red Kandosols (KA AA)	Brown Kandosols (KA AB)	Red Dermosols (DE AA)	Red Ferrosols (FE AA)
20	3	2	3

4. *AGGREGATE STABILITY*

Two field versions of the Emerson Aggregate Test were used.

1. Northern Wheatbelt SOILpak (NSW Department of Agriculture and Fisheries)

   1.1 Slaking Scores (Slake)
   0/1= soil stable to wetting
   2 = typical of self-mulching soils
   3 = soil may form surface crust
   4 = soil may crust or hardset, poor soil for cultivation

   1.2 Dispersion Scores for fresh aggregates (Disp1)
   0/1= soil has good aggregate stability
   2 = slightly unstable
   3 = soil disperses when wetted, gypsum required for stabilisation
   4 = soil disperses when wetted, gypsum required for stabilisation

   1.3 Dispersion Scores after remoulding (Disp_rem)
   0/1= soil stable after wet tillage
   1 = soil disperses to some degree if tilled wet- caution
   2,3 or 4 = soil prone to dispersion if tilled moist

2. Emerson Aggregate Field Test (Soil Conservation Service of New South Wales)

   2.1 Dispersion Scores
   1 = soil aggregates disperse completely
   2 = soil aggregates show partial dispersion
   3 = remoulded aggregates show dispersion
   5/6 = no dispersion after remoulding - stable aggregates
   Classes 2 and 3 can be subdivided into 4 categories:
   (i) slight milkiness
   (ii) obvious milkiness, < 50% of aggregates/remoulded cube effected
   (iii) obvious milkiness, > 50% of aggregates/remoulded cube effected
   (iv) total dispersion

Scores of 5/6, 3(1), 3(2), 2(1) and 2(2) are relatively stable and can be worked satisfactorily in wet conditions.

Field determination of soil dispersion-slaking (Emerson Aggregate Tests) for most layers of all 28 soil profiles are presented in Appendix 1. This data shows that the surface soils are well aggregated, the B horizons are stable and only in the C horizons does significant dispersion occur. The Soil Conservation Service of New South Wales Emerson Aggregate Field Test and the SOILpak modified Emerson Aggregate Test gave comparable results.

5. BULK DENSITY

The mean bulk density (± std) across all layers sampled was 1.15 ± 0.24 Mg m^3. A horizons were usually less than 1.00 Mg m^3 with increasing densities in the lower massive B horizons up to 1.50 Mg m^3. The only site showing any signs of surface compaction was BM15 (PGP PAB101) which had an A horizon bulk density of 1.40 Mg m^3 and had been recently logged. Profile BM11 (experiment V1/1.46, Maragle State Forest) was unusual in having high bulk densities (greater than 1.40 Mg m^3) from 0.15 to 1.30 m.

6. PH

All the soils were highly acidic (Appendix 2). The mean pH (1:5 soil-water) was 5.07 ± 0.26 and mean pH (1:5 0.01M $CaCl_2$) was 4.12 ± 0.31. The difference between the two pH measures hints at high exchangeable acidities which are verified below. In the ASC (Table 3) 23 of the 28 profiles (82%) were classed in the acidic subgroup (B2 horizon pH > 5.2).

7. TOTAL CARBON, NITROGEN AND PHOSPHORUS

Total soil C and N can be very high in the surface soils but decrease rapidly with depth (Appendix 2). Table 9 summaries these data into three depth classes.

Table 8. Mean total soil carbon and nitrogen (± std) of the productivity sites for three soil depths.

Soil layer lower depth	Total C (%)	Total N (%)
≤ 0.2m	6.76 ± 3.12	0.26 ± 0.14
> 0.2m and ≤ 0.5m	1.81 ± 0.90	0.09 ± 0.04
> 0.5 m and ≤ 1.0 m	0.83 ± 0.56	0.05 ± 0.02

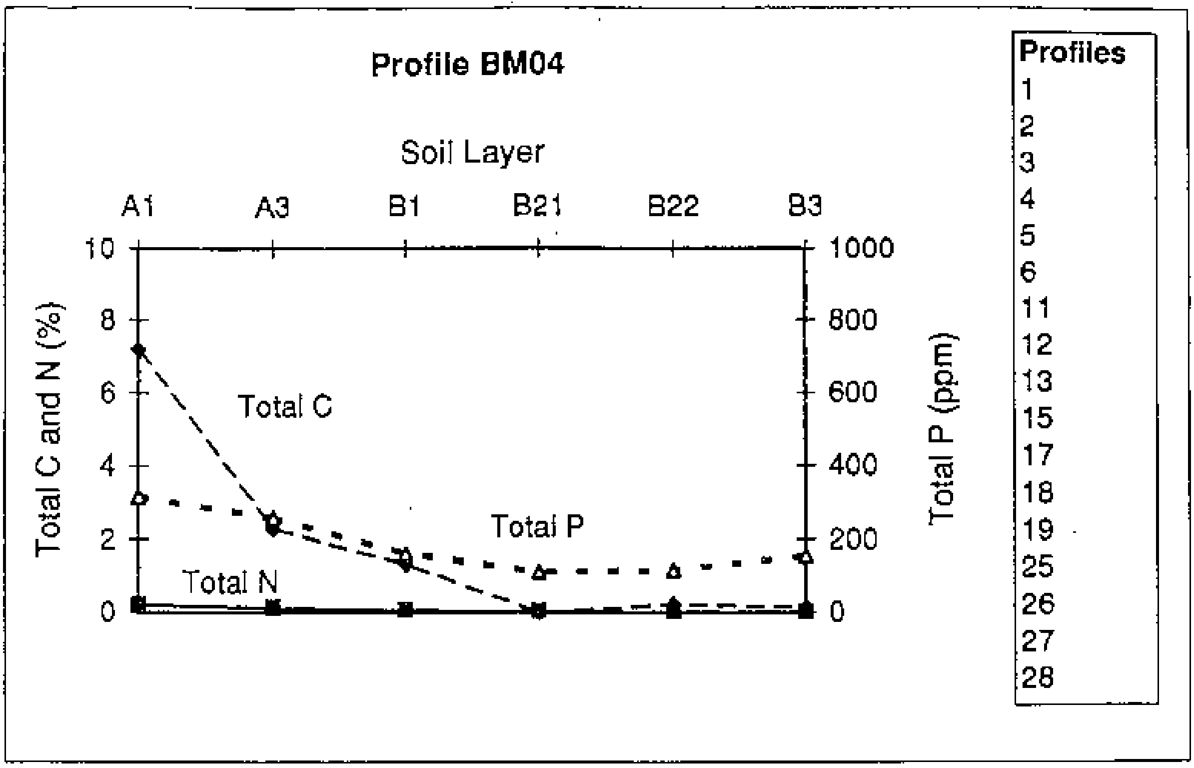
The C:N ratios for these three depth classes range from 26 to 17 although higher values occur for individual A horizons.

Total P variation with soil depth was used to qualitatively classify the 28 profiles into four groups shown in Figure 2.

1. Granodiorite soils where P decreases in the B horizons within the range 600-200 $\mu g\ g^{-1}$; 61% of the profiles.
2. Granodiorite soils where P decreases in the B horizons within the range 1000-400 $\mu g\ g^{-1}$; 21% of the profiles.
3. Granodiorite soils where P increases in the lower B horizons; 7% of the profiles.
4. Basaltic soils where P > 1000 $\mu g\ g^{-1}$; 11% of the profiles.

The first group (Figure 2.1) includes the majority of the granodiorite soils and would be considered normal profile concentrations for this parent material. The second group would be considered on the

2.1 P decreases in the B horizons; 600-200 ug/g



2.2 P decreases into the B horizons: 1000-400ug/g

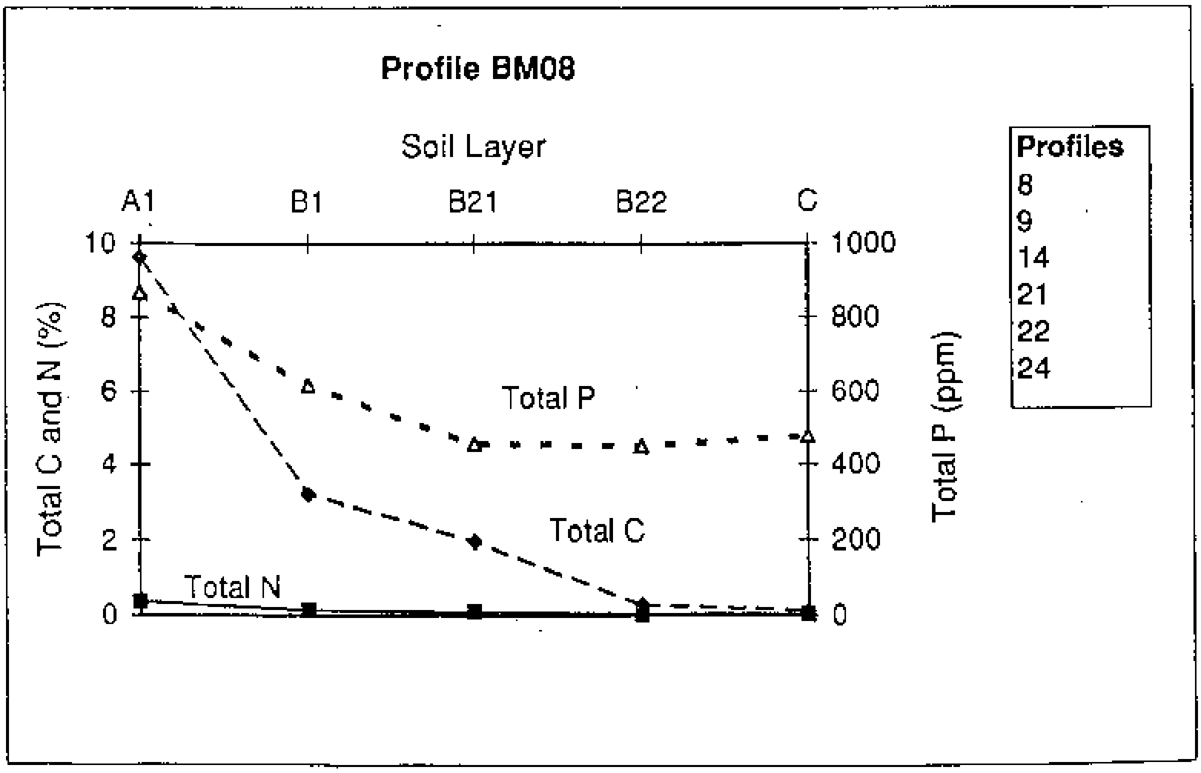
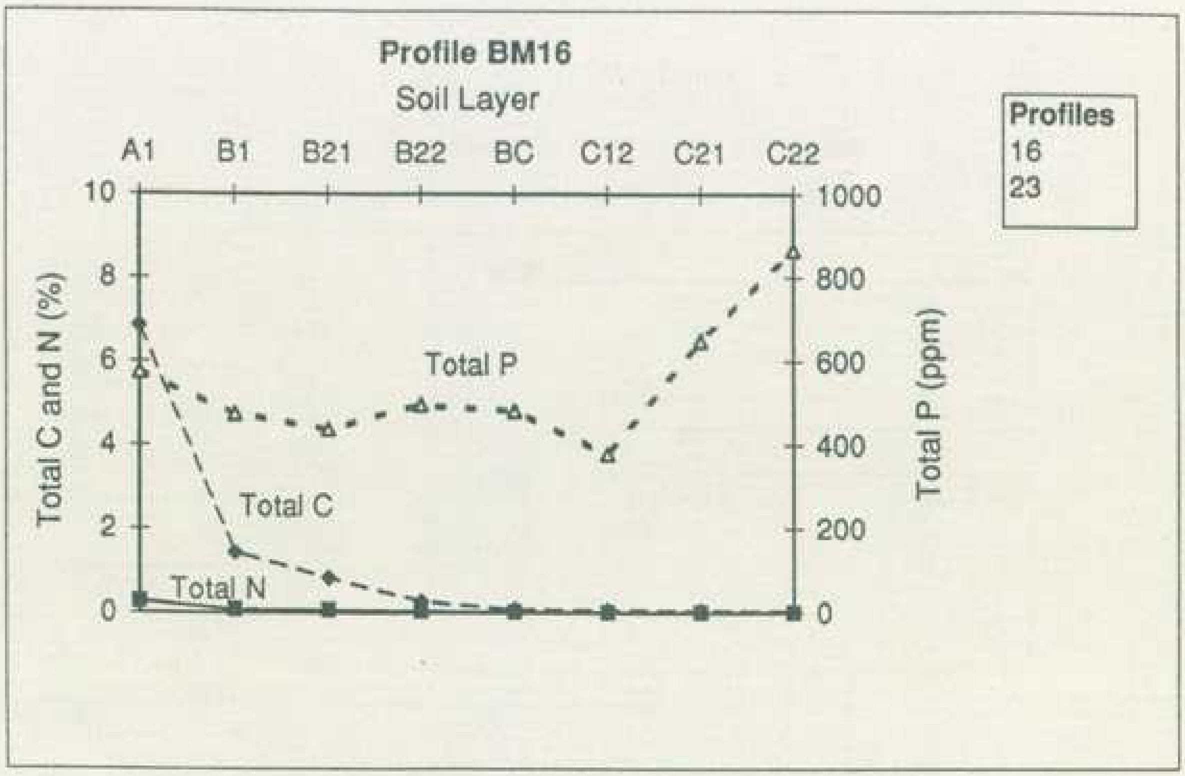


Figure 2. Soil profile patterns of total C, N and P by soil depth. Example profiles are presented for each of the four groups.

2.3 P increases in B horizons.



2.4 High P and C (Basaltic soils)

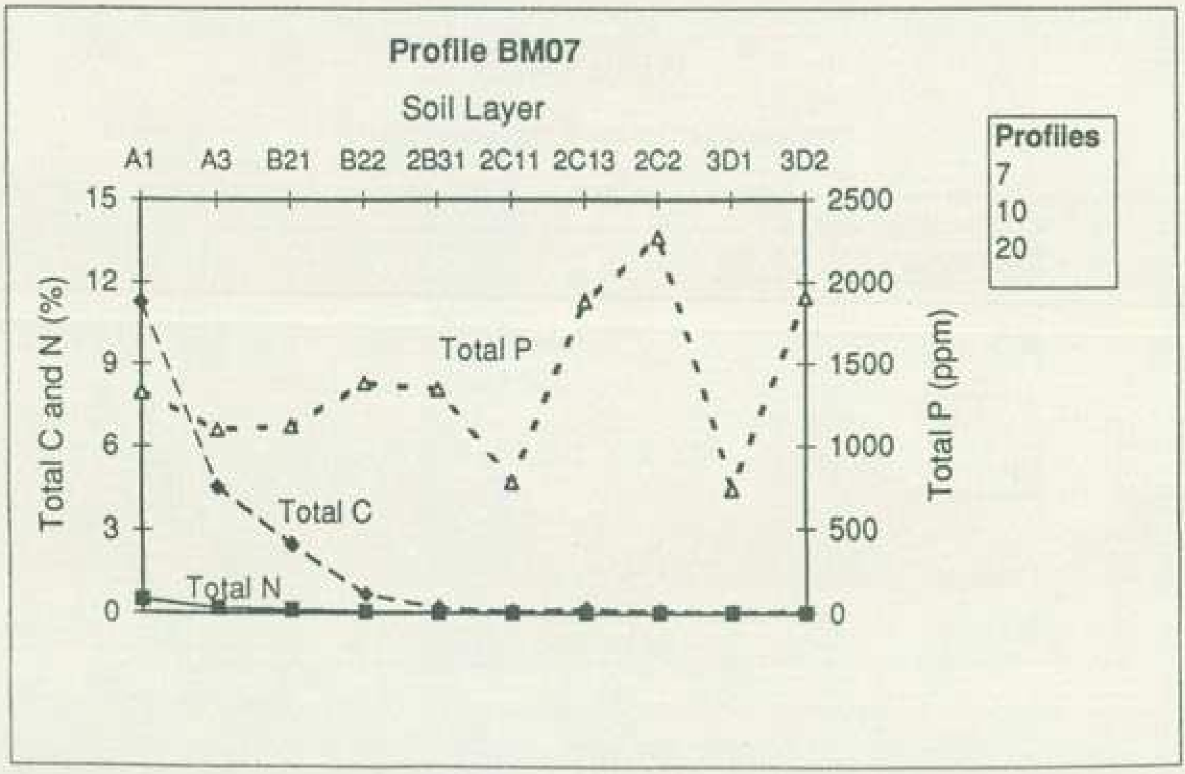
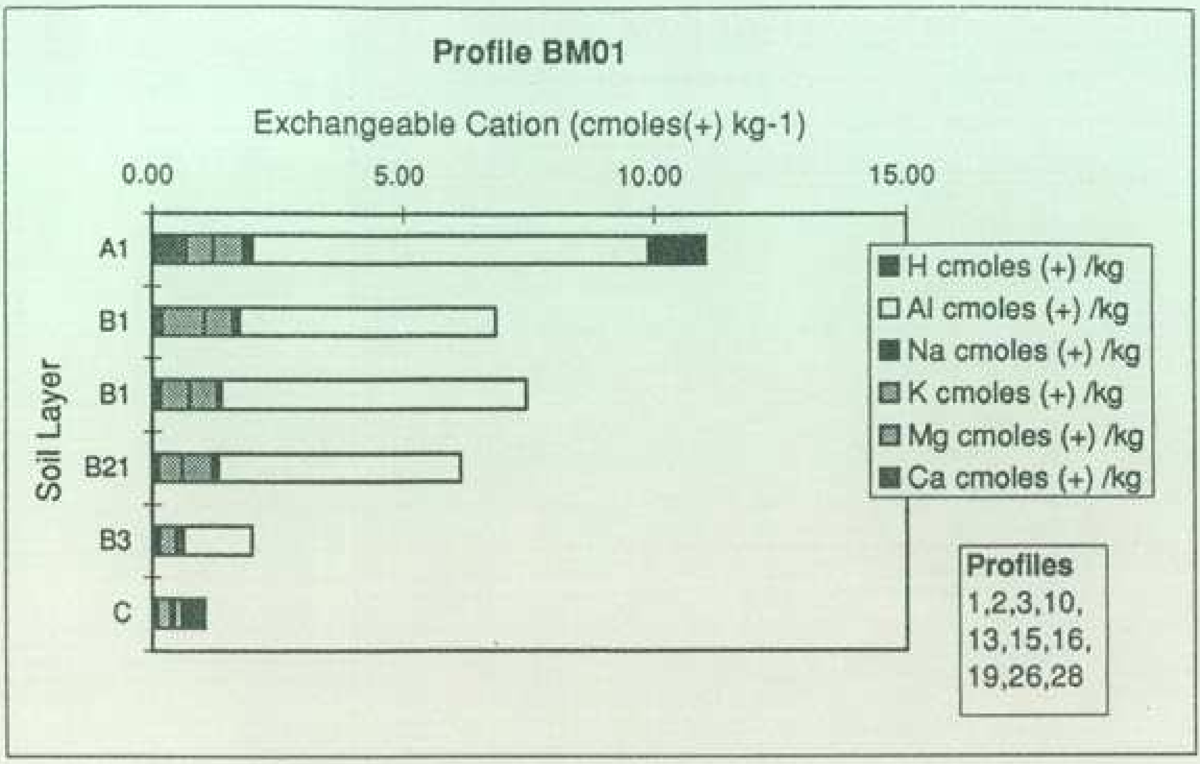


Figure 2. Soil profile patterns of total C, N and P by soil depth. Example profiles are presented for each of the four groups.

3.1 High exch. Al, low base status, ECEC > 4 in B horizons.



3.2 High exch. Al, low base status, ECEC < 4 in B horizons.

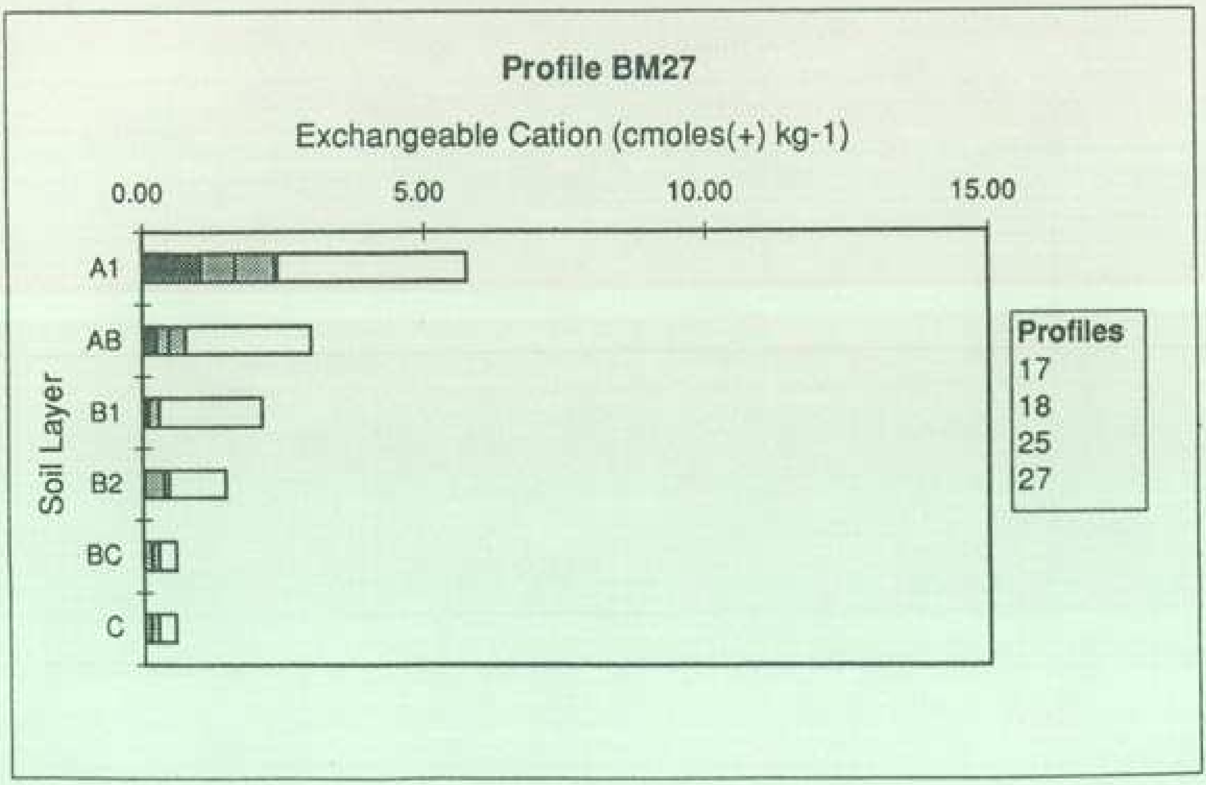
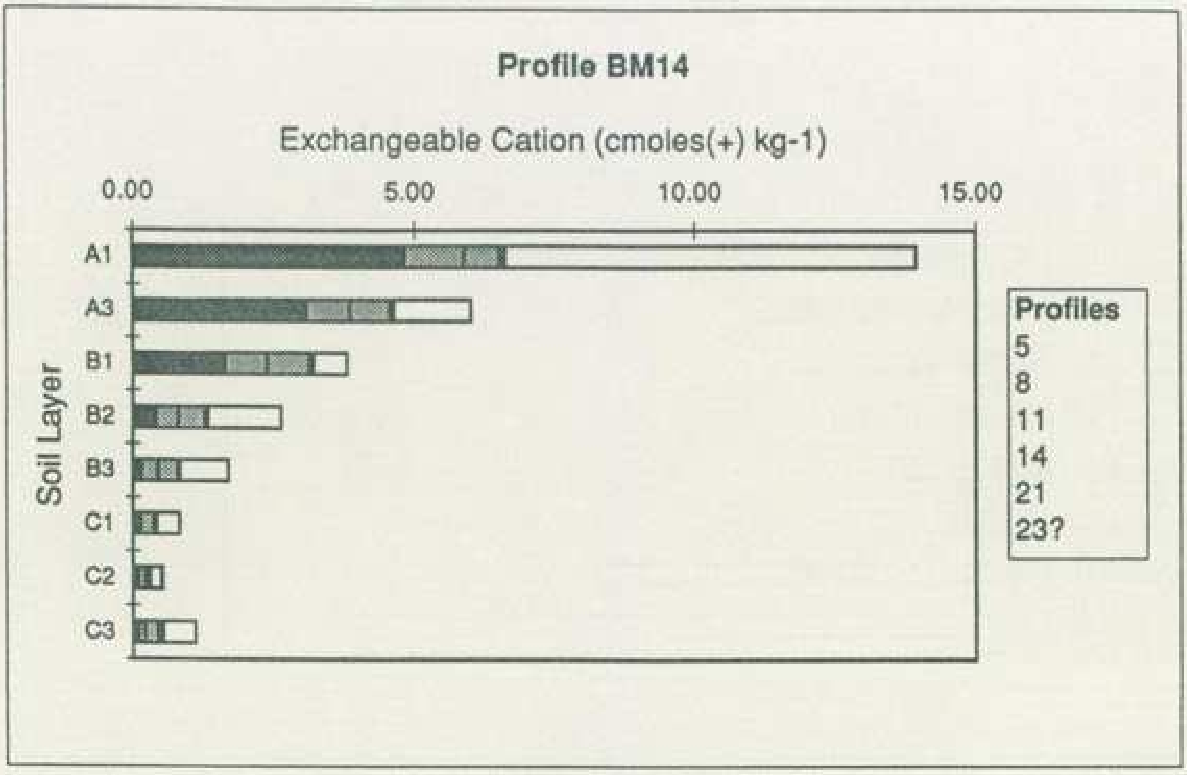


Figure 3. Soil profile patterns of exchangeable cations by soil depth. Example profiles are presented for each of the five groups.

3.3 Low exch. Al, high base status.



3.4 High exch. Al in subsoils, high base status in A horizons.

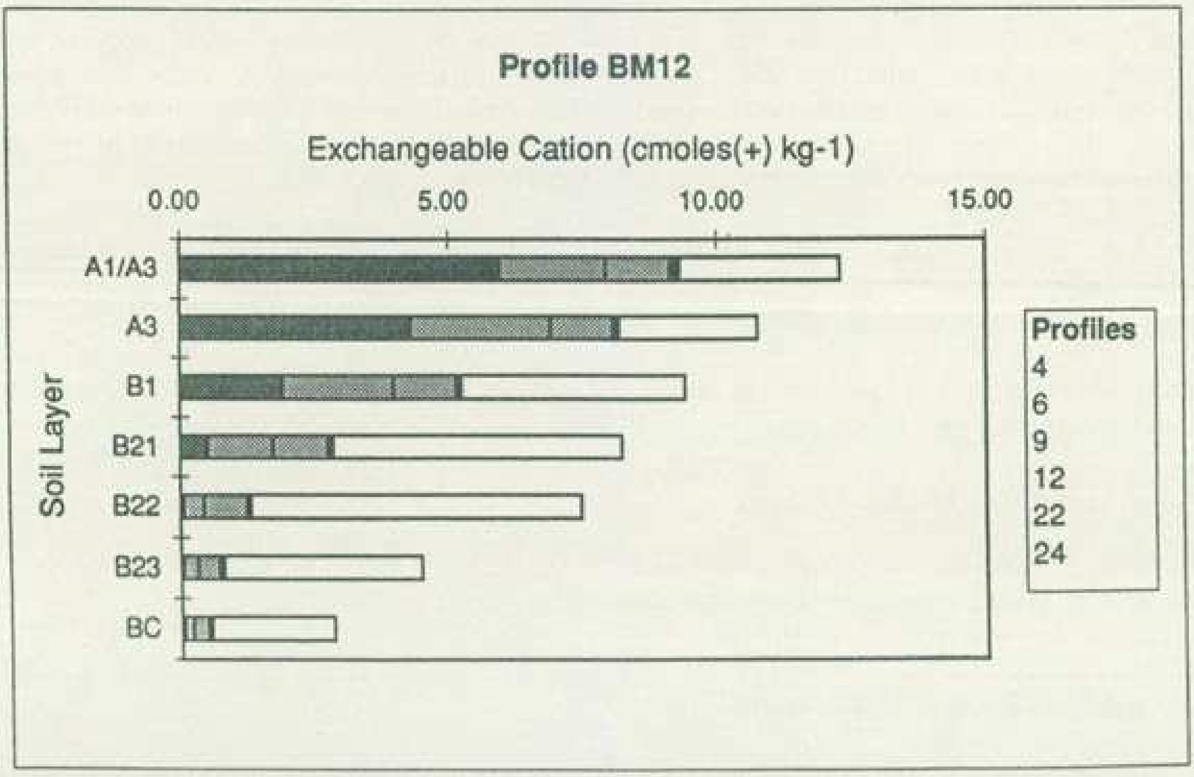


Figure 3. Soil profile patterns of exchangeable cations by soil depth. Example profiles are presented for each of the five groups.

3.5 High exch. Al in subsoils, very high base status (basaltic soils).

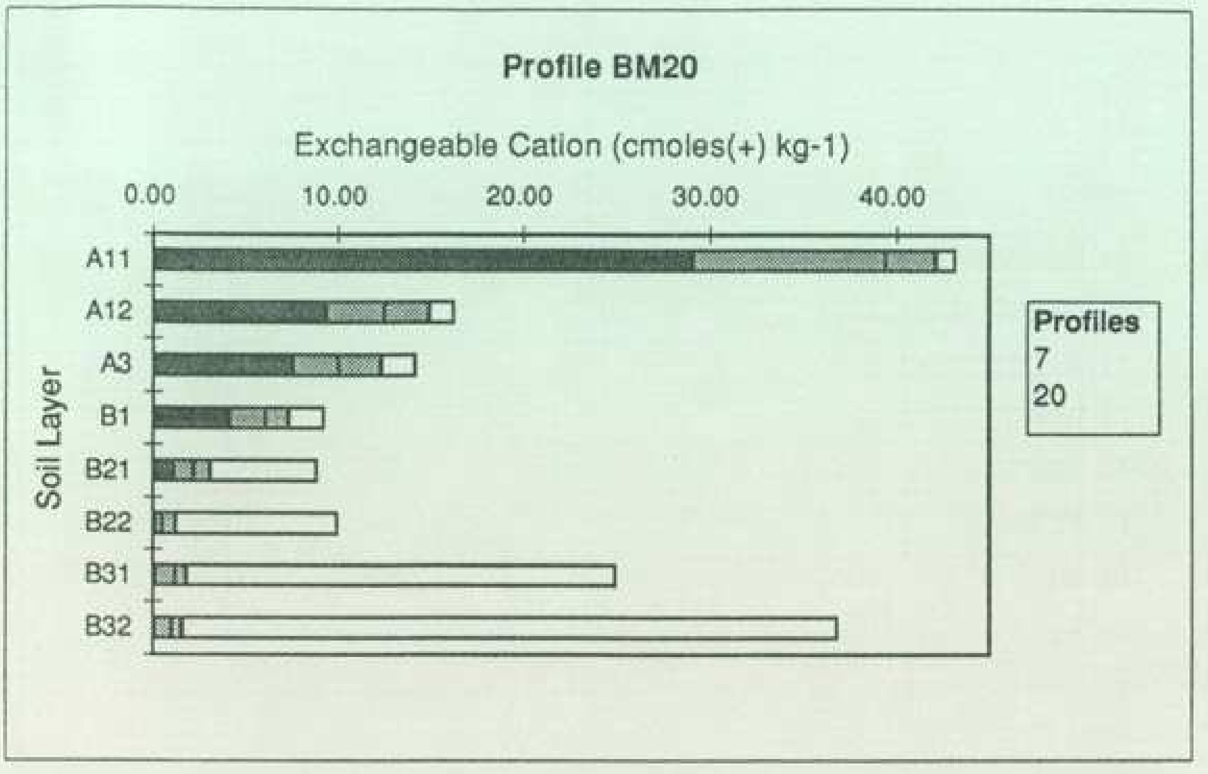


Figure 3. Soil profile patterns of exchangeable cations by soil depth. Example profiles are presented for each of the five groups.

high P end of the range for granodiorite soils while the third group represent a small group of odd granodiorite soils with either variable or multiple parent materials. Profiles in group 2 are either affected by basalt colluvium (BM14) or located in the mid-eastern part of Bago State Forest (BM21, BM22, BM24 Figure 1). Group 3 profiles also have similar locations to group 2 (Figure 1) with BM16 adjacent to a basalt flow and BM23 in the mid-east of Bago State Forest.

The fourth group includes all the basaltic soils which have the highest P concentrations. Note that for BM07 and BM20 the P concentrations in the lower B horizons were highly variable and related to the underlying tuff layers discussed above.

The four groups are only qualitative so further statistical analysis will be required to verify whether such groupings have any significance.

8. EXCHANGEABLE CATIONS

Appendix 2 list the data for exchangeable cations Ca, Mg, K, Na, H and Al for all soil layers analysed. Addition of all the cations gives the effective cation exchange capacity (ECEC).

Initial qualitative analysis of the soil profile variation in exchangeable cation concentrations produced five distinctive groups of profiles shown in Figure 3.

1. High exchangeable Al, low base status, ECEC greater than 4 in B horizons; 36% of the profiles.
2. High exchangeable Al, low base status, ECEC less than 4 in B horizons; 14% of the profiles.
3. Low exchangeable Al, high base status; 21% of the profiles.

4. High exchangeable Al in subsoils, high base status in surface soils; 21% of the profiles.
5. High exchangeable Al in subsoils, very high base status; 7% of the profiles.

Notable features of the exchange complex of these soils is the dominance of Al and low Ca:Mg ratios for nearly all of the granodiorite soils.

As with the total P data, there are interesting relationships between the above five groupings and the granodiorite profile locations. Groups 1 and 2 are mostly on the western side of Bago State Forest while groups 3 and 4 are mostly on the eastern side of the batholith (Figure 3). Cation groups 1 and 2 equate nearly with P group 1, that is granodiorite soils with low P concentrations in the B horizon tend to have their exchange complex dominated by Al. Similarly cation group 3 has nearly the same profiles as
P group 2, that is granodiorite soils with high P concentrations in the B horizons tend to have exchange complexes with low Al and high base status.

Again these five groups are only qualitative so further statistical analysis will be required to verify whether such groupings have any significance.

DISCUSSION AND CONCLUSIONS

The data presented above represents only a preliminary investigation into a small group of soils. They do not cover the range of soil parent material, topographic, climatic and vegetative variation present with Bago/Maragle State Forests and are therefore a biased sample. There are however some interesting features of these soils which have implications for developing forest productivity relationships and soil-landscape models for the area.

CONCLUSIONS

1. The dominance of deep, red acid soils on one of the highest plateaux in Australia presents numerous geomorphological problems. Is Bago/Maragle plateau a residual old land surface which has been deeply weathered in the past or is the deep weathering a contemporary process?
2. Soil clay content and exchangeable Al concentration are higher than would be expected for granodiorite soils. One hypothesis to explain these characteristics is accumulation of aeolian dust from the western plains. The Bago/Maragle plateau forms the first main geographical barrier to dust storms from the west.
3. The strong aggregate stability of the surface soils is partly due to earthworm activity. The high clay content of these soils means that earthworms may play an important part in reducing clay dispersion and soil erodibility, plus possibly ameliorating compacted surface soil.
4. P and exchange complex chemistry would indicate that the area mapped as Green Hills Granodiorite is not homogeneous but could be comprised of several geochemically distinct plutons.
5. The basaltic soil profiles display a complex of volcanic parent materials overlying possible Tertiary sediments. The presence of a perched watertable in these basalt soils on some of the highest points of the plateau surface has implications for soil water relationships with the forest stands and forest hydrological processes.
6. Dominance of Al on the soil exchange complex, the low Ca:Mg ratios, the very acid pHs, and the low P concentrations of the majority of the productivity site soils has implications to forest nutrition sustainability and possible silvicultural manipulation via fertilisation to increase productivity.

REFERENCES

Abraham, S.A. and Abraham, N.A. (1992). Soil data system site and profile information handbook. Department of Conservation and Land Management, New South Wales. 162 pp.

Heffernan, B. (1985). A handbook of methods of inorganic chemical analysis for forest soils, foliage and water. Division of Forest Research, CSIRO, Canberra. pp. 60-65.

Isbell, R.F. (1993). A classification system for Australian soils (third approximation). Division of Soils CSIRO. Tech. Report 2/1993. 92 pp.

Jackson, M.L. (1958). Soil chemical analysis. Prentice Hall, N.J., pp. 41-48.

Khanna, P.K., Raison, R.J. and Falkiner, R.A. (1986). Exchange characteristics of some acid organic-rich forest soils. *Australian Journal of Soil Res.*, 24: 67-80.

Northcote, K.H. (1979). A factual key for the recognition of Australian soils. 4th Ed. Rellim Tech. Pubs., Glenside, S.A. 123 pp.

Stace, H.C.T., Hubble, G.D., Brewer, R., Northcote, K.H., Sleeman, J.R., Mulcahy, M.J. and Hallsworth, E.G. (1968). A handbook of Australian soils. Rellim Tech. Pubs., Glenside, S.A. 435 pp.

APPENDIX1

BAGO/MARAGLE STATE FORESTS SOIL SAMPLES

					Field testing for slaking and dispersion					Bulk density
					SOILPAK			SCS		
L_No	Profile	L_Depth	Horizon	Date	Slake	Disp1	Disp_rem	Emm	REmm	(Mg/m^3)
1	BM01	0.18	A1	12/12/94	0	0/1	0/1	5/6		0.96
2	BM01	0.42	B1	12/12/94	0	0/1	0/1	5/6		1.07
3	BM01	0.86	B21	12/12/94	2	0/1	0/1	5/6		
4	BM01	1.10	B22	12/12/94	2	0/1	0/1	5/6		1.15
5	BM01	1.45	B3	12/12/94	4	0/1	1	3(1)		1.27
6	BM01	2.00	C	12/12/94	4	3	3	3(4)		
1	BM02	0.08	A1	12/13/94	0	0/1	0/1	5/6		0.89
2	BM02	0.18	A3	12/13/94	0	0/1	0/1	5/6		1.04
3	BM02	0.32	B1	12/13/94	0	0/1	0/1	5/6		1.08
4	BM02	0.60	B21	12/13/94	1	0/1	0/1	5/6		1.08
5	BM02	1.00	B22	12/13/94	1	0/1	0/1	5/6		1.08
6	BM02	1.50	B23	12/13/94	2	0/1	0/1	5/6		
7	BM02	2.70	B22	12/13/94	2	0/1	0/1	5/6		
8	BM02	3.40	B3	12/13/94	3	0/1	1	3(1)		
9	BM02	3.40	C	12/13/94	4	2	1/2	3(1)		
1	BM03	0.14	A1	12/13/94	0	0/1	0/1	5/6		0.93
2	BM03	0.42	B1	12/13/94	0	0/1	0/1	5/6		0.97
3	BM03	0.95	B21	12/13/94	0	0/1	0/1	5/6		
4	BM03	1.50	B21	12/13/94	1	0/1	0/1	5/6		1.05
5	BM03	3.70	B22	12/13/94	1/2	0/1	0/1	5/6		
6	BM03	4.00	B3	12/13/94	3	1/2	0/1	5/6		
1	BM04	0.07	A1	12/13/94	0	0/1	2	3(1)		0.82
2	BM04	0.16	A3	12/13/94	0	0/1	0/1	5/6		1.26
3	BM04	0.28	B1	12/13/94	0	0/1	0/1	5/6		1.32
4	BM04	0.74	B21	12/13/94	2	0/1	0/1	5/6		1.35
5	BM04	0.92	B22	12/13/94	3	0/1	0/1	5/6		1.53
6	BM04	1.15	B3	12/13/94	3	1/2	2	3(1)		
7	BM04	1.40	C	12/13/94	4	2	3	3(3)		
1	BM05	0.10	A1	12/14/94	0	0/1	2	3(1)		0.81
2	BM05	0.22	A2	12/14/94	0	0/1	0/1	5/6		1.14
3	BM05	0.40	B21	12/14/94	0	0/1	0/1	5/6		1.13
4	BM05	0.90	B22	12/14/94	1	0/1	0/1	5/6		1.35
5	BM05	1.30	B3	12/14/94	2	0/1	0/1	5/6		
6	BM05	1.80	C	12/14/94	3	2	1	3(1)		
7	BM05	2.80	C	12/14/94	4	2	1	3(1)		
1	BM06	0.07	A1	12/14/94	0	0/1	1			0.74
2	BM06	0.19	A3	12/14/94	0	0/1	0/1			1.10
3	BM06	0.31	B1	12/14/94	1	0/1	0/1			1.23
4	BM06	0.60	B21	12/14/94	1	0/1	0/1			1.07
5	BM06	1.80	B22	12/14/94	2	0/1	0/1			1.31
6	BM06	2.00	B23	12/14/94	2	0/1	0/1			
1	BM07	0.08	A1	12/15/94	0	0/1	0/1	5/6		0.69
2	BM07	0.20	A3	12/15/94	0	0/1	0/1	5/6		0.96

					Field testing for slaking and dispersion					Bulk
					SOILPAK			SCS		density
L_No	Profile	L_Depth	Horizon	Date	Slake	Disp1	Disp_rem	Emm	REmm	(Mg/m³)
3	BM07	0.74	B21	12/15/94	2	0/1	0/1	5/6		1.07
4	BM07	1.10	B22	12/15/94	2	0/1	0/1	5/6		1.19
5	BM07	1.60	2B31	12/15/94	2	0/1	0/1	5/6		
6	BM07	1.90	2B32	12/15/94	2/3	0/1	0/1	5/6		
7	BM07	2.10	2C11	12/15/94	3	0/1	0/1	5/6		
8	BM07	2.20	2C12	12/15/94	1	0/1	0/1	5/6		
9	BM07	2.50	2C13	12/15/94	3	0/1	0/1	5/6		
10	BM07	3.10	2C2	12/15/94						
11	BM07	3.40	3D1	12/15/94						
12	BM07	4.10	3D2	12/15/94						
1	BM08	0.12	A1	12/15/94	0	0/1	0/1	5/6	5/6	0.73
2	BM08	0.31	B1	12/15/94	0	0/1	0/1	5/6	5/6	1.10
3	BM08	0.55	B21	12/15/94	1	0/1	0/1	5/6	5/6	1.30
4	BM08	1.15	B22	12/15/94	2	0/1	0/1	5/6	5/6	1.57
5	BM08	1.30	B3	12/15/94	3	0/1	0/1	5/6	5/6	
6	BM08	2.25	C	12/15/94	4	0/1	3	3(1)	3(3)	
1	BM09	0.09	A1	12/16/94	0	0/1	0/1	5/6		0.95
2	BM09	0.21	A3	12/16/94	0	0/1	0/1	5/6		1.02
3	BM09	0.45	B21	12/16/94	0	0/1	0/1	5/6		1.20
4	BM09	0.80	B22	12/16/94	1	0/1	0/1	5/6		1.43
5	BM09	1.10	B3	12/16/94	2	0/1	0/1	5/6		1.58
6	BM09	1.40	C	12/16/94	3	0/1	3	3(3)		
1	BM10	0.06	A11	12/16/94	0	0/1	0/1	3(1)		0.58
2	BM10	0.15	A12	12/16/94	0	0/1	0/1	5/6		0.86
3	BM10	0.42	B21	12/16/94	0	0/1	0/1	5/6		0.95
4	BM10	0.90	B22	12/16/94	0	0/1	0/1	5/6		0.92
5	BM10	1.20	B23	12/16/94	2/3	0/1	0/1	5/6		
1	BM11	0.12	A1	1/23/95	0	0/1	0/1			0.82
2	BM11	0.30	B1	1/23/95	0	0/1	0/1			1.43
3	BM11	0.54	B21	1/23/95	0	0/1	0/1			1.40
4	BM11	0.78	B22	1/23/95	1	0/1	0/1			1.49
5	BM11	1.60	B3	1/23/95	3	0/1	0/1			1.59
6	BM11	1.80	C	1/23/95	3	1	0/1			
1	BM12	0.03	A1	1/24/95	0	0/1	2			0.67
2	BM12	0.11	A3	1/24/95	0	0/1	0/1			1.03
3	BM12	0.26	B1	1/24/95	0	0/1	0/1			1.03
4	BM12	0.70	B21	1/24/95	1	0/1	0/1			1.29
5	BM12	2.00	B22	1/24/95	1	0/1	0/1			1.35
6	BM12	2.80	B23	1/24/95	2	0/1	0/1			
7	BM12	3.30	BC	1/24/95	3	0/1	0/1			
1	BM13	0.10	A1	1/24/95	0	0/1	0/1			0.82
2	BM13	0.25	B1	1/24/95	0	0/1	0/1			1.16
3	BM13	0.55	B21	1/24/95	0	0/1	0/1			1.22
4	BM13	0.90	B22	1/24/95	1	0/1	0/1			1.49
5	BM13	1.40	B23	1/24/95	2	0/1	0/1			
6	BM13	2.00	C1	1/24/95	3	2	2			
7	BM13	2.55	C2	1/24/95	4	2	2			
8	BM13	2.90	C3	1/24/95	4	2	2			
1	BM14	0.12	A1	1/25/95	0	0/1	1			0.75
2	BM14	0.25	A3	1/25/95	0	0/1	0/1			0.97
3	BM14	0.38	B1	1/25/95	0	0/1	0/1			1.23
4	BM14	0.80	B2	1/25/95	1	0/1	0/1			1.31

					Field testing for slaking and dispersion					Bulk
					SOILPAK			SCS		density
L_No	Profile	L_Depth	Horizon	Date	Slake	Disp1	Disp_rem	Emm	REmm	(Mg/m^3)
5	BM14	1.05	B3	1/25/95	2	0/1	0/1			1.50
6	BM14	1.75	C1	1/25/95	3	2	2			
7	BM14	3.50	C2	1/25/95	3	2	2			
8	BM14	4.20	C3	1/25/95	4	2	2			
1	BM15	0.06	A1	1/25/95	0	0/1	1			
2	BM15	0.18	A2	1/25/95	0	0/1	0/1			1.40
3	BM15	0.38	B21	1/25/95	1	0/1	0/1			1.08
4	BM15	0.70	B22	1/25/95	1	0/1	0/1			1.23
5	BM15	1.60	B23	1/25/95	2	0/1	0/1			1.23
6	BM15	2.40	C	1/25/95	4	1	0/1			
1	BM16	0.15	A1	1/26/95	0	0/1	0/1			0.82
2	BM16	0.44	B1	1/26/95	0	0/1	0/1			1.09
3	BM16	0.75	B21	1/26/95	1	0/1	0/1			1.16
4	BM16	1.20	B22	1/26/95	2	0/1	0/1			1.36
5	BM16	1.50	BC	1/26/95	4	2	2			
6	BM16	1.70	C11	1/26/95	1	0/1	0/1			
7	BM16	2.30	C12	1/26/95	4	2	2			
8	BM16	2.80	C13	1/26/95	1	0/1	2			
9	BM16	3.30	C21	1/26/95	2/3	2	0/1			
10	BM16	4.00	C22	1/26/95						
1	BM17	0.15	A1	1/27/95	0	0/1	0/1			0.88
2	BM17	0.48	B21	1/27/95	0	0/1	0/1			1.29
3	BM17	0.82	B22	1/27/95	1	0/1	0/1			1.48
4	BM17	1.10	B3	1/27/95	1	0/1	0/1			1.40
5	BM17	1.50	C	1/27/95	3	2	1/2			
1	BM18	0.17	A1	4/3/95	0	0/1	0/1			0.93
2	BM18	0.29	B1	4/3/95	0	0/1	0/1			1.15
3	BM18	0.55	B21	4/3/95	0	0/1	0/1			1.20
4	BM18	0.75	B22	4/3/95	0	0/1	0/1			1.22
5	BM18	1.30	B23	4/3/95	0	0/1	0/1			1.39
6	BM18	2.65	C	4/3/95	0	0/1	2			
1	BM19	0.13	A1	4/3/95	0	0/1	0/1			1.05
2	BM19	0.27	B1	4/3/95	0	0/1	0/1			1.26
3	BM19	0.60	B21	4/3/95	0	0/1	0/1			1.34
4	BM19	1.20	B22	4/3/95	1	0/1	0/1			1.43
5	BM19	2.20	B31	4/3/95	4	0/1	0/1			
6	BM19	2.50	B32	4/3/95	4	0/1	2			
7	BM19	2.80	B33	4/3/95	4	0/1	0/1			
8	BM19	4.00	C	4/3/95	4	0/1	2			
1	BM20	0.05	A11	4/4/95	0	0/1	0/1			0.61
2	BM20	0.15	A12	4/4/95	0	0/1	0/1			0.75
3	BM20	0.27	A3	4/4/95	0	0/1	0/1			1.08
4	BM20	0.43	B1	4/4/95	2	0/1	0/1			1.12
5	BM20	1.40	B21	4/4/95	0	0/1	0/1			1.15
6	BM20	1.95	B22	4/4/95	0	0/1	0/1			
7	BM20	2.75	B31	4/4/95	1	0/1	0/1			
8	BM20	2.90	B32	4/4/95	2	0/1	0/1			
1	BM21	0.10	A11	4/4/95	0	0/1	0/1			0.92
2	BM21	0.22	A12	4/4/95	0	0/1	0/1			1.15
3	BM21	0.33	B1	4/4/95	0	0/1	0/1			1.30
4	BM21	0.75	B2	4/4/95	2	0/1	0/1			1.45
5	BM21	0.95	B3	4/4/95	2-3	0/1	0/1			1.52

					Field testing for slaking and dispersion					Bulk
					SOILPAK			SCS		density
L_No	Profile	L_Depth	Horizon	Date	Slake	Disp1	Disp_rem	Emm	REmm	(Mg/m^3)
6	BM21	2.10	C	4/4/95	3	0/1	2			
1	BM22	0.11	A1	4/4/95	0	0/1	0/1			1.00
2	BM22	0.21	A3	4/4/95	0	0/1	0/1			1.23
3	BM22	0.35	B21	4/4/95	1	0/1	0/1			1.21
4	BM22	0.72	B22	4/4/95	2	0/1	0/1			1.41
5	BM22	1.00	B23	4/4/95	2	0/1	0/1			1.58
6	BM22	1.75	C	4/4/95	3	0/1	0/1			
1	BM23	0.15	A1	4/5/95	0	0/1	0/1			0.72
2	BM23	0.26	B1	4/5/95	0	0/1	0/1			0.99
3	BM23	0.75	B21	4/5/95	2	0/1	0/1			1.03
4	BM23	1.10	B22	4/5/95	1	0/1	0/1			1.20
5	BM23	1.55	B3	4/5/95	3	0/1	0/1			
6	BM23	1.90	BC	4/5/95	3	0/1	2			
1	BM24	0.15	A1	4/5/95	0	0/1	0/1			0.90
2	BM24	0.33	B1	4/5/95	1/2	0/1	0/1			1.17
3	BM24	0.65	B21	4/5/95	1/2	0/1	0/1			1.19
4	BM24	1.40	B22	4/5/95	2	0/1	0/1			1.51
5	BM24	2.10	B23	4/5/95	2	0/1	0/1			
6	BM24	2.65	B3	4/5/95	3	0/1	0/1			
7	BM24	3.10	C1	4/5/95	3	0/1	2			
8	BM24	4.00	C2	4/5/95	3	0/1	2			
1	BM25	0.12	A1	4/5/95	0	0/1	0/1			1.08
2	BM25	0.25	B1	4/5/95	0/1	0/1	0/1			1.39
3	BM25	0.50	B21	4/5/95	1	0/1	0/1			1.25
4	BM25	0.75	B22	4/5/95	2	0/1	0/1			1.32
5	BM25	1.25	B23	4/5/95	2	0/1	0/1			1.64
6	BM25	1.95	B3	4/5/95	3	0/1	0/1			
1	BM26	0.13	A1	4/6/95	0	0/1	0/1			0.88
2	BM26	0.24	B1	4/6/95	0	0/1	0/1			1.11
3	BM26	0.50	B21	4/6/95	0	0/1	0/1			1.31
4	BM26	1.50	B22	4/6/95	2	0/1	0/1			1.38
5	BM26	1.90	B3	4/6/95	3	0/1	0/1			
6	BM26	2.35	C1	4/6/95	2/3	0/1	0/1			
7	BM26	2.65	C2	4/6/95	3	0/1	0/1			
1	BM27	0.14	A1	4/6/95	0	0/1	0/1			0.95
2	BM27	0.25	AB	4/6/95	0	0/1	0/1			1.24
3	BM27	0.36	B1	4/6/95	0	0/1	0/1			
4	BM27	1.10	B2	4/6/95	2	0/1	0/1			1.54
5	BM27	1.50	BC	4/6/95	3	0/1	2			
6	BM27	1.75	C	4/6/95	1	0/1	2			
1	BM28	0.12	A1	4/6/95	0	0/1	0/1			0.72
2	BM28	0.25	B1	4/6/95	0	0/1	0/1			1.10
3	BM28	0.64	B21	4/6/95	0/1	0/1	0/1			1.29
4	BM28	1.30	B22	4/6/95	2	0/1	0/1			1.22
5	BM28	1.85	BC	4/6/95	3	0/1	0/1			
6	BM28	2.45	C1	4/6/95	3	0/1	2			
7	BM28	3.45	C2	4/6/95	3	0/1	2			
8	BM28	3.70	C3	4/6/95	1	0/1	0/1			

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