STANDARDISED MEASURES OF REGENERATION SUCCESS FOR SUSTAINABLE MANAGEMENT OF AUSTRALIAS NATIVE FORESTS

Final Report for WAPIS Project PN99.180 to address Montreal Indicator 2.1.g

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FINAL REPORT

STANDARDISED MEASURES OF REGENERATION SUCCESS FOR SUSTAINABLE MANAGEMENT OF AUSTRALIAN NATIVE FORESTS

WAPIS PROJECT "PN99.810" (Regeneration success measures and monitoring methods for sustainable forest management in native forest (Indicator 2.1(g))

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Executive summary

The project (Regeneration success measures and monitoring methods for sustainable forest management in native forest (Indicator 2.1(g)) has the following objective:
to develop cost-effective, standardised methods to determine regeneration success (including stocking, species composition and early seedling growth) in Australian native forests as a basis for continuous improvement in on-ground operations, aggregation of data to regional and national levels, and accreditation.

The project roughly comprised 3 steps:
- review of current knowledge/technologies
- research on regeneration reference sites
- development of cost-effective, standardised indicators of regeneration success.

The review, research and further development of regeneration performance indicators followed a general framework which included the following processes :
- Objectives: Convert the sustainability indicator into an explicit objective or set of objectives
- Performance measures: Define quantitative/qualitative measures for each objective
- Scales: Define the forest scale (Coupe, Operations Area, Region?) for monitoring and evaluation
- Strata: Define the forest classes/strata relevant to monitoring and evaluation of the indicator
- Field monitoring systems: Develop field data collection, analysis and storage systems
- Sustainability evaluation systems: Develop sustainability evaluation systems for each objective

The project did not consider another important development step, ie:
- Management Improvement systems: Develop on-ground forest management improvement systems (Planning, operations monitoring)

Objectives

At present there are a few major inconsistencies in the current site occupancy objectives. Within one state, Queensland, the monitoring of regeneration in state forests is not considered to be necessary because of the reliability of regeneration in the forest types that are being utilised for timber production. In New South Wales state forests, regeneration is often considered to be secondary to other management objectives and only a sample of coupes harvested each year is monitored for regeneration.

Recommendation:
- Nation-wide adoption of the objective of achieving a measured level of site occupancy and species composition of regeneration on every harvested area, the achievement of success based on management objective.

Sustainability measures

Most states have well developed measures of site occupancy applicable to the forest types and range of silvicultural systems applied. Victoria and Tasmania use stocked quadrat methods whilst Western Australia uses a combination of density and stocking (triangular tessellation) and New South Wales uses average seedling density (distance to closest individual). Species composition (ie the relative abundance of species) measures are in an early stage of development in most states, where the measurement is integrated with site occupancy. The current measures give greater weighting to the spatial distribution of species, than obtained by overall abundance by species, as determined by quadrat count. An index based on stocking by species, rather than counts by species, would be the most relevant measure to be used in conjunction with stocking by quadrat measures.

Two options for standardised measures of site occupancy and species composition stand out as being superior to the others. One of those options, the adoption of triangular tessellation as the standard will involve considerable cost, which might only be recouped if intensive management systems are to be applied. It is unlikely that such a system will be warranted in the short term in most Australian states. The other option, continuing with current measures in the field and converting to a standard measure for regional and national reporting, is less costly to implement. The simplest, unbiased measure, stocking by 16 m^2 quadrat and the species composition index based on stocking by species, is recommended as the standard to reduce the imprecision associated with conversion, as assumptions about important variables such as spatial distribution are minimised. There are also options in between these approaches, such as replacing the biased closest individual measure with triangular tessellation or converting the distance data to stocking, which would increase the precision of the standardised results.
Recommendation:

- Adopt 16m^2 stocking and species composition index as the national reference and continue to apply existing measures in use throughout Australia and convert the results to the national reference. The conversion should be made at the plot level in the case of site occupancy by triangular tessellation in WA by using a different plot standard. Conversion from the closest individual to 16m^2 stocking could be made at the plot level or at the stand level, provided that a factor is applied to take account of the statistical distribution of closest distances.

Scales and Strata

A literature review of the responses to disturbance indicated a stratification based on regeneration ecology. Differences in evaluation standards between organisations for forests with similar regeneration ecology could not be resolved. If results are stratified at the regional or state level then reporting structure would accommodate these differences. For consistency, information should not be reported below the coupe or harvest area level, and the regeneration result should be reported for every coupe harvested.
Recommendations:

- That the harvest area be the basic management unit selected for reporting. For even-aged silviculture systems the unit will be approximately 10 to 100 ha; for uneven-aged silviculture 10 to 200 ha.
- The following strata be used for aggregation to the national level:

States (Regions) / Forest types (closed, eucalypt- wet intolerant, eucalypt- wet tolerant, eucalypt- dry mixed non-lignotuberous and lignotuberous, eucalypt- dry lignotuberous, woodland or alternatively the National Forest Inventory forest types) / Silvicultural systems (even-aged, uneven-aged)

Field monitoring systems

The systematic sampling grid with random starting point is the most efficient for sampling aggregated seedling distributions, which occur in most Australian native forests. Timing has been raised as a significant issue when acceptability criteria are applied. Acceptability criteria need to be developed that reflect the stage of development of seedlings. In the absence of acceptability criteria, regeneration surveys should be completed and reported within a period that is reasonable for obtaining a clear indication if regeneration has failed. Uneven-aged forest is monitored differently to even- aged forest in a number of states, and the two options presented are not intended to be applied to all uneven-aged forests. Where single tree selection is used a system that takes into account a number of stand components will be necessary, but the reporting could be limited to the portion of the stand that is unoccupied by suitable growing stock of a later stage and thus requires regeneration.

Recommendations:

- Systematic sampling with a random starting point be continued as the standard field sampling procedure.

- Timing of regeneration success surveys be at a stage when there is a clear indication of adequate establishment of regeneration; in most cases 1 to 5 years after the regeneration triggering disturbance, but up to 20 years after disturbance in some dry forest types.
- The regeneration component of uneven-aged stands be surveyed in the context of other stand components, in a separate stratum. In group selection systems this could involve sampling intensively in the gaps, whereas in single tree selection systems on a broader sampling grid across the harvested area.

Sustainability evaluation systems

Issues concerning variability in site occupancy standards for similar forest types between organisations have not been able to be resolved, but for the purpose of national reporting the lowest standard for a particular management objective, considered to have scientific validity, could be used. Ecologically based species composition standards are yet to be developed. In the interim a standard based on the pre-harvesting species composition could be applied.

Recommendation:

Reporting of regeneration performance should be by broad strata of regeneration success based on the management objective with reference to appropriate levels of 16 m^2 stocking, rather than a single pass/fail result for each harvested area. A suggested format for reporting site occupancy results for a region over a given period is as follows:

	16 m^2 stocking range (and management objective)				
Forest type	0-10% (Not stocked)	10- 40% (Minimum ecological stocking)	40- 65% (Low wood quality)	65- 85% (Optimum wood production)	85- 100% (Maximum clear wood with thinning)
Forest type A	A1	A2	A3	A4	A5
Forest type B	B1	B2	B3	B4	B5
Forest type C	C1	C2	C3	C4	C5
Forest type D	D1	D2	D3	D4	D5

Where A1....D4 are the sum of the individual harvest areas in each category. All areas harvested in the given time period should be included in the table. If harvest areas have not been assessed, then they will be assumed to be not stocked. Some categories may not be represented in a region over a given time period.

As an interim species composition evaluation method, strata for regeneration success could be based on the shift in species composition of the regeneration strata as compared to the pre-harvesting overstorey species composition. Pre-harvesting species composition should be based on relative basal areas of species for the harvest area. In other cases the target percentages for species composition may be set by other management objectives. In either situation the performance in obtaining a desired species outcome could be summarised in the following table:

	Percentage of species with reduced relative site occupancy*			
Forest type	>50% (Minimum species diversity)	26- 50% (Medium species diversity)	1-25% (High species diversity)	0% (Maximum species diversity)
Forest type A	A2	A3	A4	A5
Forest type B	B2	B3	B4	B5
Forest type C	C2	C3	C4	C5
Forest type	D2	D3	D4	D5

D					

Where A1....D5 are the sums of the harvest areas in each category.
Reduced relative site occupancy is reduction of the percentage of the species in the regeneration strata by more than 20% for species that occupied more than 39% of the pre-harvesting stand or more than 10% for species that occupied less than 40% of the pre-harvesting stand.
For example, a harvest area with a single species pre-harvesting, has the possible outcomes:
0% of species with reduced relative site occupancy- the species is the only one in the regeneration strata
>50% of species with reduced relative site occupancy- 20% or more of other species regenerated with original species, or original species not regenerated.

Management Improvement Systems

Although management systems have not been considered in any detail in this study it is clear that the recommended changes to the measures of regeneration success will require some modification of management systems.

Recommendations:
Initiate implementation of findings through the Forest Management and Co-ordination Committee or another committee under the Forestry and Forest products Committee.
Government and non-government organisations to develop / modify existing systems for national reporting of regeneration success addressing the following issues:

- frequency: 5 yearly reporting recommended
- timing: in stands harvested 5 – 10 years ago (20 years ago in some dry forest types) recommended
- training program for national consistency: technical (eg sampling method, species id), data management, report formatting.

Summary of research findings

Explicit objectives, scales and strata applicable to regeneration success were identified in the review. The project concentrated on developing the performance measures and sustainability evaluation systems to meet the current objectives, scale and strata. The current systematic sampling approach to field monitoring was accepted as a given in the development process. A simulation study approach was taken to ensure that there was sufficient replication to provide statistical confidence in the results. Real stand data from Regeneration Reference Sites (RRSs) has been used to place the simulation results into context. Management Improvement Systems were considered to be beyond the scope of the current project.

Key outcomes

Objectives

The review identified that at present there are a few major inconsistencies in the current site occupancy objectives. Within one state, Queensland, the monitoring of regeneration in state forests is not considered to be necessary because of the reliability of regeneration in the forest types that are being utilised for timber production. In New South Wales state forests, regeneration is often considered to be secondary to other management objectives and only a sample of coupes harvested each year is monitored for regeneration. The claim that regeneration is reliable or of secondary importance could be made for many of the forest types utilised in Australia, and the monitoring effort could be reduced substantially if the Queensland or New South Wales approach was applied Australia wide. In such a system one of the current objectives, the identification of areas for remedial treatment is foregone. However the regeneration of the forest is such an important process in sustainable forest management that all coupes should be monitored. The monitoring of regeneration in private forests is currently optional and also considered to be a high priority for implementation. Current objectives for species composition are generally not explicit enough, which is related to the poor understanding of species dynamics in most mixed species forests. Growth objectives have not been explicitly stated for regeneration in any native forests in Australia, because there are too many confounding factors at the regeneration stage.

Sustainability measures

The review identified that most states have well developed measures of site occupancy applicable to the forest types and range of silvicultural systems applied. Victoria and Tasmania use stocked quadrat methods whilst Western Australia uses a combination of density and stocking and New South Wales uses average seedling density.

The analysis of mapped plots varying from 0.04 to 0.08 ha in size and small dispersed plots at the RRSs indicated that by a number of nearest neighbour distance and quadrat based indices :

- Spatial distribution in real stands established by clearfelling and artificial sowing or by retention of seed trees were random to very aggregated, aggregation increasing with increasing seedling density. Planted stands were assumed to be uniformly distributed.

The simulation study of site occupancy measures in stands of varying aggregation indicated:

- Seedling density by triangular tessellation and quadrat measures were unbiased for the range of seedling distributions tested
- Seedling density by the closest individual was biased for all but random distributions
- Sampling intensity would need to be increased by a factor of 300% to reduce variation in seedling density by triangular tessellation to that by 16 m^2 quadrat. Any time advantage of applying triangular tessellation compared to the seedling count in the quadrat method would be negated by the extra sampling effort required.
- In order to achieve a sampling error of less than or equal to 15% in aggregated stands, sampling intensity of triangular tessellation would need to be greatly increased in small

stands. However acceptable sampling error may be achieved in larger stands with a sampling grid of 80 m x 20 m.
- The width of the confidence intervals of the stocking measures peaked when stocking was around 50% , reflecting the underlying binomial distribution of stocking. Sampling error could be reduced to 15% if a minimum sample size of 50 was chosen.

Site occupancy measures that include both spatial distribution (ie stocking) and intensity (ie seedling density), such as the triangular tessellation method used in Western Australia and seedling density/stocking by quadrat in Victoria, provide more information for management decisions, but at a greater cost than stocking measures alone.

Analysis of the simulation results also indicated the following relationships between estimates of site occupancy by different measures and implications for conversion between measures:

- The stocking by triangular tessellation and stocking by quadrat responded differently to changes in site occupancy and stand level conversions would require considerable further development. Alternatively a simple and accurate conversion to quadrat stocking could be obtained by using a different plot level standard for triangular tessellation to what is currently used (eg a plot standard of 312.5 spha is equivalent to 16m^2 quadrat stocking).
- Density by the distance to the closest individual decreased with increasing aggregation at a different rate to stocking by quadrat. An accurate conversion to quadrat stocking could be developed, based on the statistical distribution of the distance to the closest individuals. Alternatively quadrat stocking can be determined by altering the plot level to comparison of the closest distance to the plot standard (eg 2.26m for 16m^2 quadrat stocking).
- The relationship between all and acceptable seedlings by the Victorian acceptability criteria varied with stand, seedling density and stand age; thus conversion would require considerable development. For the purpose of national reporting the stocking of acceptable seedlings could be assumed to be equivalent to stocking of all seedlings, which would understate the level of regeneration in Victorian forests.

Species composition (ie relative abundance of tree species) measures are in an early stage of development in Victoria, New South Wales and Western Australia, where field monitoring of species composition is integrated with site occupancy, but there is generally limited evaluation of the data. The association of species in real stands was found to vary from independence to slightly associated at the RRSs. The simulation study of the alternative methods of measuring species composition in stands with varying levels of species association indicated that
- Species composition by methods other than quadrat count give greater weight to species with a wider spatial distribution; a species composition index based on stocking by species gives the greatest weighting to spatial distribution.

Growth measures have been incorporated into measures of site occupancy in Victoria, through the application of seedling acceptability criteria. There have been no further attempts to develop measures of growth at the regeneration stage. In order to incorporate growth, regeneration monitoring would need to be delayed beyond the stage when they are currently carried out. Delaying monitoring would risk compromising operational efficiency and the ability to meet the objective of early, low cost retreatment of unacceptable regeneration.

In practice seedling density and stocking estimates by the quadrat method may be less precise or biased, because of inclusion of seedlings outside the quadrat or missing seedlings within the quadrat. The use of acceptability criteria in Victoria should limit the error due to these sources, because larger, more vigorous seedlings are easier to identify and measure. Error in estimates by triangular tessellation could occur as a result of mis-identification of the Delauney triangle seedlings, missing seedlings, imprecise measurement of the triangle sides and from limiting the search area. In addition error could be introduced in species composition measures through incorrect identification of species.

A useful indicator should have a number of properties, most of which are satisfied by all the alternative measures of regeneration success, but there are important differences in sensitivity and cost/benefit (table 1). In particular the sensitivity and ability to detect critical change with confidence, is dependent on the precision of the estimates, which is likely to decrease with the inclusion of data from various sources, which is particularly relevant when converting from one measure to another. The information content of the measure will also influence the sensitivity, as more relevant information will increase the ability to detect critical change. Costs associated with the introduction, on-going implementation and equitability of costs may vary between systems. The issue of whether the cost of collecting additional information is equal to its benefit also needs to be determined.

Two options for standardised measures of site occupancy and species composition stand out as being superior to the others (table 1). Option 1, the adoption of triangular tessellation as the standard will involve considerable cost, which might only be recouped if intensive management systems are to be applied, which is indicated by the bracketed ticks under Benefit/cost for this option. In addition, the seedling density estimate by this method may be imprecise, as indicated by the bracketed tick under sensitivity and ability to detect critical change, and the cost would be high to improve the precision by increasing the sampling rate. Thus it is unlikely that such a system will be warranted in the short term in most Australian states. Option 4, continuing with current measures in the field and converting to a standard measure for regional and national reporting, is less costly to implement. The simplest, unbiased measure, stocking by 16 m^2 quadrat and a species index based on stocking by species, is recommended as the standard to reduce the imprecision associated with conversion, as assumptions about important variables such as spatial distribution are minimised.

Table 1 The performance of six options of standardisation of measures of site occupancy and species composition against sensitivity and cost criteria (the more ticks the better the performance against the criteria).

Option	Sensitivity & ability to detect critical change	Benefit vs cost
1.Triangular tessellation stocking and seedling density as the common and standard measure	44(4)* high precision of density estimate may require an increase in sampling intensity	4(44)* introduction and operating costs are high, but organisations using intensive management will benefit. Inequitable costs vs benefits.
2. 16 m^2 quadrat stocking as the common and standard measure	44 high precision of stocking estimate but less information than triangular tessellation	44 Introduction cost medium, operating cost is low, but benefit is medium
3. 16 m^2 quadrat acceptable stocking as the common and standard measure	4 low precision of acceptability criteria	4 Cost of introduction is medium, operating cost is low, but benefit is low
4. Various measures converted to 16 m^2 quadrat stocking as the standard measure;	44 precision medium due to conversion	444 Low cost of introduction, operating cost variable and benefit medium

5. Various measures converted to tri tessellation stocking as the standard measure	4 precision low due to conversion	4 Medium cost of introduction due to complex conversion, operating cost variable and benefit low
6. Various measures converted to 16 m^2 quadrat acceptable stocking as the standard measure	4 precision low due to conversion	4 Medium cost of introduction, operating cost variable and benefit low

* (4) indicates that performance varies – whilst the unbracketed ticks would always be achieved, the bracketed ticks would only be achieved in certain situations.

Scales:
The issue identified in the objectives of whether all harvested areas are monitored is also an issue of scale, whether the coupe or the broader forest type in a district or region for example, is the management unit. A further issue is that measurement is carried out in small plots below the coupe level and sometimes results are reported at the sub-coupe level. Standardisation requires that a suitable sized management unit be selected.

Strata:
In the review regeneration was discussed under groups of forest types with similar responses to disturbance. It was proposed that those groups form the basis of an ecological stratification of forest types for monitoring and evaluation. However the analysis of evaluation standards indicated some large variation between organisations within forest types with similar regeneration ecology and there is currently insufficient information to resolve these differences. If results are stratified at the regional or state level then reporting structure would accommodate these differences.

Field monitoring systems

The systematic sampling grid with random starting point is the most efficient for sampling aggregated seedling distributions, which occur in most Australian native forests. The sampling grid could be made more intensive to increase precision of estimates. Generally 50 sample points would give precise enough estimates of stocking, but a sample size of at least 100 would be required for precise estimates of seedling density by triangular tessellation in aggregated stands. Fewer and larger plots, as used in North American coniferous forests, would be more efficient for planted or more uniformly distributed regeneration.

Timing has been raised as a significant issue when acceptability criteria are applied. Acceptability criteria need to be developed that reflect the stage of development of seedlings. In the absence of acceptability criteria, regeneration surveys should be completed and reported within a period that is reasonable for obtaining a clear indication if regeneration has failed. In the case of *E. marginata* this may be 20 years after the regeneration cut at the assessment before the shelterwood removal. In most other cases it would be from 1 to 5 years after the harvesting \ disturbance event when regeneration is expected to occur.

Uneven-aged forest is monitored differently to even- aged forest in a number of states, and the two options presented are not intended to be applied to all uneven-aged forests. Where group selection is the silvicultural system, consideration should be given to a stratified sampling approach, with the gaps within a harvesting unit being measured as a separate stratum using the same measures developed for even-aged forest with a similar sampling intensity. Where single tree selection is used a system that takes into account a number of stand components will be necessary, but the reporting could be limited to the portion of the stand that is unoccupied by suitable growing stock of a later stage and thus requires regeneration.

Sustainability evaluation systems

The review and simulation study of evaluation systems for site occupancy have shown the following:

- the triangular tessellation and stocking of acceptable seedling evaluation system are sensitive to changes in site occupancy
- the mapped as stocked system is relatively insensitive to changes in site occupancy
- the density by closest individual system does not respond to changes in seedling density but to changes in site occupancy
- standards vary between existing systems in order of decreasing standard as follows: the stocking by triangular tessellation, stocking of acceptable seedlings, % mapped as stocked and density by closest individual.
- the standards of the sensitive systems could be modified to provide an equivalent standard of site occupancy to the other systems.

The review and simulation study of evaluation systems for species composition has shown the following:

- the triangular tessellation, closest individual, quadrat density, closest density and 2 indices of species composition based on stocking by species are sensitive to changes in species composition
- explicit objectives and standards are specified for one organisation only, but they only loosely reflect the policy of that organisation.
- Interim objectives and evaluation standards need to be developed for all organisations; a natural objective that reflects current policy is to establish regeneration with area occupied by each species the same as the area occupied by each species prior to harvesting. The standard would be based on an appropriate reference measure and include margins for error in estimating species composition.
- The measure that most closely indicates the area occupied by each species is the species composition index based on stocking; this could be used as the reference measure and other measures converted to this measure before comparison to the standard. An alternative is to accept the level of bias in existing measures, which give less weight to spatial distribution.
- the species composition objectives and standards for the major commercial forest types require further development, including consideration of management objectives and the ecological basis of the standard.

Management Improvement Systems

Although management systems have not been considered in any detail in this study it is clear that the recommended changes to the measures of regeneration success will require some modification of management systems. The national 5-yearly state of the forests report presents a good avenue for national reporting. Data from annual regional summaries for 5 consecutive years could be processed and incorporated into the five-yearly report. The most recently harvested areas reported on would likely be 5 years prior to the report, so that the report would cover all areas harvested 5 to 10 years prior to the reporting date. This would provide opportunity for retreatment of areas of marginal regeneration success to improve the overall regeneration performance.

Requirements for further research and development

The following issues have been raised that require further research and development action, that will need to be continued beyond the life of the current project.

Growth measures:
The attempt to include growth into the indicator of site occupancy, ie the stocking of acceptable seedlings, has resulted in poor precision of that measure. The inclusion of growth has the potential to increase the value of the indicator of regeneration success, especially if monitoring is carried out later than it currently is. Inclusion of growth measures may best be integrated with soil indicators, the stratification of soil impacts providing a sound basis for stratification of growth measurement. Thus the timing of measurement and the field monitoring systems becomes an important issue. Potential indicators are height and diameter of potential co-dominant and dominant trees. Bole quality, ie form, branching habit, potential for internal defect, could also be included.

Mapping systems:

- There is some variation between organisations in the interpretation of stocking maps and stratification of harvested areas into satisfactorily and unsatisfactorily stocked areas. Species composition information could be included and an attempt made to check whether pre-harvesting species distribution matches post-harvesting species distribution. The inclusion of growth measures and integration with soil indicators suggests that overlaying of maps of soil impacts and regeneration may be a useful analytical approach. Thus there is scope for revising and improving methods of stratifying and mapping stocking status at the coupe level.

Uneven-aged systems:

- measures of site occupancy for components of multi-aged and uneven-aged stands need to be further evaluated.

Sustainability evaluation systems:

- The development of evaluation methods and standards requires a thorough understanding of stand dynamics from seedling through to maturity in order for measures to be indicative of long term ecosystem productivity.
- There is considerable variation between evaluation standards between states, even for forest types which have similar regeneration ecology that need to be resolved.

The RRS strategy introduced in this project should be continued in order to meet these long term research needs. The sites include six previously established sites representing regeneration after clearfalling of dry to wet forest were utilised in the current project. In addition, new sites have been established to increase the range of forest types and silviculture covered by detailed studies of spatial distribution and early stand development. 18 sites have been established in eucalypt regeneration covering wet forests of south-eastern Australia, dry forests of north-eastern Australia, south-eastern and south-western Australia. Silviculture includes clearfalling, seedtree, shelterwood and group selection systems.

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The collaborators in this project were:

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1. Background

The Australian national forest policy statement (Govt Aust 1992) has been agreed to by all Australian states and territories. It includes a commitment to ecologically sustainable forest management. The NFPS forms the basis of subsequent policy such as the Wood and Paper Industry Strategy (WAPIS) and Regional Forest Agreements. Regional Forest Agreements include the aim to demonstrate sustainable forest management through the development of criteria and indicators of sustainable forest management. These criteria and indicators are to be consistent with the Montreal Process Criteria and Indicators (Govt. Aust 1997). Concordantly, a number of projects have been established with part Commonwealth funding, under the WAPIS, administered by Forest and Wood Products Research and Development Corporation (FWPRDC), to research and develop sustainability criteria and indicators. The proposed indicator "Area and percent of harvested area of native forest and plantations effectively regenerated" was deemed to have a high priority for further research and development (FWPRDC 1998). Although it is not one of the original indicators specified by the Montreal Process it was accepted as a valuable indicator, of the criterion of maintenance of productivity of forest ecosystems, by the Australian Montreal Implementation Group.

One of the reasons for the high priority given to development of this indicator is that regeneration or renewal of the forest has been viewed as a fundamental part of sustainable forest management since intensive harvesting began in the 1960s. As harvesting became more intensive the need for regeneration, as consistent with even-aged silviculture, and some way of determining regeneration success became necessary. Since then there has been a need for greater accountability and development of formalised methods and standards. Thus all government organisations that use intensive harvesting methods have developed a system of monitoring regeneration. Historically there has been a lack of formal monitoring on selectively harvested areas (uneven-aged silviculture) but there has been a recognition of the need for similar approaches to those used in even-aged silviculture. Current methods generally assess site occupancy of commercial species, but do not assess growth or species diversity.

The project "PN99.810 (Regeneration success measures and monitoring methods for sustainable forest management in native forest (Indicator 2.1(g))" was formally agreed to by the FWPRDC and the Victorian, Tasmanian, Western Australian, New South Wales and Queensland governments through signing of a Research Agreement in July 1999. The project has the following objective:

to develop cost-effective, standardised methods to determine regeneration success (including stocking, species composition and early seedling growth) in native forests as a basis for continuous improvement in on-ground operations, aggregation of data to regional and national levels, and accreditation.

Although current methods may provide a basis for continuous on-ground improvement, a standardised approach would enable consistency of reporting from regional to national levels. This would serve the purpose of accountability (accreditation) that will be necessary to demonstrate the agency's commitment to sustainability and assist in certification for marketing of forest products.

The project roughly comprises 3 steps:
- review of current knowledge/technologies
- research on regeneration reference sites
- development of cost-effective, standardised indicators of regeneration success.

As the final report on this project, it provides details of the development of standardised indicators of regeneration success. It integrates the knowledge gained from the review, studies at the regeneration reference sites and simulation studies of the application of regeneration measures to stands of various spatial distributions. It presents the details of the regeneration reference sites and studies carried out on them. The development of standardised site occupancy and species composition measures using the results of regeneration reference site studies and simulation studies is reported in full. Priorities and proposals for further research are presented.

2. Review

2.1 Objectives

The objective of this review is to
- review regeneration processes and determine the stand parameters pertinent to regeneration success
- gain a broad and complete overview of current regeneration survey methods and standards in Australia and a sample from abroad and evaluate with respect to the following:
  - whether objectives are consistent with a national indicator
  - inclusion of the parameters pertinent to regeneration success
  - scientific validity
  - operational efficiency
- identify the most appropriate measures of regeneration success for major Australian forests and evaluate the possibility of standardising at the national level
- identify research and development needs and prioritise for further development of standardised measures of regeneration success.

2.2 Methods

The scientific literature was reviewed with particular emphasis given to:
- reviews of regeneration survey methods and standards
- ecology and silviculture of eucalypt and other Australian commercial native forests
- spatial characteristics of regenerated forests and effects on estimates of stand parameters.

The review introduced potential measures of regeneration success (Section 2.3) and considered the relevance of these to regeneration and early stand development in the major commercial forest types of Australia (Section 2.4).

A questionnaire was circulated to the contributing states (Victoria, Tasmania, Western Australia, NSW and Queensland) and overseas organisations to obtain a sample of internationally applied methods. The questionnaire covered the following aspects of regeneration surveys:
- Policy and organisational framework
- Description of current methods including objectives, measurements, plot size, sampling intensity, standards, reporting
- Description of historical methods and standards
- Evaluation of historical/current methods and standards
- Scientific basis of methods and standards.

The review summarised the current methods in Australian states and the northern hemisphere mixed coniferous/ deciduous forests (section 2.5.1). Then the current measures were evaluated against the following conceptual framework of development of sustainability monitoring and continuous improvement systems (Lutze and Campbell 1997):

OBJECTIVES
Convert the sustainability indicator into an explicit objective or set of objectives

⇓

PERFORMANCE MEASURES
Define quantitative/qualitative performance measures for each objective

⇓

SCALES
Define the forest scale (Coupe, FMA, RFA?)
for monitoring and evaluation of the indicator

⇓

STRATA
Define the forest classes/strata relevant to monitoring and evaluation of the indicator

⇓

FIELD MONITORING SYSTEMS
Develop field data collection, analysis and storage systems

⇓

SUSTAINABILITY EVALUATION SYSTEMS
Develop sustainability evaluation systems for each objective

⇓

MANAGEMENT IMPROVEMENT SYSTEMS
Develop on-ground forest management improvement systems
(Planning, operations monitoring)

⇓

ONGROUND ECOSYSTEMS

In section 2.5.2.1 the objectives are described at coupe, regional and state scales and discussed in relation to whether they are consistent with a national level indicator. In section 2.5.2.2 the current methods are evaluated with respect to inclusion of important parameters. In section 2.5.2.3 field monitoring systems are evaluated with respect to statistical validity of sampling and cost effectiveness. In section 2.5.2.4 current evaluation standards are compared and evaluated with respect to whether they constitute part of a scientifically valid sustainability evaluation system. In the current monitoring system the major stratification is on the basis of state, which is evident throughout the discussion in section 2.5.2. However there is potential to stratify across states on the basis of onground ecosystem similarities as discussed in section 4. The discussion and development of management improvement systems is beyond the scope of this review and project.

2.3. Stand parameters pertinent to regeneration success

2.3.1 Management objectives and silvicultural systems

Regeneration success must be defined in terms of objectives of forest management. These can be broadly grouped into production objectives (eg maximising volume production, sawlog production or financial return) and ecological objectives (eg conservation of biodiversity, soil and water resources). There are a number of stand parameters that are pertinent to both objectives but the standards of sustainability will vary between objectives. Natural systems provide a benchmark for most ecological objectives, but wood production objectives may require more explicit regeneration standards. Silvicultural systems are applied to forests in order to meet the objectives of management. The success of the system, as indicated by stand parameters, largely depends on the ecological response of the forest type.

2.3.2 Regeneration ecology and silviculture

The identification of stand parameters pertinent to regeneration success requires an understanding of regeneration and early stand development in major ecological types and how silvicultural systems applied in these forests influence those processes. As background to the detailed discussion by forest types in Section 2.4, some general regeneration ecology and silvicultural principles will now be introduced.

The important components of a regeneration system can be classified as seed supply (or plants), seedbed and retained vegetation. There are two main methods of seed supply in native forests: seedfall from retained trees or direct sowing of seed collected from fallen or standing trees. The use of seedfall from retained trees (or seedtrees) has the advantage of providing a lot of seed at minimal cost and conserves the genetic resources of the regenerating tree species on the site. Direct seeding is often carried out at a much lower rate (generally expressed in terms of no. viable seeds per ha or kg of bulk seed per ha) than that supplied from retained trees. Direct seeding is often used in silvicultural systems employing clearfelling where there is insufficient seed supply from retained trees to regenerate the site. Planting may be used in these systems where there are insufficient stores of seed for direct sowing. Vegetative reproduction from cut stumps (coppice), lignotubers or other vegetative structures is also common in some forest types.

The seedbed refers to the soil surface and immediate below ground soil conditions that effect germination, survival and early growth of seedlings. Disturbance (by fire or mechanical means) is necessary in many forest types to achieve germination and establishment of seedlings. In eucalypt forests, when a favourable seedbed exists, there is typically profuse germination of seed at the first occurrence of favourable weather conditions after seed supply. This is important because eucalypt seed is generally short-lived once it is in contact with the soil and will not survive more than two growing seasons (ie 1 year) after sowing or seedfall. The timing of germination is generally predictable from seasonal weather patterns. Survival (often expressed as a percentage of the quantity of supplied seed or seedling percent) and growth are dependent on seedbed quality, including the organic matter, microorganisms and nutrient content and porosity of the soil and coverage or shading by vegetative material.

Competition of two main types, overstorey or understorey, affects the survival and early growth of seedlings, either regenerated from seed, planted or vegetatively reproduced. The degree of overstorey competition is directly related to harvesting intensity or level of retained vegetation, but the effect on growth and survival varies between forest type and species. The influence of understorey is related to the degree of disturbance and the initial seedbed quality, although the longevity of disturbance effects and the rate of development of understorey competition differs between forest types. Thus both seedbed/ understorey competition and retained overwood/ overstorey competition are an integral part of the silvicultural system being used, but the effect of those systems varies with forest type.

The study of regeneration ecology and silvicultural systems has resulted in the identification of some fundamental measures of the inputs and outputs of the regeneration processes. In this project we are concerned with monitoring the output of the regeneration process, which includes the quantity of seedlings and their potential to survive and grow. Potential measures are discussed in the following paragraphs.

2.3.3 Site occupancy

Site occupancy is the degree to which trees use the available space on a particular site. The concept of site occupancy is pertinent to regeneration success for a number of reasons. From the ecological perspective, sufficient abundance of regeneration of particular species or life forms of plants are necessary to ensure that there is a viable vegetation community which forms an integral part of a healthy ecosystem. From the timber production perspective there needs to be sufficient trees to fully utilise the soil and water resources on the site.

Stocked quadrat

Site occupancy is generally assessed as stocking, the frequency or percentage of a sample of the site area that contains acceptable regeneration. It incorporates the concept of a requirement for a minimum density of desirable trees dispersed across an area being assesssed for regeneration. In its simplest form it includes only acceptable seedlings within a sample of fixed size plots dispersed across an area of even-aged regeneration. Experience indicates that this measure of site occupancy is sensitive to the range of factors affecting initial establishment. In some forest types where regeneration is unreliable, the range in stocking is centred around a lower value than in more reliably regenerated forests. Thus from the point of view of whether there is an initial supply of growing plants for stand development this approach may be adequate. However there is potential to determine the degree of competition within the occupied sites, by determining the seedling density at each point sampled for stocking. Thus in addition to estimating stocking , an estimate of seedling density is useful. In uneven-aged stands the survey may include an estimate of site occupancy based on the basal area of mature or advanced regrowth trees obtained from a basal area sweep from the sampling point.

Successful seedlings

One of the major issues with the stocked quadrat measure of regeneration is that precision is limited by the definition of what is an acceptable seedling or tree. In most drier forest types there are a number of growth forms of eucalypts which may not be acceptable because their growth potential is limited. For example, coppice may be unacceptable because it is easily dislodged from stumps in windy conditions or new seedlings may be unacceptable because they need to enter a lignotuberous stage before they have potential to grow to maturity. Similarly in wet forests, seedlings that occupy a poor competitive position, which have little potential of reaching maturity, may be considered unacceptable. It is apparent that doubt over what is acceptable will diminish with time, as self-thinning progresses and height growth performance is expressed, and growth/survival potential becomes more obvious. Thus the timing of assessment will affect the definition of what is acceptable stocking, and delaying assessment for as long as possible would be advantageous, although there are a number of operational disadvantages of delaying assessment. There is a need for the development of an acceptable seedling definition that can be reliably related to a particular stand condition at a later stage. The simplest definition would include all seedlings, but there is a large range in survival potential at the seedling, clump within stand and stand levels, which limits the reliability of prediction. The *successful seedling* concept, the seedling that will survive to sapling stage (Maas 1991), may be a useful one to pursue.

Seedling density

Seedling density or the number of seedlings in a given area (no/ha usually) is an important measure as it is often included as a variable in stand based growth models. It is also a commonly measured variable in regeneration studies, and the basis of current standards of regeneration success. As discussed above, current stocking standards are based on the requirement for a minimum density of evenly spaced trees, but the stocking assessment in its simplest form does not give an estimate of mean density. Generally growth models do not account for variability in stands at the regeneration age, but begin at the pole stage - eg greater than 15 years. However utility of growth models would be greatly increased if effects of initial stand density were incorporated. Seedling density is a dynamic measure of regeneration success varying with age, forest type and silvicultural treatment. Eucalypts are generally less shade-tolerant than most other genera, but there is a large variation between species. Wet sclerophyll species generally have low tolerance of competition, which lead to self-thinning, rapid early growth of dominant individuals and small branches and good wood quality under a range of stand densities. Some dry sclerophyll species exhibit similar qualities, but other species are relatively more tolerant and develop good quality wood under competition from more vigorous species, but growth stagnation may occur in the absence of self-thinning.

In stands regenerated from seed, the seedling distribution is characteristically aggregated, and the resulting spatial variation in density is likely to have an influence on site occupancy and self-thinning rate. There may be areas of seedling density lower than that required for maintenance of site productivity and good seedling form. Thus a major issue is that seedling density is difficult to interpret as a measure in aggregated stands, where average stand density could be misleading from the effect on stand growth and wood quality. Aggregation also presents problems for some methods of determining density, eg methods based on the nearest plant to a sampling point may be biased. Also aggregation presents difficulty with translating density estimates to stocking or vice versa. For a random distribution of seedlings there is a statistically determined relationship between seedling density and stocking. However for aggregated regeneration the relationship varies with the degree of aggregation. This issue is discussed further in the section, Evaluation of current methods-scientific validity.

2.3.4 Species composition

Although species composition is important for wood production, the methods for measuring species composition have been developed by community ecologists. Ecologically sustainable management is concerned with maintenance of ecological communities, particularly the species abundances. Thus a large facet of statistical ecology is concerned with measuring and detecting patterns of species abundances (Ludwig and Reynolds 1988). Species abundances are usually based on individuals per species, but other variables such as biomass and percent cover may be as important. Abundance data are generally arranged in the form of a species abundance distribution, a frequency distribution of the number of species containing X= 1, 2, 3,.... R individuals. A number of statistical models have been developed for fitting such data in the hope of finding a general model that would only require the estimation of a few, easily calculated parameters. Diversity indices are an alternative way of describing species abundance relationships in communities. Diversity indices are either concerned with species richness (total no. species in a community) or with a combination of species richness and evenness (ie the relative abundances of the species). There are three levels of diversity of interest to ecologists: (a) within habitat diversity; (b) between habitat diversity-changes along environmental gradients and (3) large-scale landscape diversity (a combination of a and b).

A considerable amount of ecological study is devoted to the affinities of coexisting species; ie how do coexisting species utilise common resources. Interspecific association is concerned with how often two species are found together in the same location and is it more or less than what would be expected if they were independent. Interspecific association is based solely on presence or absence, whilst interspecific covariation is based on quantitative measures of abundance; ie do species abundances together change more or less than if they were independent. More complex analysis of species data are aimed at community interpretation using community classification and ordination methods.

The aim of community ecology is generally the desire to discover and describe patterns (ie pattern detection methods) rather than testing *a priori* hypothesis. Possible goals include estimating overall species composition within an area, correlating species properties with environmental factors, and studying temporal and spatial variability in species pattern. In contrast in the case of regeneration monitoring our main goal is *a priori* hypothesis testing: Has the species composition changed too much as a result of timber harvesting? Species composition is what ecologists might refer to as species diversity (the relative abundances of species) at the landscape level, which includes within and between habitat diversity. For convenience, coupe scale monitoring may be able to ignore the between habitat scale (or environmental gradients) and treat it as a within habitat assessment of relative abundance of species.

Species composition could be expressed in a number of ways; eg seedling density by species, percentage composition by species, presence or absence or by species groupings.

Evaluation of species composition data poses a challenge at present. Species occurrences generally respond to environmental gradients in the long term, but species composition may be changed in the establishment phase by operational factors such as the sowing mixture, seed tree selection or site preparation that favours particular regeneration sources (eg advanced growth). At present there is insufficient knowledge of the successional patterns in eucalypt forests to determine the long term effects of these changes. However one may generalise that the broad ecological vegetation community (EVC) is rarely changed during harvesting and regeneration, with key species represented in the regenerating stand. The main exception is when sites are replanted with faster growing, preferred species that are not native to the site. In forests where there are distinct changes in the vegetation community across a harvesting area, there is a clear case for stratification of the site for the regeneration survey, rather than detecting changes along an environmental gradient. Species composition and other parameters could be very different between such strata (eg dry *E. sieberi* dominated forest on ridges grading into wet *E. obliqua* forest in gullies).

2.3.5 Growth

Changes in site productivity may be detected through measurement of growth, whereas not by stocking or seedling density, which are dominated by seed supply factors. Silvicultural and physical factors determine at what age growth can be relied on to represent long-term productivity. Disturbance during harvesting and site preparation have the potential to affect growth positively or negatively. Short term growth responses to burning have been reported due to soil chemical and biological factors; these may be insignificant over a single rotation but over several rotations loss of nutrients may be significant (Campbell *et al* 1984). Of more significance in the medium term may be the changes in soil physical properties associated with harvesting and mechanical site preparation which may reduce long term productivity. These include loss of topsoil and exposure of subsoil and compaction. Damaged soil may take in excess of 25 years to recover (Jakobsen 1983) and there may be a long term loss of site productivity if this type of disturbance is widespread. The changes are important from both the ecological and timber production objectives. The relationship between soil damage and long-term productivity has been explicitly recognised in Montreal Process indicators 4(d) (area and percent of forest land with significantly diminished soil organic matter and/or changes in other soil chemical properties) and 4(e) (area and percent of forest land with significant compaction or change in soil physical properties).

Height- at an early age height growth responds to varying silviculture treatments and site differences; but this can be confounded by microsite (eg ashbed effects), animal browsing and adverse climatic events. This may be addressed by delaying assessment. Height vs age relationships have not been developed for the early stand development stage, but they are becoming a priority in regions where intensive stand management is being applied in order to identify the better quality stands for treatment (Forestry Tasmania 1998). Height indices are generally based on a few dominants, a measure which is independent of stand density over a large range of stand densities. In mature stands the initial differences in height with stand treatments may be insignificant and thus of little ecological importance.

Diameter- dbhob (diameter at breast height, ie 1.3 m above ground level, over bark is the standard for later age measurements. At the regeneration stage diameter at ground level has been used and found to be sensitive to site factors. Diameter is very sensitive to stand density and spatial distribution with differences between inter- and intra-species competition being shown.

Basal area- is a common index of stand productivity in even-aged regrowth stands and a reference for management of uneven-aged forest. Basal area at a given age tends to be constant over a range of seedling densities, with growth being concentrated on fewer stems in stands with lower seedling density. Basal area growth in eucalypt forest is rapid during the sapling to pole stage then reduces to zero in overmature stands, most growth occurring in 10-40 year old stands, total basal area plateauing during this period. This parameter is not very sensitive to different spatial distributions. In an uneven-aged stand basal area is reduced intermittently to create growth; with a minimum basal area of productive trees required to ensure that a site is "occupied".

Volume- is a function of basal area and height, with individual tree diameter having a large effect on merchantable volume. Seedling volume calculated from the diameter at ground level and seedling height can be a useful measure of early responses to silvicultural treatment, provided it is not confounded by browsing or abnormal climatic effects. Total volume of eucalypt bole wood or of all biomass components is a potential indicator of site productivity.

Diameter, basal area and volume are generally not included in regeneration assessments as they vary greatly between individuals across the regeneration area in the early stage of stand development. From approximately 5 years of age they could become useful parameters.

Tree quality- stem characteristics such as branching (apical dominance), straightness and damage due to animal or mechanical causes are important for wood production, because they influence the amount of wood decay and appearance of wood products. Perhaps habitat potential is also related to stem characteristics at an early age. Branching is sensitive to spatial distribution, seedling density and species composition of competitors. Potential indicators of tree quality are green height relative to stand height, height/diameter ratio, form factor (volume/height) and green branch diameter, there being significant correlations between these indicators. There are important differences between evenly spaced plantations and aggregated natural regeneration and the regeneration standards based on the requirement for a minimum density of well-spaced trees may not adequately address tree quality. For example in plantations grown at the minimum standard of equivalent to 400 evenly spaced trees in Victoria (see Table 2.2) stem quality is likely to be poor. In aggregated naturally regenerated stands with the minimum stocking standard there may be sufficient trees in clumps to maintain stem quality, but in the lower density areas, stem quality may be poor. Stem quality problems usually develop beyond the age of regeneration survey and the ability to predict tree quality problems need to be based on indicators such as local density and damaging agencies such as logs in close proximity to seedlings or animal browsing.

Tree quality also refers to general tree health. It is common for seedlings to suffer from intra or inter-specific competition, and a variety of pathogens and environmental factors can adversely affect seedling health. In contrast to stem quality factors these problems arise at the usual time of regeneration surveys and it is possible to predict some of those seedlings which will die in the short term.

2.4. Regeneration ecology and silviculture of major forest types

Australian commercial forests may be broadly grouped on the basis of the overall productivity, generally expressed by the degree of canopy closure and height of the dominant tree stratum. Further sub-classification is often on the basis of major physiognomic and associated dominant species groups with similar ecological attributes. Still further sub-classification is on the basis of distinct vegetation types associated with local variation in environmental factors. There would be considerable efficiency in using a measure of regeneration success that could be applied to all forests regardless of classification. However there is much diversity amongst Australian forests and it is likely that a number of different measures will be needed to cover this diversity, and the level at which forests are differentiated needs to be determined. The following discussion of the variation in regeneration processes with forest types is based on the classification into rainforest, wet sclerophyll and dry sclerophyll forests and woodlands. The national forest inventory uses forest types that are broader than this, being based on height (eg tall is greater than 30m, medium is 10-30m), canopy closure (eg closed >70%, open 30-70%) and genus of the dominant stratum (eg Eucalypt, Callitris). Rainforest generally falls into the closed forest, wet sclerophyll into tall, open eucalypt forest but dry sclerophyll forest and woodland could be tall or medium open forest.

The discussion includes the variation in processes in natural and managed stands, including the effects of seedbed and overstorey density, from a quantitative and qualitative perspective. Some of the seedbed and overstorey conditions presented are the result of research into alternative systems to those routinely applied. These situations are considered, because silvicultural systems are evolving in response to changing socio-economic demands, and measures of regeneration success need to be flexible enough to cover the range of silvicultural systems that may be applied. The discussion relates quantitative information about inputs and outputs of the regeneration process to silvicultural practices and standards (quantitative and qualitative) of regeneration success in those forest types. The implications for selection of a standard set of measures, including timing of measurement, are pointed out.

2.4.1 Wet Sclerophyll forest

The major forest types in this group include the following:
- *E. regnans* forests of southern Victoria
- Lowland wet eucalypt forests of Tasmania dominated by *E. obliqua* and *E. regnans*
- *E. delegatensis* forests of south-eastern Australia (*E. delegatensis* also dominates some drier forests of Tasmania)
- *E. grandis* forests of the north coast of NSW and south-eastern Queensland
- *E. diversicolor* forests of south-western Western Australia
- Tall moist coastal hardwoods of New South Wales and Queensland
- High elevation mixed species forests of eastern Victoria.
- Tablelands moist hardwoods of New South Wales.

The dominant eucalypt species in these forests are generally intolerant of competition, have strong apical dominance and are non-lignotuberous. Typically these forests have dense mesic understoreys and well-developed litter layers which make it difficult for regeneration to develop without substantial disturbance. Fire frequency tends to be low, but intensity of these infrequent fires is usually high because they are only able to burn under extreme weather conditions when the mesic understorey will burn. These forests tend to be floristically simple, at least with respect to the dominant tree species.

Ecological groups, management objectives and silvicultural systems

An ecological grouping of tall open forests may be made on the basis of fire tolerance of mature trees and stand response to wildfire. This grouping is useful because it is generally indicative of objectives and silviculture which may be successfully applied in managed stands.

In *E. regnans*, *E. delegatensis*, *E. grandis* forest types, natural stands are usually even-aged, primarily because the type of disturbance that produces regeneration, intense wildfire, kills the fire sensitive mature trees. The result of the fire is a large wave of regeneration (Florence 1996), as a result of fire induced seedfall (several million seeds per ha) and prolific germination (100 000s per ha) within 6 months. The profuse germinants are subjected to high early mortality as a result of frost, fungal activity, animal browsing and intense competition of fire induced regeneration of non-eucalypt vegetation. It is of great significance that the eucalypt genus, particularly the species in the wet forests, have rapid juvenile height growth, with maximum annual growth rate occurring as early as 5-10 years of age. Under relatively open stand conditions, on growth-stimulating ash-beds, eucalypts generally achieve dominance in a few years. The developing stand will experience intense intra-species competition, strong expression of dominance of a number of individuals and self-thinning.

These forests are typically managed for a range of objectives through the maintenance of even-aged stands of a range of age classes. This is achieved through the manipulation of rotation length and reservation of some old-growth stands. They are harvested using a clearfelling, followed by slash-burning or mechanical disturbance with artificial sowing or planting system. The result is a large wave of regeneration, as described for the wildfire killed stand, but usually at an initial lower seedling density than in natural stands.

Most of the other species in wet forests are moderately fire resistant and can survive low to moderate intensity fire, as indicated by naturally occurring multi-aged stands with older trees showing the scars of previous fires. Thus a larger range of silvicultural systems may be applied on an ecological basis in the managed forest. However there is a tendency to use methods developed for the less fire resistant species in the southern forests (eg *E. obliqua* dominated forests of Tasmania, high elevation mixed species of eastern Victoria, *E. diversicolor* forests of south-western WA), primarily in order to reduce understorey competition and thus increase the reliability of regeneration. In the moist coastal and tableland types of New South Wales and south-eastern Queensland the management objective is to maintain a more complex stand structure throughout the landscape and thus selection systems are routinely applied.

Firstly, the regeneration and early stand development processes will be covered in detail for *E. regnans* because it has been the most intensively studied forest type. The discussion of *E. regnans* will include details of other species of the wet forests of south-eastern Australia occurring at low elevations (less than 600m) (ie *E. obliqua* and *E. delegatensis*). This is desirable because studies of regeneration in Tasmania have treated this group of species as a single forest type, Wet Lowland Sclerophyll forest (Forestry Tasmania 1998). Other wet sclerophyll forests will be covered briefly and separately in the following paragraphs.

Wet forests – E. regnans, E. delegatensis and E. obliqua

Effect of seedbed on seedling establishment

Ashton (1956) studied regeneration and stand development of *E. regnans* in mature forest and regrowth regenerated by wildfire. He reported that regeneration does not develop on undisturbed seedbeds, but regeneration can occur on burnt or disturbed seedbeds under a mature canopy. Ashton (1976) reported initial stand densities of 500 000 to 4 500 000 seedlings per hectare in wildfire regenerated stands. These seedling densities are much higher than reported for managed stands, which is probably a result of the greater seed supply in wildfire regenerated stands.

Gilbert (1958), Cunningham (1960) and Grose (1960) reported acceptable regeneration on bare soil created through logging disturbance in Lowland Wet Eucalypt, *E. regnans* and *E. delegatensis* forests respectively. Gilbert reported unacceptable survival on low intensity burnt seedbeds. The benefits of an intense, broadcast burn for establishment and early growth were recognised in the 1960s in Victoria and Tasmania where it became standard practice. Campbell and Bray (1987) reported a trial in *E. regnans* forest of the Central Highlands of Victoria comparing regeneration after a range of site preparation methods, including high intensity and low intensity slash-burning and mechanical disturbance, closely followed by seeding during autumn. Germination occurred in the autumn and there was very heavy mortality during the first winter. By age 3 approximately 4 % of applied seed survived across all treatments, the main treatment effect being the faster growth and competitive position of seedlings on the high intensity burnt seedbeds. At usual artificial sowing rates of 150 000 seeds per ha in Victoria this would give an acceptable seedling density.

Grose (1960) studied the regeneration of *E. delegatensis* in north-eastern Victoria and found that germination generally occurs in the spring after disturbance, seed requiring stratification over winter before germination. Grose (1961) obtained seedling percents at 12 months of 0.6% to 1.8% on bare soil and 1.1% to 3.1% on ash beds (seedling density of 1 375 to 3 875 seedlings per ha with the recommended artificial sowing rate of 125 000 seeds per ha). Seedlings suppressed by grass competition rarely survived their first winter, succumbing to snow injury. As in *E. regnans* height growth was faster on intensively burnt seed beds; at 12 months average seedling height varied from 18cm in grass, 30cm on bare soil, to 1.2m on ashbed and at 2.5 years from 25cm in grass, 40cm on bare soil to 2.4m on ash bed.

In Victoria during the period 1989-1993, routine treatment (clearfelling followed by burning or mechanical site preparation and artificial sowing) resulted in 7.5 % of the area of *E. regnans* and *E. delegatensis* surveyed with a stocking by 16 m^2 plots of less than 50% (the acceptable standard regardless of distribution) at age 1-3 years (Murphy and Fagg 1996).

There have been a number of studies of the variation in stocking estimates over time in wet eucalypt forest. Mount (1964) reported the variation in frequencies of stocked permanent milacre plots in the Styx and Florentine Valleys of Tasmania. The surveyed areas included tractor and high-lead logging and burnt and unburnt site preparation. Milacre (4 m^2) stocking (all treatments combined) steadily increased from 9.0% at 1 year after treatment to 12.4% at 5 years after treatment. The low values reported (compared to a standard of 30%) indicate the effect of low intensity burning or no site preparation on seedling density, which were common practice up until that time. Wehner (1984) reported the variation in estimates of stocking (16 m^2) with time on slash-burnt coupes, artificially sown or with seed tree retention. Frequency of stocked plots increased from 1 year to 2 and 3 years, but was not significantly different at 4 and 10 years after site preparation. The mean number of stems per plot decreased from 17.4 (10 875 seedlings per ha compared to the standard of 2500 seedlings per ha for aggregated distributions) at age 2 to 2.2 (1 375 seedlings per ha) at age 10. The stocked quadrat results in both studies were inconsistent with an expectation of decreasing stocking as a result of mortality with little recruitment. The following reasons were suggested for the anomalous changes in stocking over time: operational error (missed seedlings), limitations in the stocked quadrat method (eg definition of an acceptable seedling), increase due to natural, biological factors. Subsequent studies indicate that the latter reason is unlikely because of the rapid loss of seedbed and the apparent increase is due to operational or methodology problems.

It is apparent from the research and operational results that acceptable initial seedling densities can be reliably achieved on intensely burnt and mechanically disturbed seedbeds, but the actual density will vary with quantity of seed supply. It is most probable that where regeneration is the aim of management, slash burning and mechanical disturbance will continue to be used. It is apparent that the wet eucalypt forests of south-eastern Australia have a tightly controlled regeneration cycle under such silvicultural practices, which makes it possible to predict the timing of germination and schedule regeneration surveys. *E. delegatensis* in Victoria germinates approximately 6 months later and early growth is slower, particularly on bare soil, which indicates that regeneration surveys should be carried out later than for *E. regnans*.

The apparent increase in stocking over time on routinely prepared seedbeds is an issue that needs to be addressed in this project because the timing of surveys differs between states.

Effect of retained overwood on seedling establishment

In the Central Highlands of Victoria, Dignan *et al* (1995) studied regeneration under a range of overwood densities on mechanically disturbed seedbeds. Germination commenced in the autumn following harvesting, but peaked in the following spring. On coupes with an ongoing seed source there was a further small peak in the second autumn, after which time little germination occurred probably because of shading from established vegetation. The proportion of applied seed that germinated and survived to 15 months varied greatly between the 2 years of the study (13.7% compared to 4.4%), but seedling percent and density did not vary greatly with level of retained overwood. The major contribution to stand composition, regardless of treatment, was germination from the first spring which had a 15-30% probability of achieving dominance/codominance by age three. On burnt seedbeds most regeneration occurred in the first autumn, and by the first spring seedbeds had low receptivity as a result of fire induced recolonisation. In the 30%, 50% retained overwood and clearfelling treatments seedling density at age 3 were similar (approximately 25 000 seedlings, 6 000 co/dominant seedlings per ha). Under 100% overwood the density of seedlings at age 3 was unacceptably low. This result contrasts with that found by Ashton and Willis (1982) who reported that under a mature canopy seedlings developed on disturbed soil to approximately 5 years.

In the same trial (Dignan *et al* 1995) regeneration was studied over a range of gaps, from 10 m x 10 m to 140 m x 140 m, the smaller gaps prepared after harvesting by mechanical disturbance and larger gaps by mechanical disturbance or slash-burning. Seedling densities increased with increasing gap size at age 1, but did not differ significantly with site preparation. In the smallest gaps there were no co/dominant seedlings at age 1. At age 3 seedling density varied from 20 to 70% of seedling density at age one and the number of co/dominants had increased in all treatments. The co/dominants at age 3 varied from approximately 2 m to 5 m in height and 10 mm to 40 mm dbhob respectively, tree size being greater in the larger gaps and on burnt coupes. It should be noted that all treatments in this experiment (including the clearfelling) received seed equivalent to approximately twice the recommended artificial sowing rate.

The research indicates that seedlings can become established under dense overwood or in small gaps, and even in unharvested stands, provided that there is disturbance. However subsequent monitoring of growth indicated that in unharvested stands on disturbed soil, seedlings stagnated and were replaced by understorey species by 10 years. On areas disturbed by a surface fire, regeneration developed slowly but persisted and grew to heights of 10-20m after 30-40 years (Ashton and Willis 1982). This result is consistent with retrospective data, that indicates that low to moderate intensity fire can create openings in the overstorey that allows regeneration to develop sufficiently to attain dominance and dual and multi-aged stands to develop (McCarthy and Lindemeyer 1998). Thus it is apparent that a range of retained overwood density and gap treatments may be implemented with the expectation of obtaining regeneration and measures may need to be flexible enough to be applied under these circumstances. The results also indicate that by the age of 3 years it may be possible to differentiate long term growth between silvicultural systems through measurement of height and/or diameter. This is particularly relevant where wood production is a major objective of management, because system productivity can not be differentiated on the basis of the quantity of established seedlings. The research also indicates that even as late as age 3 there is a danger with assessing regeneration too early in some silvicultural systems, particularly in the absence of fire, because apparently successful treatments may fail during the sapling stage due to excessive overwood competition. There needs to be flexibility in timing of surveys to accommodate differences in stand dynamics between silvicultural systems.

Species composition in Lowland Wet Eucalypt Forest

Neyland (2000) studied the performance of mixed *E.delegatensis / E.obliqua* seed artificially sown onto a clearfallen coupe after slashburning. The coupe straddled the *E. delegatensis / E. obliqua* ecotone at 300-500 m asl. He found that at 21 months after sowing species composition of the seedlings closely matched the species composition of the seed across the ecotone. At 33 months after sowing (Neyland and Dingle 2001) found that the species composition had not changed. They also found that over the 12 months since the last assessment seedling density had decreased on most plots but increased on others.

Sapling to pole stage

Van der Meer (1998) reported growth to year 8 in the same trial reported by Dignan *et al* (1995). Sapling density varied from 350 to 9 400 seedlings per ha, and 95 to 2 338 co/dominants per ha, density increasing with gap size but there was no clear trend with retained overwood treatments. Co/dominants varied from 7.4 to 16.4m in height and 46-100mm dbhob respectively, the tallest and fattest occurring on the clearfelling treatment. Thus by year 8 there was some indication of low seedling density and the possibility of failure in small gaps and there was a definite difference in growth rate between treatments that supported the indications at age 1 and 3. This is significant because it suggests that seedling density and growth measures at age 1 to 3 are indicative of long term regeneration success.

In the same trial sapling quality (height/diameter ratio, length of clear bole) was not significantly affected by treatment. Van der Meer (1998) also reported on the quality of seedlings in clearfelled stands with varying seedling densities at age 4. He found that an increased density of competing seedlings (regardless of their species) resulted in dominants with a relatively longer free bole, narrower crown, more slender and with less taper. Under low competition indices stem volume growth increased under increasing eucalypt competition but decreased under increasing wattle competition. Under high competition indices increasing eucalypt competition led to decreased volume growth. Similarly, Marks *et al* (1986) reported the effects of spacing on crown development in *E. regnans* planted at densities varying from 120 to 6 720 seedlings per ha. The ratio of tree height /crown depth increased with seedling density and with age up until 15 years after which it remained relatively constant. Green branch diameter increased with decreasing seedling density and increasing crown depth. The probability of successful branch occlusion decreased with increasing branch diameter. Hamilton (1984) using a number of stand maps of regeneration aged 4 and 30 years, reported that the spatial distribution of regeneration was initially aggregated in *E. regnans* forest, but there was variation in the degree of clumping and seedling density between stands. The process of self-thinning was more intense in the denser clumps, which tended to create a more random spatial distribution and reduce the variation in stand density with age.

Wardlaw et al (1997) studied the incidence of decay in *E.obliqua*, *E. regnans* and *E. delegatensis* regrowth aged from 22 to 54 years in the Lowland Wet Eucalypt forest of Tasmania. They found that up to 15 and 29% of potential sawlog volume was downgraded due to decay in the butt and head logs respectively. At the stand level the number and diameter of live branches and the diameter of dead branches were correlated with the amount of decay. The branching characteristics associated with decay were correlated with local density. Local density below 1000 stems per ha produced 35% and 40 % more decay than local density of 1000 to 1500 stems per ha and local density greater than 1500 stems per ha respectively.

Ashton (1976) described the stand development of fire regrowth: initial stand densities of 500 000 to 4 500 000 seedlings per hectare self-thinned to 17 000 seedlings per ha at age 8 years , 2000 trees per ha at 20 years to 400 trees per ha at 40 years, and 125 trees per ha at 80 years. Early growth is rapid and by age 40 stands have reached maximum basal area and half their ultimate height. Hickey (1993) studied the structure of even-aged regrowth stands, resulting from both wildfire and harvesting. The stands were in mixed eucalypt/ rainforest, some of which were dominated by *E. regnans*, and varied in age from 19 years to 30 years. He found that there was a tendency to higher density and lower mean dbhob of *E. regnans* in wildfire regeneration compared to logging regrowth density, but for all species combined there was little difference in density, diameter or height growth between regeneration from logging and wildfire.

Thus the research on stand development during the sapling and pole stages indicates that there could be large differences in initial seedling density and spatial distribution between stands, but density and stand structure may be similar by rotation age. However the path by which the stand reaches this point may be significant from the point of view of wood quality. The aggregated distribution of seedlings could result in under-stocking and excessive branching in some parts of stands with acceptable average seedling density. Regeneration from wildfire or harvesting with high initial seedling density would avoid these problems, but at the expense of volume growth. The relationship established between initial seedling density, spatial distribution and wood quality and utilisable volume demonstrate the importance of these as measures of regeneration success. Another important consideration is the effect of intial seedling density and spatial distribution on competition and self-thinning and subsequent effects on genetic diversity and understorey composition. There is little information available about these relationships, but a monitoring program could be used to establish these relationships.

E. grandis

Floyd (1960) studied the regeneration of *E. grandis* forests on the north coast of New South Wales. Techniques developed for regeneration of even aged stands of *E.grandis* in the sub-tropics typically involve clearfelling, slash-burning in early summer, and direct seeding after summer rains in February. The rapid early height growth (2m at 12 months, 6m at 2 years) of *E. grandis* enables it to outcompete vigorous fire successional species. However it was found that sowing rates needed to give adequate regeneration across the range of seedbeds produced very dense regeneration on more receptive seedbeds. As a result direct seeding was discontinued on high quality sites about 1970 and since then have been planted at rates as low as 625 seedlings per ha (NSWFC). At such wide spacing, where woody weed competition has been low, problems with excessively heavy branching and poor wood quality have been reported. Typically seedling density declines much slower under self-thinning in planted stands, with minimal mortality occurring over the first 10 years.

The more even distribution, wider spacing and lower mortality of planted seedlings than in forest regenerated from seed pose a different statistical scenario for measurement and evaluation of regeneration success in planted *E. grandis* forest. The effect needs to be considered in this project.

Moist Coastal Hardwoods

The moist coastal hardwood forests of NSW (wet sclerophyll forest with an overstorey of *E. microcorys*, *E. saligna* and *Lophostemon confertus*) can be the most difficult in the sub-tropical zone to regenerate, because of the dense rainforest understorey and slow growth of some important species in their regrowth stage. Harvesting typically removes about 50% of the overwood, the retained stems being mainly defective trees. Although site preparation by fire gives superior results, slash-burns are difficult to achieve because of weather conditions and mechanical disturbance by extending snig tracks is often carried out. Van Loon (1966) reported seedling percents of 0.6 to 0.9% for untreated seeds and stocking of $4m^2$ plots at 6 months of 40% on burnt sites and 33% on tractor-cleared sites. Stocking increased to 46% at 1.5 years then decreased to 39% at 2.5 years, whereas it decreased steadily to 31% at 2.5 years on burnt sites. Height growth to 2.5 years was 1.4m on burnt sites and 0.7m on tractor-cleared sites. King (1985) retrospectively studied the regeneration in this forest type in the hinterland of the north coast of New South Wales. He reported that seedling density and percentage of 0.01ha plots stocked was greater on sites that were burnt following logging, and that there was a greater occurrence of *E. saligna* on these sites. He also found that stocking of competitive eucalypts and *Lophostemon* decreased with increasing overwood density. In this study that included stands logged from 3 to 26 years ago there was not a clear trend in stand density or percentage of stocked plots with time since logging. Data from a number of sources (NSWFC) indicate that early height growth varies between species (*E. saligna* 0.8m at 1 year, 3.4 m at 3 years compared to *E. microcorys* 0.3m at 1 year, 1.6m at 3 years). King's report raises some questions about what is sufficient stocking in these forest types. Regeneration success is based on percentage of 0.01 ha plots stocked, which implies that a density of 100 trees per ha would be acceptable, from as early as age 3. In fact the report implies that if 40 to 65 trees per ha showed promise of achieving dominance, then it would be acceptable because it would be capable of attaining the characteristics of the mature forest before harvesting. This standard would appear to be very low, considering that natural mortality is likely to occur, wood quality is likely to be poor at such wide spacing and it clearly ignores the prospect of optimising wood production in this forest type.

It is apparent from the research of Van Loon (1966) that acceptable stocking (>30% of $4m^2$ plots which is approximately equivalent to >65% of $16m^2$ plots stocked or seedling density of approximately 2500 seedlings per ha in an aggregated stand (Mount 1964, Squire 1991)) can occur in this forest type with site disturbance by fire or mechanical means. Routine results could produce much lower site occupancy , which may be considered to be adequate from an ecological point of view, if not from a timber production view. Differences in evaluation standards do not pose a problem for application of a common regeneration survey method, but standardised reporting of success needs to be able to distinguish between different objectives of management, which is an important consideration in this project. The study results also indicate that early growth may be slower in this forest type than in some of the other wet forest types which indicates that surveys may need to be carried out later. Species composition also poses a challenge for measurement of regeneration success, particularly because there is a difference in growth rate between species which will increase the difficulty of interpretation of results.

High Elevation Mixed Species and Tablelands Moist Hardwoods

In Victoria the High Elevation Mixed Species forest (HEMS) type generally occurs in the eastern highlands and extends over the border into south-eastern NSW where they are referred to as Moist Tablelands forest. The species include representatives from the damper lower elevation forests (eg *E. obliqua*, *E. viminalis*, *E. dives*, *E. fastigata* and *E. nitens*), where they regenerate reliably, but at higher elevation regeneration is often unsatisfactory under the extremely cold weather conditions. In Victoria there is a distinct contrast between the unreliability of HEMS regeneration compared to the reliability of *E. delegatensis* which is specially adapted to the extreme conditions at high elevations. The High Elevation Mixed Species of Victoria are typically harvested in summer followed by an intense slash burn or mechanical disturbance in autumn, with seed supply from retained seed trees and supplementary sowing in winter. On warmer sites, at lower elevation germination occurs from the first autumn, whereas on colder sites germination is delayed to spring. Fagg (1981) reported seedling percents of 1.7% for burnt soil and 5.0% for disturbed bare soil up until 3 years after sowing and resultant variation in seedling density with the proportion of seedbed type. However Lutze *et al* (1999) reported seedling percents less than 1.0% at 15 months after sowing during two years of drought, resulting in marginally low seedling density and percentage of stocked plots at 15 months (920 seedlings per ha, 62% of $16m^2$ plots stocked) on areas without seed trees and receiving standard operational sowing rates, whereas on areas with seed trees acceptable seedling density and percentage of stocked plots was obtained (3 020 to 9 140 seedlings per ha, 96 to 100% of 16 m^2 plots stocked). In Victoria during the period 1989-1993 19% of coupes recorded stockings by 16 m^2 plots of less than 50% (Murphy and Fagg 1996). Early growth is typically slow with height to 15 months in the range 10 to 50 cm and approximately 1.5m at age 3 (Lutze et al 1999, Fagg 1981), often under intense competition from fire succession species, seasonal suppression by cold and browsing by animals. Featherston and Squire (1989) reported increases in apparent stocking from the first (about age 1) to second survey (about age 3), which was probably a result of poor ability to detect seedlings under the cover of competing vegetation at the time of the first survey. Often the decision about whether an area is successfully regenerated is delayed beyond 3 years after site preparation in order to allow eucalypts to emerge from the competing vegetation, but surveys are particularly difficult under these conditions.

In NSW there have been less problems obtaining regeneration in this forest type, presumably because of less understorey competition, although they may take several years to regenerate (NSWFC). As a result, silvicultural systems as diverse as selection and clearfelling have been used, with reliance on mechanical disturbance to create a seedbed. Thus there is great diversity of management objectives and silvicultural systems applied to this forest type which indicates that a number of different survey methods and evaluation standards may need to be applied. It is also evident that timing of surveys may need to be delayed for this forest type, regardless of the silviculture system used.

E. diversicolor

The *E. diversicolor* forests of south-western Australia are regenerated by seed tree retention or clearfelling followed by slash-burning in autumn. As good seed years are restricted to about 1 year in 5 the ability to use seed tree systems is limited and clearfelling followed by planting (at 2200 seedlings per ha) is often used. White (1974) reported on a study in a seed tree coupe which had the seed trees removed at nine months after burning, when seedling density was approximately 85 000 seedlings per ha. Subsequent height growth was rapid with an average of 1.5 m/yr in the following 3 years. This study coincided with a very large seed crop, and such high seedling densities are rarely encountered in these forests. Experimental data indicates that seedling density in seed tree areas is typically in the range of 16 000 to 45 000 seedlings per ha at 9 months after the regeneration burn, mostly a result of autumn germination (White 1971). The rate of self-thinning in *E. diversicolor* is considered to be slightly lower than for *E. regnans* and *E. delegatensis* but similar to *E. grandis* (Burrough et al 1978).

Bradshaw and Gorddard (1991) studied the effect of local density in even- aged regrowth stands less than 20 years of age. They found that the maximum length of clear bole was obtained where local density exceeded 3000 stems per ha. Assuming that mortality had been negligible since year 1, they recommended that optimal stocking at year 1 for high quality timber production is greater than 3000 stems per ha. When stands are regenerated by planting, it is not economic to plant at such a high density. They recommended planting at 2000 stems per ha, a compromise that would yield an acceptable quantity of pulp wood at first thinning age and length of clean bole in crop trees at rotation age.

Similar issues to those in *E. grandis* apply to *E.diversicolor* where planting is the major source of seedling regeneration. Timing of regeneration surveys could be similar to *E. regnans* and *E. grandis*, based on the rate of stand development.

Summary of regeneration and early stand development in wet forests

It is apparent from the intensive studies of regeneration in various wet forest types that there are differences in the management objectives and regeneration ecology and the silvicultural systems applied to accommodate those differences. These differences have the potential to affect the timing and method of regeneration survey. The main points of variation are as follows:

- site preparation is necessary to give a sufficient break from competition for germination to occur and ensure adequate survival. Germination is generally restricted to the period up to 12 months after site preparation, but there could be up to 6 months difference in germination time in southern, mountain forests. This is a result of a strongly seasonal germination pattern, germination peaking in autumn or spring (higher elevation forests in spring).

Damage from frost and snow can cause regeneration failure. Delay in germination and slow recovery from damage may warrant delaying regeneration surveys in higher mountain forests.

- the quantity of germination, survival and rate of growth vary significantly with site preparation method, particularly where disturbance is used instead of slash-burning. Perhaps the spatial distribution of seedlings also varies with site preparation. The aggregation of natural regeneration in wet eucalypt forests has only been described for a few stands prepared by slash-burning.
- high site quality warrants greater investment in establishment, and planting instead of direct sowing or using seed trees, provides more certainty of success and early growth advantages. Some forest agencies regenerate their wetter forests by planting. Planting tends to produce a uniform espacement of seedlings, as opposed to the aggregated distribution of natural regeneration.
- in stands naturally regenerated by wildfire, seedling density may be much higher than in logged stands, even higher than in stands with retained overwood, but rapid self-thinning should result in similar density by rotation age.
- the density of established seedlings / planting density has an effect on intra- and inter-species competition which effects tree form and wood quality and sawlog production rate. There may also be genetic effects produced by the variation in the processes of competition and genetic selection.
- the rapid development of competing vegetation is likely to impede detection of eucalypt regeneration in the early stages, then impede access for survey during later stages of stand development.
- browsing damage can cause regeneration failure or restrict early growth which may delay the optimal time for survey or warrant inclusion of special regeneration parameters.

However there are similarities in regeneration quantity and timing and early growth between some forest types which may be used to advantage in development of standardised regeneration measures. Ecological groups based on fire tolerance would be appropriate strata for reporting, with the exception of *E. diversicolor* which behaves similarly to the less fire tolerant group of *E. regnans*, *E. delegatensis* and *E. grandis*. Stratification at a higher level, such as wet sclerophyll or tall, open eucalypt forests may also be possible, provided that there is sufficient flexibility in timing and sampling method to accommodate differences in establishment rate and silvicultural systems.

2.4.2 Dry Sclerophyll Forests and Woodlands

The major forest types in this group are as follows:
E. sieberi dominated mixed species forests of south-eastern Australia
E. obliqua / peppermint forests of south-eastern Australia
E. pilularis forests of coastal NSW and Queensland
Dry high altitude forests of Tasmania
E. marginata forests of south-western Western Australia
E. maculata forests of coastal NSW and Queensland.
Dry coastal/inland hardwood forests of the eastern states (includes box/ironbark)
E. camaldulensis dominated riverine forests
Callitris glaucophylla woodlands
E. wandoo woodlands

Ecological groups, management objectives and silvicultural systems

The open forests typically have less dense, xeromorphic understorey and less litter accumulation than the tall, open forests. Wildfires and fuel hazard reduction burning are relatively frequent but of lower severity. The eucalypt species in these forests have medium to high resistance to fire and have evolved various regeneration strategies to deal with the high fire risk environment. Multi-aged stands are very common, although natural, even-aged stands also occur, after severe wildfire. Most species are lignotuberous, with a few notable exceptions (eg *E. sieberi* and *E. pilularis*). These forests tend to be more complex with respect to the various regeneration processes, which is confounded by the variation between species in these mixed species forests. However an ecological grouping of the open forests may be made on the basis of whether regeneration is most reliably obtained form seedlings established after harvesting or from existing growing stock such as lignotubers, advanced growth or coppice. The regeneration mechanism of the species tends to be correlated with their tolerance of competition and apical dominance.

E. sieberi, E. obliqua, E. pilularis and E. camaldulensis dominated forests and drier Tasmanian forest types regenerate reliably from seedlings established after harvesting. Typically these forests are harvested less intensively than the wetter forest types in the south eastern forests, with shelterwood and seed trees systems commonly applied. In the northern states there may be little difference in silviculture between the Moist Coastal or Moist Tablelands types and the *E. pilularis* dominated forest, group selection being commonly applied. In south-east Queensland this forest type is managed very conservatively, with frequent light thinnings and presumably clearfelling after a long rotation, if wood production is allowed to continue in this forest type. Disturbance and reduction of overstorey competition is necessary for successful regeneration from seedlings in these forest types, but seedling regeneration is often supplemented by advanced growth and coppice.

In contrast , lignotubers play a major role in regeneration of the *E. marginata* and the drier *E. maculata* dominated forests and box / ironbark forests. The pool of lignotuberous seedlings may develop over a number of years in the absence of any large disturbance, and serve as a source of regeneration when harvesting occurs. Typically these forests are managed to maintain a high level of overstorey and low quantities of high valued timber products, using single tree or group selection systems. Frequently coppice from cut stumps may form an additional source of regeneration.

E. sieberi / stringybark

The *E. sieberi* / stringybark forests of south-eastern Australia are regenerated reliably from seed trees with disturbance from harvesting with or without slash-burning. When seed bed receptivity is high, such as obtained by broadscale mechanical disturbance or slash-burning very high seedling densities are obtained.

<u>Victorian experience</u>

In East Gippsland, Victoria, Faunt *et al* (in prep) reported that germination occurred soon after autumn site preparation and by 1 year seedling percent of approximately 1.2 % on burnt sites and 4.8 % on disturbed sites was obtained on handsown plots over a range of harvesting intensities. However in seed tree areas at year one, seedling density was approximately 10 000 seedlings per ha on both burnt and disturbed sites, the seed supply being much greater on the burnt sites, the result of fire-induced seedfall. On both burnt and disturbed sites considerable germination occurred after year one which tended to offset natural mortality and seedling density had decreased slowly to approximately 8 000 seedlings per ha at age 3. Where more trees were retained, seedling density at 3 years increased accordingly with 18 000 seedlings per ha where 30% of overwood was retained and 30 000 seedlings per ha where 50% of overwood was retained, the main factor being increasing seed supply with increasing overwood. Early height growth varied with the amount of retained overwood and site preparation-75 percentile height of first cohort germinants varied from 68.0 cm at age 3 on burnt seed tree areas to 25.2cm at age 3 on disturbed seed tree areas; under 50% retained basal area from 15.1cm at age 3 on burnt areas and 13.1cm at age 3 on disturbed areas. After clearfelling, followed by a high intensity slash-burning and aerial seeding at a rate of 60 000 seeds per ha seedling density was approximately 3 000 seedlings per ha at age 3 and height growth was similar to that in the burnt seed tree areas. The height difference between treatments increased over time as indicated by the range of 75 percentile height over harvesting treatment which was 3.5 cm to 10.5 cm at year 1 and 12.8 cm to 72.3 cm at year 3. Lutze (1998) reported that in seedtree and clearfelling treatments seedling species composition was similar to that of the preharvesting species mix but there was a shift to *E.sieberi* after logging in small gaps and under retained basal areas of 30% and greater (which was due to seed supply). Raison *et al* (1993) present a case for more productive management of *E. sieberi* regrowth forests which involves limiting seedling density through clearfelling and aerial seeding.

A simulation exercise based on *E. sieberi* dominated regrowth in eastern Victoria indicated that the self-thinning rate could be twice as fast on more productive sites. Marks *et al* (1986) studied the effects of inter-specific and intra-specific competition on crown development in *E. sieberi.* Under competition from similar densities of *Acacia verniciflua* or *E. sieberi*, height growth and height/crown depth was greater under *A. verniciflua* competition to 7 years after planting. By 3 years the wattle had closed around the eucalypts , but by age 7 the dominant eucalypts were showing evidence of strong crown development and diameter growth was similar to that in the plots with eucalypt competition.

<u>NSW experience</u>
Bridges (1983) reported that site preparation was not routinely carried out after integrated logging (leaving a retained basal area of approximately 10%) in the Eden District of NSW, but seedling densities of 5000 seedlings per ha occurred at 12 to 18 months. On permanent $4m^2$ plots seedling density increased slightly from 4 300 at year 1 to 5 700 at year 2 then gradually decreased to 4 800 at year 5. Regeneration consisted of a mixture of new seedlings, small seedling advance growth (seedlings or lignotuberous seedlings originating before logging), advance regrowth, coppice and retained overwood. These initial seedling densities contrasted greatly with seedling density in wildfire regenerated stands, estimated to be around 85 000 seedlings per ha (Bridges 1983). Species composition of logging regrowth at 4-5 years after logging was similar to that of the forest before harvesting in the Eden integrated logging. Current practice in Eden is to greater retention of basal area, but with light or no slash-burning, which may avoid the very high seedling density and species composition changes that occurred in the Victorian experiment. The rate of growth and self thinning in these forests is much slower than in most of the wet forest types. Bridges (1983) reported densities and dominant heights of 26 700 trees per ha and 12.5m at the age of 14, 2 300 trees per ha and 20.1 m at age 25 years and 1 470 and 27.1 m at age 38 years in wildfire regenerated stands in the Eden area.

E. pilularis

E. pilularis forests occur across a large ecological range in pure or mixed species stands throughout the subtropical zone of NSW and Queensland. On wet sclerophyll sites similar principles and methods to *E. grandis* forest apply. On dry to intermediate sites its regeneration and early stand development is similar to the *E. sieberi* / Stringybark forests of the south-east, with respect to the potential sources of regeneration and site preparation treatments applied after harvesting. However Florence (1996) reported that seed supply from seed trees can be limiting to regeneration and careful attention to seed crop monitoring and timing of site preparation is required. In group selection openings in a mixed species stand, seedlings had reached approximately 60 cm height after approximately 1.5 years, at which time they were considered to have become established and capable of outgrowing competing vegetation (especially grass). At 2.5 years after harvesting seedling densities of 1 970 (870 *E. pilularis*, 1 100 other species) seedlings per ha and 2 020 (300 *E. pilularis*, 1 720 other species) stems per ha of advanced growth and average height of *E. pilularis* seedlings of 1.2 m were reported. However without disturbance and removal of grass competition, seedlings became chlorotic and persisted without growth.

The silvicultural system applied to these forests in north-eastern may include thinning, single tree or Australian Group Selection depending on existing stand structure and stand management objective (Nicholson 1999). The maximum allowable gap size is 40 m, which appears to not unduly suppress growth of regrowth. However regeneration may not occur if disturbance during harvesting is inadequate or seed supply is low due to lack of seedfall induction or seed dispersal in slash. In some areas management objectives other than wood production may be given precedence, and harvesting may be by single tree selection, resulting in poor regeneration. In such cases firstly the decision needs to be made about whether there is a requirement for regeneration and secondly about the level of regeneration required. A low density of regeneration may be considered adequate to meet the ecological objective of maintaining the forest type on that site.

E. obliqua / peppermint

The *E. obliqua* / peppermint forests of south-eastern Australia include the drier productive forests of the ranges of central Victoria and eastern Tasmania. These forests are managed using a range of systems including group selection, shelterwood, seed tree and occasionally clearfelling systems. Typically seed supply is from retained trees and seed bed is generally created during harvesting with some supplementary seed bed preparation from top disposal burning. As for the *E. sieberi* / stringybark forest in Eden, regeneration is from a range of sources, and there is potential to alter species composition through the amount of overwood retention. For example in central Victoria the retention of high basal area of overwood (>12 $m^2 ha^{-1}$) favoured the regeneration of the more strongly lignotuberous peppermint, and *E. obliqua* which mainly regenerates from seed was disadvantaged (Weir 1969). Kellas (1994) reported that under shelterwoods mean seedling density varied from 0 to 30 000 seedlings per ha at two years after the first cut (regeneration cut) and from 0 to 22 000 seedlings per ha at 6 years. In single tree selection seedling density was similar. There was not a consistent difference between seedling density on burnt, cultivated and bare mineral soil. Mean height growth of the tallest seedling per plot varied from 4 to 10 cm at age 2 and from 0.4 m to 3.1m at age 6 over the range of treatments from single tree selection to clearfelling. Height did not differ greatly with seed bed preparation method. Species composition of the regeneration closely agreed with the species mix sown under all the treatments applied, but height growth was greater for *E. obliqua* than peppermint.

In Victoria the choice of even-aged (shelterwood, seed tree or clearfelling) or uneven-aged (group or single tree selection) silviculture is generally made on a geographic basis, so that a stand will be managed by an even- or uneven-aged system, usually not a combination. However highly variable pre-harvesting stand structures may result in a large range of growth stages and gap sizes under a group/ single tree selection harvesting system. Under these conditions regeneration silviculture and measures of regeneration success become more complex than in the even–aged forest. A recent review of silviculture objectives in areas managed by uneven-aged silviculture has identified a need to maintain a more balanced distribution of size classes and growth stages in the growing stock. A system that regenerates at each harvesting event and ensures growth through each of the age classes should enable selective harvesting of sawlogs and other products in perpetuity.

Dry eucalypt forests of eastern Tasmania

Elliott *et al* (1991) reported that species composition of dry eucalypt forest in eastern Tasmania 9 years after clearfelling, burning and sowing was not greatly altered from the pre-harvesting composition, although sown with a mixture of seed that was different from the pre-harvesting composition. In addition to artificially sown seed, the sources of regeneration included seed from cull trees remaining after logging and coppice, but species/site interactions on seedling establishment are also probably responsible for the result. Lockett and Candy (1984) reported that early height growth was not greater on slash-burnt coupes compared to coupes regenerated without burning, coppice shoots and advance growth contributing to the favourable height growth on unburnt sites.

These two studies and other information has led to a shift away from clearfelling followed by slash-burning in the dry forests of Tasmania. Currently the silviculture applied to these forests includes seed tree retention, shelterwood, overstorey removal, advance growth retention, potential sawlog retention, thinning, single tree and group selection, which are collectively referred to as "partial logging". The decision about the most appropriate harvesting and regeneration methods are based on the condition of the forest (Forestry Commission Tasmania 1994).

Pennington et al (2000) compared regeneration resulting from pre- or post- harvesting burning, pre- or post-harvest cultivation and normal logging disturbance. He found that pre-harvest cultivation was the most effective, as measured by the percentage of stocked plots and density of seedlings and was comparable in cost to burning or post-harvesting cultivation. Stocking increased rapidly up until 2 to 3 years after harvesting and then remained relatively constant up until 7 to 8 years after harvesting. Lockett and Goodwin (1999) conducted a long term study of survival and growth in clearfelled and artificially sown coupes at Brockley Rd. In 9 x 20m x 20m plots in which the location of all seedlings were mapped, stocking by 4 m^2 plots reached a peak of 16% (425 stems/ha) to 96% (11 275 stems /ha) somewhere between 2 and 5 years of age. The results of these studies supported the prescription to carry out regeneration surveys later in dry forests (after 2 years) than in wet forests (in January or February after initial sowing) (Forestry Tasmania, 1996).

Through use of stem volumes measured at 13 and 16 years of age, Lockett and Goodwin (1999) modelled the effect of different initial stocking on percentage of maximum achievable volume at various ages through to maturity, not taking tree form into account. The model showed a strong relationship between initial stocking and volumes achieved over time. They also reported that seedling density decreased marginally over the 16 years of monitoring, the greatest decrease occurring in the densest stands. They also showed that seedling spatial distribution was aggregated, the degree of aggregation decreasing over time.

Dry, high altitude forests of Tasmania

Florence (1996) suggests that the high altitude forests dominated by *E. delegatensis* with grassy understoreys in Victoria and Tasmania should not be regarded as fitting the large wave regeneration model. In contrast to the mainland ssp. the Tasmanian ssp. is fire resistant. Natural regeneration may have been the result of small gap creation through tree falls and seedbed creation through low intensity fire. Under relatively closed stand conditions the development of grasses would have been less competitive than in the clearfallen stands, where regeneration success may be poor.

In Tasmania these forests occur above approximately 600m elevation and experience annual rainfall in the range 700- 1000 mm per year and are not considered as wet sclerophyll forests. In these forests seedlings may develop a slow bushy habit of growth that persists for 5-15 years (Bowman 1986) after clearfelling, which is referred to as "growth check". In order to increase stocking and minimise the risk of "growth check" partial logging is generally applied in this forest type. The shelterwood system is generally used in forests with one or two age classes present, whereas selection logging is used in multi-aged stands with advance growth (Forestry Tasmania 1990). Pre-Logging Assessments are used to determine the appropriate prescription and Progressive Harvesting Assessments (Cunningham and Neyland 2001) are made to determine how well the prescriptions are followed.

Under the shelterwood and selection systems germination is likely to be extended over a number of seasons and provided basal area is less than approximately 12 m^2ha^{-1}, growth will not be greatly compromised. Battaglia and Wilson (1990) reported that stocking by 4 m^2 plot s increased from 28% to 85% on unburnt seedbed and from 46% to 85% on burnt seedbed when retained basal area was increased from 0 to 12 m^2 ha^{-1}. However in none of the treatments did "growth check" occur, annual height growth in the 4 years following harvesting and site preparation varying from 10cm to 35cm yr^{-1} under 12 m^2 ha^{-1} basal area to 26cm to 42 cm yr^{-1} under 0 m^2ha^{-1} basal area.

E. camaldulensis

E. camaldulensis is non-lignotuberous in its commercial forestry range and widespread natural regeneration occurs after winter/spring flooding followed by a wet summer. Harvesting is generally by group selection after which some active regeneration operations such as slash burning or mechanical disturbance and artificial sowing may be carried out (Parsons *et al* 1991). Dexter (1967) reported that growth of seedlings to 10 months was greater on ash beds (61cm) than on cultivated soil (38cm), hard bare earth (10 cm) or light grass (6cm). Since survival was also good (53% to 10 months) on ash beds, Dexter recommended clearfelling, slash-burning and artificial seeding to maximise regeneration success. Under current management, regeneration may be slow to develop until a suitable flood event and follow up rains occur. In the early stage of stand development a higher seedling density than in other eucalypt forests is desirable because of poor apical dominance. However too high a seedling density will lead to stands stagnating if thinning is not carried out.

Woodlands

The main timber producing forests of western NSW and Queensland are *Callitris glaucophylla* dominated forests and woodlands. These forests may also contain a number of eucalypt species, of which the main timber species are Ironbarks (E. crebra, E. fibrosa spp. nubila, E. melanophloia). Regeneration is restricted to wet periods with a run of consecutive wet seasons. Under such conditions, ample seed supply, light understorey and ground vegetation ensures that dense regeneration of *Callitris* occurs without site preparation with less than approximately 14 m^2 ha^{-1} of retained basal area. Under these conditions Lacey (1972) reported several million germinants per ha and seedling densities of several hundred thousand per ha one year later. Over widespread areas 20 years later regeneration densities of 125 000 stems per ha were commonly encountered. Eucalypts may be severely disadvantaged under dense competition and the occasional wildfire that stimulates coppice growth is important for their survival. *Callitris* spp. have a very limited capacity to self thin and stand density tends to remain high and growth slow, without intervention by thinning. Initial growth is generally slow with seedlings reaching 2.5 to 10 cm height in the first year and increasing to approximately 60cm in the third year.

Subsequent growth can be very slow with stand height of 2 m being reported for a 40 year old unthinned stand, but in a thinned stand in the same forest, height was approximately 10 m and dominant stems 15 cm dbhob (NSWFC).

The silvicultural objective in the *E. wandoo* woodlands of south-western Western Australia is to maintain a 3 age class structure (veterans, intermediate and regrowth), which reflects the clumpy age class distribution of natural stands. Regeneration is obtained in gaps with less than 8 m^2 ha^{-1} of retained overwood by creating ashbeds of at least 2 m in diameter or scarified seedbeds at least 3-4 m in diameter followed by hand sowing if seed crops are poor on retained trees (CALM 1989).

Summary of findings in open forest types regenerated from seedlings

- The research results indicate that these forests are reliably regenerated under a range of harvesting intensities and site preparation treatments. However rate of growth and productivity may vary considerably between silvicultural systems and regeneration survey methods need to include some measure of growth if these differences are to be evaluated. The contribution of retained overwood to growth needs to be considered in regeneration survey methods and evaluation of results.
- early growth rates are generally less than in wet forests and the expression of dominance or potential to survive to sapling stage will take longer to detect. However some of the less reliably regenerated wet forests, such as HEMS, may be similar to the drier forests. In high elevation forest where growth check may occur, consideration should be given to delaying surveys until the time when this condition, if it is to occur, becomes evident.
- germination may be extended over several years as seedbed can remain receptive and seed supply from retained trees may be ongoing. Although the first season of successful germination/survival will outcompete subsequent regeneration, the timing of this event could occur over a wide time frame. Delay in successful establishment may warrant delaying regeneration surveys in drier forests.
- the aggregation of natural regeneration in dry eucalypt forests has only been described for a few stands.
- drier forests often have complex species dynamics characterised by multiple sources of regeneration, varying growth and survival rates between species. Regeneration surveys need to take into account species composition.
- some species have poor apical dominance requiring a high density to maintain tree form but low enough to prevent stagnation on poor sites. Regeneration survey methods should be sensitive enough to density variations to enable evaluation of higher than acceptable density.
- in stands naturally regenerated by high intensity wildfire, seedling density may be much higher than in intensively harvested stands, but similar to density in partially harvested stands with a high proportion of retained overwood. Early growth of non-lignotuberous species is similar in areas regenerated by high intensity wildfire and intensive harvesting followed by slash-burning.

E. marginata

Regeneration in the *E. marginata* forest of south-western Australia does not develop continuously from seedling to maturity as indicated for the previously described forest types. Abbott and Lonergan (1984) intensively studied this forest type and as a result categorised development into 6 growth stages; seedling, lignotuberous seedling, seedling coppice, ground coppice, sapling and pole. They found that seedling growth and survival was low with a mean height of less than 8 cm and survival of 14% of first year germinants to 6 years. Typically during the first year seedlings develop a lignotuber (lignotuberous seedling) which must grow to about 10 cm in diameter before it is capable of producing a shoot which will develop into a sapling and thence into a pole. Fire or other damage regularly cause the lignotuberous seedling to resprout into a seedling coppice or ground coppice, depending on the size and age of the lignotuber. Studies in the northern *E. marginata* forest indicate that the time required for a lignotuber to grow to 15 cm is about 20 years after low intensity burning and 16 years after high intensity burning. In the southern *E. marginata* forest lignotubers grow faster, and where there is no overstorey and seedlings have been fertilised they may grow through to saplings directly from the lignotuberous seedling.

Before harvesting, regeneration surveys are carried out to determine the presence of poles (suitable for thinning); or saplings and ground coppice (suitable for complete overstorey removal). In the absence of these growth stages, partial overstorey removal (shelterwood regeneration harvesting) may be necessary to establish seedling regeneration, or harvesting may be delayed to allow time for the ground coppice to develop. The growth rate of *E. marginata* seedlings and advance growth has been shown to increase with decreasing levels of overwood (Stoneman *et al* 1995, Abbott and Lonergan 1984) and thus gap size has a large influence on early growth rates. Gap sizes of at least 4 tree heights are desirable, but existing stand structure may not allow gaps of this size to be cut, in which case the practioner attempts to push the gap towards the desirable size (CALM 1995). Harvested areas cut to a shelterwood receive a moderate intensity burn to provide a seedbed for seedling establishment within 12 months of harvesting, whereas after gap creation, top disposal burning or release burning is carried out within 2 years after harvesting, the intensity dependent on whether regeneration is already established and whether it needs to be protected or burnt back to encourage re-sprouting.

The terms applied to the silviculture of the *E. marginata* forest indicate the difficulty of classifying silviculture as even- or uneven-aged, particularly the scale-dependence of the definition. Shelterwood systems are usually classified as even-aged systems, because the objective is to establish an area of even-aged regrowth. Gap systems are usually classified as uneven-aged systems, because the objective is to establish groups of different ages throughout a stand. However gap systems could be viewed at the smaller scale, the individual even-aged groups making up the stand. The even-aged groups usually are harvested and regenerated entirely in one operation, eg Australian Group Selection system as applied in *E. pilularis* on the north coast of NSW. However in *E. marginata* the individual groups are harvested and regenerated by the shelterwood system, involving two harvesting operations, the first to obtain regeneration and the second to remove the remaining overwood and release the regeneration from competition. Bradshaw (1992) argues that the difference between even-aged and uneven-aged stands are represented by a continuum rather than there being a distinct division between them. From the point of view of regeneration surveys in uneven-aged forest, at some stage along the continuum it becomes more efficient to stratify the stand into regenerating and regenerated areas and focus regeneration surveys on the regenerating areas than to broadly sample the harvested area.

E. maculata and Box/Ironbark

The *E. maculata* dominated and dry coastal hardwood forests of NSW and Queensland and Box-Ironbark forests of Central Victoria have similar regeneration responses to *E. marginata* forests. A number of studies of stocking of lignotubers in Spotted Gum-Ironbark forest in NSW and Queensland have recorded seedling density in the range of 600 to 2 500 seedlings per ha in regenerating stands (NSWFC). Henry and Florence (1966) reported the responses of lignotuberous advanced growth in Spotted Gum-Ironbark forests in coastal Queensland. Densities of lignotuberous seedlings remained relatively stable over a period of 13 years, with mortality and recruitment occurring. Removal of the overstorey induced a growth response in lignotubers, the average height increment in 15 months being 1.2m and maximum was 3.5m, and the full response was only achieved at distances greater than 15-20 m from the canopy edge.

The regeneration of the dry coastal forests and Box-Ironbark forests have not been studied in as much detail as the *E. marginata* and *E. maculata* forests, however, lignotuberous seedlings are considered to be an important component. Coppice from cut stumps is also an important source of regeneration of Ironbark. Coppice from a harvesting event may be thinned several times before the regrowth is ready for sawlog harvesting. At each thinning more coppice will be produced resulting in a range of age classes in the uneven-aged forest and an ongoing supply of sawlogs for selective harvesting.

Summary of findings in open forests regenerated from lignotuberous growth

- in some dry forest types seedlings may not grow continuously through to sapling/pole/mature stages, but develop a lignotuberous phase, in which it may develop for an extended period before it is capable of growth into a sapling. In such forest types disturbance is created and regeneration obtained whilst forest cover is maintained by shelterwood or selection logging systems.
- On-going germination, mortality and the slow development of seedlings to the dynamic stage creates a lignotuberous pool of which a variable component will be capable of effectively occupying the site if an opening is created. Regeneration measures must be sensitive to the stage of development of lignotuberous seedlings and be timed with respect to events that will stimulate growth of the lignotuberous pool.

Ecological groups based on whether seedlings or lignotubers are the main source of regeneration would be appropriate strata for reporting. Stratification at a higher level, such as dry sclerophyll, would be difficult because there would be considerable variation in the rate of establishment between some forest types within the stratum. Stratification into tall or medium, open eucalypt forest may be more appropriate, because most of the forests regenerated from seedlings would be classified as tall (ie >30 m), whereas forests regenerated by lignotuberous, advanced growth and coppice would be generally less than 30 m tall.

2.4.3 Rainforest

Timber production in closed forests is restricted to certain rainforest and blackwood swamp communities in Tasmania, and the following information has been taken from Forestry Tasmania Technical Bulletin No. 9, Rainforest Silviculture (Forestry Tasmania 1998). The utilisable component of rainforests is often only a small proportion of the total stand. These species regenerate under shelter and without broadscale disturbance, and a number of silvicultural systems have been developed to suit the utilisation and regeneration of the better quality rainforests, containing Myrtle, Sassafras, Leatherwood and Celery-top pine. In addition, a limited amount of harvesting of Huon pine occurs for which special regeneration methods are applied, but these forests will not be considered further because of their very specialised nature. In tall Myrtle stands either an overwood retention system or sawlog selection system is applied. In both systems there is a dependence on seedfall for Myrtle regeneration, and seedfall has been found to be periodic, whereas Sassafras coppices readily and Leatherwood has more consistent seedfall. Thus timing of germination and establishment may vary with species. In the lower quality rainforests, Celery-top pine is selectively harvested, after which it regenerates from ground-stored seed and seedfall. The regeneration and early stand development of rainforests is slow, research indicating maximum growth of Myrtle of 40 cm per year in the 20 years following logging, whereas growth rates of 7 cm per year have been reported for the first 8 years in Celery-top pine. Early growth and survival may be significantly reduced by animal browsing.

The foregoing discussion of regeneration processes in closed forest indicates that:

- The slow development of rainforest regeneration and the large variation in sources of regeneration between species indicates that special methods of regeneration survey should apply.

2.4.4 Classification of forest types on the basis of regeneration and early stand development

The review of regeneration and early stand development indicates that there are general similarities in regeneration processes between groups of forest types with respect to timing and regeneration sources under current management. A possible grouping of the major eucalypt dominated forest types, as a basis for regeneration survey development, is shown in table 2.1. However it must be noted that there is large variation within each group, and even within each forest type, in the magnitude of regeneration responses as a consequence of variation in ecological and silvicultural factors. These are narrower than the national forest inventory classes, which are also shown in table 2.1.

2.4.5 Summary – relevant measures of regeneration success

The review of regeneration ecology and silviculture has indicated that the general classes of regeneration success measures introduced in section 3 (site occupancy, species composition and growth) are relevant to the objectives of management systems and ecosystems of Australian forests. Bole quality is also a measure applicable to high quality wood production.

Table 2.1 Eucalypt forest types with similar regeneration processes

NFI type	Ecological Group	Forest types	regeneration source	time to establish
Tall, Open Eucalypt	Wet, rapid establishment	*E.regnans* forests of southern Victoria Wet *E.delegatensis* forests of south-eastern Australia Lowland Wet Eucalypt forests of Tasmania dominated by *E.obliqua* and *E.regnans* *E.grandis* forests of the north coast of NSW and south-eastern Queensland *E.diversicolor* forests of south-western Western Australia	seedlings	0-1.0yrs
	Wet, slower establishment	Tall moist coastal hardwoods of New South Wales and S.E. Queensland High elevation mixed species forests of eastern Victoria. Tablelands moist hardwoods of New South Wales	seedlings and advanced growth	0.5-5.0 yrs

	Dry, mixed non-lignotuberous and lignotuberous	*E. sieberi* dominated mixed species forests of south-eastern Australia *E. pilularis* dominated forests of northern NSW and SE Queensland *E. obliqua* / peppermint forests of south-eastern Australia *E. camaldulensis* dominated riverine forests	Seedlings, coppice and advanced growth	0-3.0 yrs
Medium, Open Eucalypt	Dry, lignotuberous	*E. marginata* forests of south-western Western Australia *E. maculata* forests of coastal NSW and Queensland. Dry coastal/inland hardwood forests of the eastern states (includes box/ironbark)	advanced growth, coppice and seedlings	0-20 yrs

2.5. Overview of current methodologies used in Australia and overseas

2.5.1 Methods

A tabular summary of the survey methods, regeneration standards and reporting used by each state are given in table 2.2, table 2.3 and table 2.4 respectively.

Victoria

The Victorian policy is to regenerate all harvested areas to the same eucalypt species occurring on the site before harvesting and a survey must be carried out to assess whether the site is regenerated (DNRE 1996). Survey methods have been developed to assess site occupancy in even-aged and uneven-aged stands (DNRE 1997). For the purpose of identifying and treating understocked areas, and provide a record for accountability purposes an establishment survey must be carried out between 18 and 30 months after the regeneration establishment treatment (ie sowing / seedfall / planting). The survey assesses stocking of acceptable seedlings by 16 m^2 circular plots established on a 80m x 20 m grid across the harvested area. Seedling counts (estimate for greater than 5) and species of acceptable seedlings present on each plot and seedbed type on unstocked plots are also recorded. Procedures are also available for preliminary seedling surveys to check for early remedial treatment needs, and sapling surveys to confirm stocking status in sapling aged stands. The sapling survey assesses stocking of acceptable saplings by 40 m^2 circular plots on a 80 m x 30m grid. Regeneration in shelterwoods is assessed by the established seedling survey at 18-30 months after the post logging burn. A sapling survey may be also be conducted at the time of shelterwood removal. In uneven-aged stands all structural components or growth stages are assessed on a wider grid than used for even-aged stands. The mature tree and pole component are assessed using a basal area sweep whilst the younger components are assessed using the same plot sizes used for establishment and sapling surveys.

Acceptable seedlings have the following characteristics:

- *Species*: native to the forest type
- *Vigour*: a healthy growing tip
- *Origin*: seedlings or coppice (if attached within 20 cm of ground level)
- *Stem damage*: free of severe cambial damage and free from rubbing on logging slash
- *Height and competitive position*: at least 40 cm tall, potential to grow above competing understorey.

Harvested areas are considered successfully regenerated if 65% of plots are stocked. All or part of the area may be reassessed if stocking is less than the acceptable standard, the reassessment is carried out using a 40m x 20m grid and the acceptable standard is 55% of stocked plots. At least 10 seedlings or coppice of all eucalypt species present before harvesting is the minimum standard for species composition.

Internal reporting of regeneration success is on-going, as survey maps, percentage of stocked plots, and area of stocked and unstocked areas are recorded in District data bases as they occur. Approximately every 3 to 4 years a summary of regeneration results is made and published externally. The summary contains areas in broad ranges of stocked plot percentage by forest type and Forest Management Area.

Tasmania

The Tasmanian policy is to implement appropriate silvicultural treatments to ensure that all forests are adequately stocked following harvesting operations, where the objective is to replace forest (FC Tasmania 1993). Harvested forest must be assessed using methods developed for clearfelling, shelterwood, even-aged regrowth retention and multi-aged stands within a specified time after harvesting or site preparation (Forestry Tasmania 1996). Surveys are carried out early enough to allow any remedial treatment to be applied whilst receptive conditions for re-sowing or planting remain. As in Victoria, the survey assesses stocking by the dominant tree species on a systematic grid. In clearfelling situations regeneration is usually assessed within 1 year of slash-burning by assessing the presence of seedlings on circular plots of 4 m^2 and 16m^2 (if the 4m^2 plot is unstocked) established on a 100m x 20m grid. Similar procedures are used in *Acacia melanoxylon* and rainforests (Forestry Commission Tasmania 1991, 1990) but are usually scheduled later, up to 5 years after logging.

For partial logging systems, usually applied to dry forests, regeneration is usually assessed after two years. New growing stock, seedlings or advanced growth, are acceptable, provided they are healthy. The seedbed type is recorded on each plot. The same grid is used in even-aged regrowth and multi-aged stands, but plot size is increased in regrowth to 0.02 and 0.04 ha and basal area sweeps are used in multi-aged stands. If the basal area standard is not met then the 4m^2 and 16m^2 plots are assessed for seedlings. Regeneration surveys are also carried out prior to removing shelterwoods in eucalypt forests. The same procedure is used as in clearfelled treatments but plots are only considered stocked if seedlings are greater than 1.5 m height. On private land currently there is no formal requirement for regeneration surveys, but large companies use the methods required on public land.

A mapping rule is applied to determine if an area is successfully regenerated, a stocked section containing less than 3 consecutive unstocked plots, no understocked patch should exceed 1 ha and at least 80 % of the harvested area must be mapped as stocked. It follows that if seedlings were regularly distributed then the minimum standard would be one third of plots on 80% of the area stocked (ie 27% of plots stocked). In practice, seedlings are irregularly distributed and the minimum standard is higher than 27 %.

As for Victoria, internal reporting of regeneration success is on-going, as survey maps, percentage of stocked plots, and area of stocked and unstocked areas are recorded in District data bases. As part of the RFA commitment a summary of regeneration results will be made and published externally each year. The summary will contain areas by clearfelling or partial logging in a given year and the percentage of that area successfully regenerated 3 years after treatment.

Western Australia

The WA policy is to maintain a balanced age / growth stage structure at the landscape level which requires ongoing recruitment through regeneration. As for Tasmania, surveys are carried out in time to identify understocked areas and carry out infill planting before competition becomes too great. It is also stated that regeneration surveys will yield information for the prediction of future stand development and yield possibilities. There are well documented survey methods which assess site occupancy by the dominant tree species on a systematic grid (CALM 1990,1997). However the survey methods differ between the two major forest types (*E. diversicolor* and *E. marginata*) in timing and sampling. In *E. diversicolor* forests, regeneration is assessed within 1 year of post-harvest burning by determining point seedling density by triangular tessellation at plot points established on a 80m x 20m grid. In *E. marginata* forest, regeneration surveys may be carried out 5-10 years before harvesting to determine the appropriate harvesting treatment. These surveys are normally scheduled following a prescribed fire to allow lignotuberous advance growth to be readily observed. The presence of acceptable growth stages indicates that the overstorey can be completely removed by cutting a gap up to 10 ha in area, the alternative being retention of a shelterwood to provide a seed source for regeneration and maintenance of forest values until lignotubers become sufficiently developed. Areas cut to shelterwood are surveyed on a 50m x 20m grid for regeneration within 1 year of post-harvest burning, and a variety of growth stages can contribute to an acceptable stocking. Only stems which appear likely to survive in the immediate future are considered acceptable stems in both *E. diversicolor* and *E. marginata* forest. The species of seedlings forming the triangle vertices are recorded. In *E. wandoo* woodland a survey of established seedlings is carried out 12 months after site preparation (CALM 1989).

Point density standards are applied at the plot level to determine plot stocking status, the standards varying with forest type and growth stage of the regeneration. Minimum point density for *E. diversicolor* is 1666 spa; minimum point density for *E. marginata* is 5000 spha of seedlings, 1000 spha of ground coppice or advanced growth or 500 spha of saplings. Harvested areas are considered successfully regenerated if a certain percentage of plots (85% in *E. diversicolor*, 65% in *E. marginata*) are adequately stocked and there are no understocked areas exceeding 1 ha in *E. diversicolor* or 0.5 ha in *E. marginata* (ie 6 adjacent sampling points in *E. diversicolor* , 5 in *E. marginata*, not meeting the acceptable standard). Point seedling densities are used to calculate infill planting requirements. Additionally in *E. diversicolor*, point stocking is assessed against a minimum seedling density (3000 spha) to obtain maximum clear bole length (ie optimum stocking), but this information is not used to determine infill planting requirements. In *E.wandoo* woodland 10 seedlings per ashbed on 50% of ashbeds is the minimum acceptable standard.

Internal reporting of regeneration success is on-going, as survey maps, percentage of stocked plots, and area of stocked and unstocked areas and estimated species composition are recorded in a statewide data base (SILREC) annually. The gross area of each major forest type harvested and the area of even-aged *E. diversicolor* regeneration established in each year are listed in the CALM Annual Report. There is no specific external reporting of area stocked to specific levels.

New South Wales

NSW state policy is currently being prepared. The new silvicultural policy will be based on Ecologically Sustainable Forest Management policy and 16 regional indicators which will incorporate regeneration assessment and rehabilitation of failed areas. In the meantime the policy in the 1992-1995 Corporate Plan applies, and accordingly monitoring is carried out after logging on a randomly selected sample of 20% of harvested areas. Operational Circular 94/2 (SFNSW 1994) is the guideline for these surveys, with it left to the discretion of individual Regions and Districts to determine the details of the implementation of the method. Unlike the other states mentioned above, the methods are designed to allow for a more variable spatial pattern of harvesting and regeneration encountered in N.S.W. coastal forests. Sample points are located on a stratified random basis or systematically within strata on a grid with a random starting point. Density of eucalypts for strata are determined by measuring the distance from the sample point to the nearest individual with the desired characteristics and calculating the average distance. Species composition may be estimated by tallying the total of sampled seedlings by species and expressing as the proportion of total number of seedlings of all species. More recently Regions are developing guidelines and procedures which are based on the operational circular method (eg south coast and south-east regions). The surveys may be designed to include a range of environmental measurements (including eucalypt regeneration), both before and after (within 2 years) harvesting. However as the silviculture policy, manual and field guides are still in preparation, the Operational Circular 94/2 still applies to a large proportion of the state.

The current standard for regeneration success is density>500 spha. The percentage of compartments surveyed which are adequately stocked are reported in the annual Environmental and Social Values Report. The current approach to ecologically sustainable management in NSW produces a highly variable forest structure in most forest types (excluding *E. delegatensis* and *E. sieberi* / stringybark). Often there is limited disturbance and high levels of retention of overstorey which compromises the potential for regeneration and regrowth development (Ellis 1999). Under this type of silviculture, where regeneration and future wood production are minor objectives, there is not a strong commitment to monitoring of regeneration on all harvested areas, as practiced in Tasmania, Victoria and Western Australia.

Queensland

Queensland has a silviculture policy of maintenance, restoration or enhancement and monitoring of forest productivity and regenerative capacity. There is a post harvesting requirement to apply silvicultural (including regeneration) strategies described in harvesting plans and residual stands must be assessed and remedial treatments carried out where necessary (DNR 1998). Currently regeneration surveys are not carried out and there are no documented methods for regeneration surveys in Queensland.

SA , ACT & NT

These states do not routinely harvest native forests for sustainable wood production and are not likely to commence to do so. Thus they are not included in this evaluation.

Northern hemisphere coniferous/hardwood forests

The stocked plot methods used in Australia originated in the mixed coniferous/hardwood forests in the USA (Lowdermilk 1927). Since the late 1980s regeneration surveys in those forest types have evolved from simple site occupancy measures to fixed area plots in which a number of parameters are measured (Ministry of Forests 1999). Parameters include height, species, stand density and competitive position of preferred species relative to other species. There is generally a requirement for a follow up survey (eg free growing survey in British Columbia) in the sapling stage to ensure that stands are growing free of competition. The greater effort in regeneration surveys is probably a result of ongoing competition problems for the preferred species (conifers) during the early stages of stand development. It is common for brush control to be carried out on the basis of the stocking or free-growing survey. Another key difference between the methods in mixed coniferous/hardwood forest and Australian forests is the sampling approach. Fewer, larger plots are used, and sampling intensity is low (about 0.5% by area), which is claimed to achieve less than 15% sampling error.

In Canada the data from regeneration surveys are used to form labels for mapped units in GIS layers for inventory and silviculture. These and regular external reporting of data provide a record for accountability purposes.

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Table 2.2 Summary of regeneration survey methods currently used in Australian commercial forests and a selection of methods used in other countries

Purpose of survey: establishment after clearfelling, seed tree and shelterwood regeneration harvesting						
Source / State	**Timing (yrs after site preparation)**	**Survey method**	**Sampling intensity**	**Plot size or max distance**	**Data collected**	**Data summary**
DNRE (1997), Victoria	1.5-3.0 yrs (ESS[1]) (0.5-1.0 yrs (PSS) 4-10 yrs (Sapling))	Stocked quadrat (seedling count)	80 x 20 m (80 x 30 m sapling survey)	16 m^2 (40 m^2 sapling survey)	Count/species of acceptable seedlings Seedling damage, Seedbed if unstocked	Map of un/stocked plots; Calculate % stocked plots for total area; % stocked plots for area not to be retreated
Forestry Tasmania (1996),(1991), (1998)	0.8-2.0 yrs (A[2]) 2-5 yrs-rainforest 5 yrs-blackwood	Stocked quadrat	100 x 20 m	4 m^2 or 16 m^2	Seedbed, stocking status; on every 3rd stocked plot seedling height, health	Map boundary under/stocked areas Calculate % $4m^2$ & $16m^2$ stocking for whole, stocked and unstocked areas
CALM (1990,1997), W. Australia	0.8-1.5 yrs (*E. diversicolor*); 1.0 yrs post burn (*E. marginata*)	Stocked quadrat (density by triangulation)	80 x 20 m (*E. diversicolor*) 50 x 20 m(*E. marginata*)	5.0 m (8.0 m saplings)	Point density, Stocking status, Species composition. Point density by growth stage and forest structure in *E. marginata* forest. Seedbed type in *E. diversicolor* forest	Map un/stocked plots; Calculate % stocked plots for cells (excluding large unstocked areas)
Ministry of Forests (1999), BC, Canada	4.0-7.0 yrs[3] (7.0-15.0 yrs-FG)	Seedling count	strip line- var. spacing 1.0-1.5 plots per ha by strata	3.99 m radius (50 m^2)	Count, height, species of well-spaced, species preferred, acceptable (free-growing) trees.	Inventory and silvicultural label for each strata containing species composition , age, height, site index, stand density
Republic Forest Dept., St Petersburg, Russia	5-10 yrs	Seedling count	evenly spaced across strata at 5 plots per ha.	4 m^2, 10 m^2 or 16 m^2; size increases with ave. coupe height and decreasing density	Count acceptable seedlings of all main tree species by height class; estimate of no. and height of unwanted deciduous species. Estimate of regeneration age.	Average height of coniferous trees, ratio of ave. ht of coniferous to deciduous trees, species composition and regeneration age.

Table 2.2 (continued) Summary of regeneration survey methods currently used in Australian commercial forests and a selection of methods used in other countries

Purpose of survey: establishment before shelterwood removal						
Source*/ State	**Timing**	**Survey method**	**Sampling intensity**	**Plot size or max distance**	**Data collected**	**Reporting format**
For. Tasmania (1996)	before removal- (B[2])	Stocked quadrat	100 x 20 m	4 m^2 or 16 m^2	As for A but only seedlings>1.5m counted	As for A
CALM (1997), Western Australia	- 5-10 yrs (before removal) 0.5-1.0 yrs post burn	Stocked quadrat (density by triangulation)	50 x 20 m(*E. marginata*)	5.0 m (8.0 m saplings)	Point density by growth stage, Species mix, forest structure.	Harvest coupe map with un/stocked plots; Calculate % stocked plots for cells (excluding large unstocked areas); identify harvesting/regen. treatment
Purpose of survey: site occupancy of multi aged stand after selective harvesting						
Source*/ State	**Timing**	**Survey method**	**Sampling intensity**	**Plot size or max distance**	**Data collected**	**Reporting format**
DNRE (1997), Victoria	1.5-3.0 yrs	Stocked quadrat	100 x 50 m to 250 x 100 m	as for ESS and sapling plus VPS	Basal area of non/productive poles/mature , count of sapling/coppice (40m^2 plot) and count of acceptable seedlings (16m^2 plot)	As for ESS etc. but also calculate coupe ave. BA of merchantable and non-merchantable poles/mature
Forestry Tasmania (1996)	up to 2.0 yrs (D[2]) 2-5yrs- rainforest 5 yrs- blackwood	Stocked quadrat	100 x 20 m	VPS for pole/mature; 4 or 16 m^2 regen	BA of poles/mature and (if BA<12m^2/ha) seedbed, stocking status, height and health of seedlings	Map regen, retention and combination patches (under/stocked boundaries) Calculate % stocking for patch types
SFNSW, (1994)	1-2 yrs	Closest Individual Method	>100ha-100points < 50 ha-50 points 50-100ha- 1 per ha.	Typically 5m for regrowth, 20m for pole/mature.	Distance to nearest eucalypt, species, merchantability and diameter of nearest eucalypt to plot points. In small areas point centred quarter method (closest individual in each of 4 quadrants) is recorded.	Average distance to the nearest eucalypt, density of regrowth by species and retained overwood by merchantability class.
Ministry of	4.0-7.0 yrs[3]	Seedling/tree	strip line- var.	3.99 m radius	Count, height, species of well-spaced,	Inventory and silvicultural labels

Forests, BC, Canada (1999)	(7.0-15.0 yrs-FG)	count	spacing 1.0-1.5 plots per ha by strata	(50 m^2)	species preferred, acceptable (free-growing) trees by layer. BA for layer 1 (mature trees)	for all 4 layers

1 ESS (established seedling survey) is compulsory, PSS (preliminary seedling survey) is optional, sapling survey is optional unless ESS not carried out.
2 Stocking standard A to D. C (standard for residual regrowth stands) is not included in the table.
3 Legislation requires a stocking survey and a later free growing survey
4 VPS = Variable Probability Sampling; plot size is dependent on individual tree size (dbhob)

Table 2.3 Minimum stocking standards for Australian regeneration surveys

Source	Forest type	Plot standard	Coupe standard- % plots stocked (unless specified)
DNRE,Vic	even-aged	1 acceptable stem	>65% (55%*)
	uneven-aged	1 acceptable stem, 30% of reference BA	>70% (60%)
Forestry Tasmania	even-aged	1 seedling	mapping rule - understocked sections; >80% coupe area stocked.
	uneven-aged	BA>12 m^2/ha, 1 seedling	>80%
CALM, WA	*E. marginata*	density>1000 spha coppice density>500 spha saplings density>5000 spha seedlings	>65%
	E. diversicolor	density>1666 spha-adequate density>3000 spha-optimal	>85%
	Wandoo	Density >10 seedlings per ashbed	50% of ashbeds
SFNSW	Various	not applicable	density>500 spha

* a lower standard is applied if sampling is more intensive

Table 2.4 Reporting procedures for Australian regeneration surveys

Source	What is reported internally	What is reported externally	Report frequency	Where is it reported
DNRE,Vic	Coupe map with transects and plots showing stocking status. % potentially productive area stocked; adjusted % potentially productive area stocked (after discrete understocked areas excluded); Presence/absence of eucalypt species present before harvesting	Area and % of area in stocking classes by forest type and forest management area for 1st attempt , 2nd-3rd attempt regeneration and reforestation for the period since 1989	External-every 3-4 years Internal- ongoing (within 3 years of site preparation)	External- DNRE Forests Service Technical report Internal- Forest Coupe Plan (part B); coupe history database
Forestry Tasmania	Coupe map with strips and plots showing stocking status and boundary of under/stocked areas, seedbed in understocked areas. % $4m^2$ & $16m^2$ plots stocked for whole, stocked and understocked areas	Area and percent of area stocked and understocked for clearfall and partial logging operations for a given year of regeneration operations.	External- every year commencing 1999 (report on 1995 harvesting) Internal- ongoing (within 2 years of site preparation for eucalypts, 5 yrs for blackwood and rainforest)	External- annual report (RFA requirement) Internal- Coupe History (CHiS) database Annual Quality Standards Report
CALM, WA	Coupe map with plot points, stocking status and cell boundaries, delineating areas of different regeneration success. % plots stocked, species composition for each cell and whole coupe. Mapped location of large understocked gaps and understocked areas requiring infilling.	The gross area of each major forest type harvested and the area of even-aged *E. diversicolor* regeneration established in each year are listed in the CALM Annual Report. There is no specific external reporting of area stocked to specific levels.	External-Annually Internal- ongoing (initial establishment surveys in Dec-Jan following regen. burning or infill planting). Annual regeneration report prepared by State Forest Resource Business Unit.	ExternalCALM Annual Report Internal- Attached to coupe plans and in SILREC system.
SFNSW	Regrowth stocking (spha) by species or retained stocking (spha) for harvested area.	% compartments adequately stocked in the annual Environmental and Social Values Report	External-annual Internal- ongoing (within 1 to 2 years of harvesting on 20% sample of harvested areas.	External- Environmental and Social Values report Internal- Compartment history file or FAMIS.

2.5.2 Evaluation of current methods

Objectives

In this section the differences and similarities of current objectives are summarised and the ability of current methods and standards to meet those objectives are discussed.

The objectives and standards of regeneration measures are directly related to the policy, management and operational objectives of the forest owners and users. In the Australian context there is an overall policy for sustainable management of forests, which will be partly ensured through timely regeneration. Indicator 2.1(g) would be an integral part of the overall forest management system that delivers sustainable forest management. The fact that this national indicator is being developed with the participation of the relevant states is strong evidence that the concept of a national indicator of regeneration success is appropriate to the Australian situation. It is also apparent that this commitment to sustainable forest management at the national level is supported by the silvicultural policy of each state. However there is considerable variation in what is reported and the standards applied between states, that indicates that the objective of a national indicator can not be achieved immediately.

At the management level regeneration measures could be used to predict stand development and yields and generally manage the long term productivity of the forest. However the relationship between the current measures of regeneration success and long term productivity are poorly understood, which may explain why plot and stand level standards differ between states for similar forest types, with similar ecology. However the differences could be a reflection of different management objectives. For example a simplistic analysis suggests that there may be lower stocking standards in New South Wales and Tasmania (see 2.5.2.4), which may be a result of less emphasis on high quality wood production than in the Western Australian *E. diversicolor* forest. Measures involving both seedling density and distribution are potentially more useful for the prediction of long term productivity, such as the Western Australian approach, although seedling density is not currently recorded in the statewide database. Timing of surveys is also an important factor in the ability to predict long term productivity. Later surveys, such as the established seedling survey in Victoria, are potentially more accurate, particularly where results are near the minimum acceptable standard, experience indicating a tendency for stocking estimates to increase from age 1 to 3. Currently none of the existing survey methods include growth , which could greatly improve the ability to predict long-term productivity.

In uneven-aged forest ecologically sustainable forest management may require the maintenance of a balanced size/age class distribution. Such a system should enable selection harvesting in perpetuity by managing all the stand components. Monitoring the regeneration of gaps, regardless of size, is just one component of stocking control. However, if other systems are in place to monitor the cutting cycle and age class distribution, then stocking surveys need only address regeneration. Historically management of dry forests in which selective harvesting occurs has been extensive with limited monitoring. With geographic information systems becoming widespread it should be feasible to effectively monitor harvesting events and manage uneven-aged forest for a greater balance of age classes. However one could argue that the balanced age class distribution is not ever likely to be achieved with current management constraints. A more realistic objective might be to restore productivity to stands that have generally been exploited by sawmiller selection or damaged through frequent fire events. If an uneven-aged structure is desired this could be achieved by harvesting and regenerating patches as market conditions and long term supply commitments allow. Monitoring of all stand components will indicate how closely the resulting structure approaches an ideal stand structure, but monitoring of the regeneration component is the most critical.

Regeneration measures are routinely used to identify understocked areas and target remedial treatments to specific forest areas in Victoria, Tasmania and Western Australia. There is a difference in approach between Victoria and the other two states with respect to timing of remedial treatments which is reflected in the timing of surveys. In Victoria, a 'preliminary seedling survey' may be carried out at 6 to 12 months after seed application on sites of moderate-high risk of failure. If a problem is identified then remedial action, such as rough-heaping next season, may be planned, or it may be decided that regeneration may improve over time without intervention. There is always an established seedling survey prior to 3 years. It is only on the basis of this survey that an area is considered successfully regenerated, otherwise remedial treatment is carried out, usually involving mechanical disturbance. In Tasmania and Western Australia surveys are timed to remedy failure through additional seeding or planting, which is much less costly than having to prepare the site again. These treatments are probably not always successful, but these states accept less than 100% of coupes meeting the stocking standard. The 20% sampling approach in New South Wales is more strategically oriented, and its effectiveness in improving on-ground performance of regeneration is doubtful. That is, the lower intensity of survey is an inadequate basis for a routine remedial treatment program and such a system is likely to result in a lower level of wood production in the long term.

Success Measures

In this section there is an evaluation of whether important measures of regeneration success are included in the current approaches to regeneration surveys. There is also a discussion of the information content and accuracy of the current measures.

Site occupancy

Current methods in Australian native forests generally assess site occupancy. Amongst the methods applied in even-aged silvicultural systems, the greatest information is provided by the West Australian approach. The method provides estimates of seedling density at locations distributed across the surveyed area. This is extra information than provided by the Tasmanian approach which provides an estimate of whether there is a minimum seedling density at locations distributed across the surveyed area. The Victorian method provides an estimate of seedling density at each point, although the estimate is not accurate at high seedling density. The New South Wales method provides an estimate of seedling density at the stand level.

The main source of error in estimates of site occupancy is probably the aggregation of regeneration. The triangular tessellation method used in Western Australia provides an unbiased estimate of seedling density, regardless of spatial distribution (Ward 1991, Loetsch *et al* 1973). Current methods that rely on distance from a point to the nearest seedling are likely to be biased for aggregated distributions, because sampling points tend to fall more often into gaps than into dense areas (Cox 1976). Both the closest individual and point-centred quarter method used in New South Wales (SFNSW 1994, SFNSW 1999) are in this category, and are likely to underestimate seedling density. Although more accurate than distance based methods, quadrat count methods, may produce biased estimates of seedling density, the size of the quadrat having an influence on the edge effect and wrongful inclusion or exclusion of seedlings (Ghent 1963).

The inclusion of all stand components in uneven-aged stand surveys is desirable if they are used for determining future stand treatments. Current site occupancy is not sufficient to ensure that ongoing recruitment occurs in a timely manner for long term productivity. The quality of growing stock, particularly in stands that are dominated by pole to mature trees, is important in achieving particular objectives such as wood production or habitat recruitment (eg the basal area of potential sawlog trees or future habitat trees with incipient decay).

It is apparent that none of the systems used for monitoring uneven-aged forest address all stand components. Victoria has a system that measures all stand components, but evaluation of site occupancy does not take all stand components into account. Tasmania only considers regeneration if other stand components are absent. Western Australia only considers the regeneration component in the gaps and disregards the remainder of the stand.

In defense of the current systems, it may be unnecessary to consider regeneration in areas with sufficient pole to mature trees if such advanced regeneration is not a preferred option for stocking after future removal of overwood. That is, if the long term aim is to convert the uneven-aged forest to an even-aged forest or even-aged patches, then there is no need to monitor regeneration until the stand replacing operation occurs. However in some forest types the regeneration may take a long time to develop through a lignotuberous stage or may require shelter to become established, in which cases regeneration is best obtained before removal of all the overstorey. For the purpose of indicator 2.1(g) reporting of the regeneration component could be at any time after the regeneration cut, but late enough to determine if the regeneration will develop. For example in *E. marginata* forest a shelterwood system is applied as part of an uneven-aged system – reporting of regeneration established at the time of the regeneration after a decade when lignotubers have become well established may be most appropriate. However shelterwood areas in *E. obliqua* or dry high altitude *E. delegatensis* classified as even-aged systems, the reporting of regeneration at the time of the regeneration cut may be more appropriate.

Growth

Height is sometimes recorded in Tasmania on a sub-sample of plots. However estimates of height at the time of the survey (1 year in wet forests and up to 2 years in dry forest) are likely to be unrelated to long term height growth. Height is not recorded in other states, although height is implicit in the definition of acceptable seedlings for contribution to stocking in Victoria. Other parameters related to growth (seedling quality, green height or height/diameter ratio) are not recorded. Also growth parameters (diameter, basal area, volume) are not measured because they are not relevant at the age of current regeneration surveys; but could be included in sapling surveys. The Tasmanian pre-commercial thinning surveys include fixed area plots in which seedling density and growth parameters are recorded.

Species composition

The presence of each eucalypt species represented on each plot is recorded in Victoria, but species composition is evaluated on the basis of whether there are at least 10 seedlings of the required native species present across the surveyed area. In Western Australia an estimate of percentage composition is provided by recording the species of seedlings used for the seedling density estimate. In Tasmania stocking is based on the presence of acceptable species and species may be recorded on a sample of plots (not routinely). In NSW species composition is estimated from the proportion of closest individuals to the sampling point by species. Current survey methods do not include understorey because the focus is on the tree component of the forest. The case for inclusion of understorey in regeneration surveys is supported by studies of the effect of harvesting on understorey composition, as it can not be assumed that processes that regenerate the tree component also regenerate the understorey (Ough and Murphy 1999). However the task of developing measures for the understorey is great, considering the diversity of species, regeneration mechanisms and interactions between ecological components. There are insufficient resources to include measures of understorey at this time in indicator 2.1(g).

Alternative approaches

The current approaches in Australia are generally consistent with historical approaches in the coniferous/deciduous forests of the northern hemisphere, which focussed on site occupancy. However, in the latter forests, the approach has increased in complexity to include the measurement and evaluation of seedling density, height and species composition. The inclusion of a later survey permits the inclusion of growth and quality parameters. However there are differences in forest types and early stand dynamics which prevent direct transfer of the experience in mixed coniferous/ deciduous forests to Australian eucalypt forests. The inter species competition factor is a lot more evident and the successional pattern in mixed coniferous/ deciduous forests is different to that in eucalypt forests. In the case of the Australian eucalypt forests the climax species are generally desirable timber species and it is not necessary to manipulate species composition to increase wood production outcomes. This facilitates the management for multiple objectives (eg biological diversity and timber production) on the same forest. However later surveys than currently used in Australian forests may be desirable for the purpose of making stand management decisions and assessment of long term productivity.

Field monitoring systems

The current approach in Australian forests is to monitor intensively at the coupe level, although in NSW a sample of coupes are measured to provide a regional level estimate of regeneration success. The following discussion refers to statistical validity and cost effectiveness of sampling within coupes, although the same principles could be applied to sampling coupes within a region.

Statistical validity

The stocked plot survey method is based on the probability of a randomly selected plot containing a seedling. A plot size is chosen that will indicate if stocking meets a desired stocking level. The desired stocking at a given age generally represents a level at which total volume production is not compromised, but wide enough to promote rapid sawlog growth (see below). Thus a plot of the area A (m^2) = 10 000/desired stocking (x evenly spaced seedlings per ha) would theoretically contain at least one seedling. Considering that natural regeneration is seldom evenly spaced, a very large plot size would be required to obtain at least one seedling in 100% of plots. In order to reduce the time spent searching plots, it is usual to have smaller, but more frequent plots, thus maintaining a sampling intensity of about 1% by area, but with the expectation of a smaller proportion of the plots containing a seedling. This approach has the added advantage of quantifying stocking which exceeds the minimum level.

In general plots are selected systematically, instead of randomly, which has a number of implications for statistical validity. That is, if the systematic sampling pattern coincides with some ecological pattern, then there is a possibility that the estimate will be biased. In addition, the sampling error can not be reliably determined for estimates derived from systematically sampled populations. Corbett and McCulligh (1989) (after Freese 1962) point out that systematic sampling is more efficient than random sampling when actual sampling time is considered. Systematic sampling is likely to be more precise in aggregated distributions(eg naturally regenerated) stands, whereas random sampling is more precise in uniform (eg planted) stands. Precision can be increased by stratification. A common approach is to randomise the starting point for the systematic survey within a strata and calculate the precision as though the sampling was random. Precision can also be increased by increasing the frequency of plots, or by changing the plot size. Thus, provided that the sampling achieves the desired level of precision, it is valid to alter the sampling procedure to improve cost efficiency, which is discussed in the next section. In order to achieve the minimum precision, sampling intensity may be changed during a survey.

Generally the sampling intensity specified in guidelines in Australia should ensure an acceptable sampling error. However in marginally stocked stands the error could be unacceptably high to make a decision about success, and the sampling intensity could be increased to determine success more reliably. Increasing the sampling size has the effect of reducing sampling error, reducing the width of confidence intervals and increasing the lower confidence interval for an estimate. In Australia sampling error or confidence intervals are not calculated and error margins should be built into the system by increasing the value of standards. Thus, in Victoria the minimum stocking standard is marginally higher than the desired value to account for error in the estimate, and in marginally stocked stands a double sampling intensity is used and a lower standard is able to be applied. In Canada a formula is used for determining the number of plots required for marginal stocked areas (Ministry of Forests 1999). It should also be noted that they use a lower sampling intensity than used in Australia (approximately 0.5% compared to 1.0% by area) and claim to achieve a sampling error of around 15% for stand parameters.

Cost efficiency

Husch et al (1972) give an equation for relative efficiency based on the comparison of standard error (%) and the cost of surveys with alternative plot size, shape or survey technique. An alternative approach was taken by Czaplewski *et al* (in prep) who assumed that sampling cost was fixed by fixing the total area to be sampled. Thus by varying plot size x no. plots sampled, and comparing the coefficients of variation, an optimum plot size was determined for basal area measurement in *E.regnans* regeneration at a given age. Cost efficiency has not been reported for regeneration surveys in eucalypt forests in Australia, but a review of methods in Canada suggest that distance methods are more cost efficient than stocked quadrat for determining stocking or seedling density in aggregated stands. In the Australian states where quadrats are the usual, the use of circular plots up to $16m^2$ are probably the most cost efficient because this size can easily be searched from the plot centre and the boundary is easily located. Experience in East Gippsland, Victoria, indicates that the triangular tessellation method takes approximately twice as long as the stocked plot method (pers. comm. Mark Lutze, CFTT).

Regardless of the method of survey, timing of the survey affects cost efficiency because of access and ability to detect seedlings. Later surveys enable easier detection of seedlings and survival potential, but access difficulty and time spent moving between plots increases with time since harvesting. There may be potential to reduce costs of later surveys through remote sensing and DMSV (digital multi-spectral videography) methods are currently being evaluated for use in eucalypt regeneration surveys.

In Australia, decisions regarding the use of regeneration surveys could be improved on the basis of cost/benefit analysis. Variables related to survey costs would include the type, timing and option of additional surveys (eg at year 5 to determine productivity). The benefits would include the timely correction of regeneration failure (reduce lost production years); growth and yield forecasting, and identification of best stand management practices (potential gains in financial returns).

Sustainability evaluation systems

The following discussion firstly covers current evaluation systems which are targeted at sustainability at the coupe level. Then the potential for aggregation of current systems is discussed.

Comparison of current standards

A simple analysis of the current coupe standards for seedling regeneration indicates there are differences. For simplicity, if one assumes a systematic distribution of seedlings and converts stocking to minimum seedling density (see 5.2.3) the following values are obtained:
Vic: 625 spha x 65% = **400** spha; **Tas** (see 5.1.2): 625 spha x 80% x 33% = **170** spha; **WA** ***E. diversicolor***: 1666 spha x 85% = **1400** spha; **WA** ***E. marginata***: 5000 spha x 65% = **3250** spha; **NSW**: **500** spha.

The current initial stocking standards for even-aged stands are based on achieving:
- desired number of crop trees at time of first thinning in Western Australia (CALM 1990, Bradshaw and Gorddard 1991)
- fully stocked regrowth stands in Tasmania (Mount 1961)
- wood production objectives over the rotation in Victoria (Edgar and Opie 1967).

The literature is deficient because it is stated or implied that they include a margin for mortality, but the actual target density and allowance for mortality are not explicitly stated. Another difficulty with the current standards is that in Victoria, Tasmania and New South Wales there is no variation in standard with forest type and silvicultural objective. Thus it is apparent that there is insufficient information about the scientific basis of the standards to determine the appropriateness of the standards.

The analysis of variation in estimates of stocking over the period 1 to 5 years in the section on early stand development, suggests that timing will have little influence on the total number of seedlings present, but will have a large influence on the ability to assess survival potential or dominance of individual seedlings.

In Victoria, Tasmania and Western Australia there are similar rules concerning the excising of understocked areas from stocked areas and the calculation of stocked vs unstocked areas. However there is variation in the standards applied to the point estimates between WA and the two other states, which means that the area estimates are not directly comparable. There is considerable similarity between the Victorian and Tasmanian systems, the main difference is that in Tasmania the area that meets the mapping rule standard is reported. In Victoria an understocked part of a coupe may be excised and retreated, but up until now, the percentage of stocked plots in the entire coupe area has been reported.

Thus the differences in standards between states may be considerable and it may be a major task to resolve these to the satisfaction of all parties. An alternative approach to the reporting of binary data (ie successful or unsuccessful) which is implicit in current approaches, is to report measurement data along with evaluation standards. For example, one could present data in a table like the following:

Forest type	Area with Seedling Density 0-1000 spha Stocking 0- 40% (Understocked)	Area with Seedling Density 1001-2000 spha Stocking 40-60% (Low wood quality)	Area with Seedling Density 2001-4000 spha Stocking 60-80% (Optimum wood production)	Area with Seedling Density >4001 spha Stocking 80-100% (Overstocking)

Forest type A	A1	A2	A3	A4
Forest type B	B1	B2	B3	B4
Forest type C	C1	C2	C3	C4
Forest type D	D1	D2	D3	D4

Where A1....D4 are the area (ha) of forest in each category.

In addition to simplifying the comparison of existing standards, this approach has the advantage of being able to determine the variation in regeneration measures over time, even if the standards change.

Aggregation to regional and national scales

When results from a number of sources are aggregated, precision of the combined estimates can be reduced through variation between the source data resulting from:

- Assessment procedure: bias associated with interpretation of procedures (eg identification of acceptable seedlings), ability to detect differences (eg species or growth stage identification) and/ or technical error (eg equipment failure)
- Forest type and geographic location: differences in regeneration ecology and silviculture between forest types and regions and associated variation in regeneration success
- Ecological patterns (eg spatial distribution of seedlings)

The error from the assessment procedure is likely to be random and not of particular consequence, but the latter two sources of error need to be addressed in this project. Forest type and geographic location bias requires further study and will probably be addressed through stratification. However the aggregated distribution of regeneration is probably highly variable within any forest type or region and needs to be addressed in another way.

One of the greatest difficulties with aggregated seedling distributions in the context of this project is the complication of the comparison of seedling density and stocked quadrat estimates. In the case of random distribution of seedlings, quadrat counts fit the Poisson distribution. The probability of obtaining at least one seedling in a plot of a given area (ie the frequency of stocked plots) amongst a population of a given mean seedling density can be readily determined from the theoretical distribution (Kershaw 1964). However, for aggregated distributions, empirical relationships between frequency and seedling density have been derived, but their general applicability must be questioned. Cunningham(1960) reviewed the relationship between seedling density and frequency of stocked plots that had been reported by various studies in coniferous forests of North America and compared them to results on one milacre plots in *E. regnans* forest. He found that at lower stockings there was similar seedling density in coniferous and *E. regnans* forest but at higher stockings seedling density was greater in *E. regnans* in the Central Highlands , Victoria, indicating greater over–dispersion. Mount (1964) reported that seedling densities were even higher over a large range of stockings in Lowland Wet Eucalypt forest in the Florentine Valley, Tasmania. The complexity of the correlation task is increased by the fact that the apparent spatial distribution and the relationship may change with plot size (Ghent 1963, Kershaw 1964, Bella 1976, Boyer 1977).

Mount(1964) proposed the use of a heterogeneity index and seedling density to describe regeneration, avoiding the reporting of frequency or stocking. Heterogeneity indices, a measure of the degree of departure from randomness, have been proposed by a number of authors (Fracker and Brischle 1944, Gill 1950, Mount 1964). Essentially they are based on the departure of the observed distribution of counts from the random (Poisson) distribution, where the mean and variance are equal (Kershaw 1964). Instead of calculating the variance to mean ratio, the observed mean density is expressed as a ratio of the density with a random distribution corresponding to the observed frequency of stocked plots. Mount (1964) suggests that his index is generally constant over a range of stocking and quadrat sizes, and is a measure of the factors that produce aggregation. Routine determination of the heterogeneity of regeneration could increase the scientific validity of the standardisation of regeneration results.

2.5.3 Summary- appropriate measures of regeneration success and potential to standardise at the national level

Site occupancy, species composition and growth are important measures of regeneration of Australian native forests. Bole quality is also a measure applicable to high quality wood production. Of these, site occupancy is most developed, species composition is in an early stage of development and growth has not been developed at all. There are similarities in objectives between states that indicate that standardisation at the national level is appropriate. However there is variation between measures and evaluation standards that requires substantial research and development to achieve national standardisation.

2.6 Research and Development Needs

2.6.1 Research and development priorities

The current measures in Australia do not fully meet the requirements of the sustainability indicator proposed for development in this study. Although site occupancy is generally covered at an early age there is little scientific evidence relating site occupancy at an early age to long term productivity. Other parameters such as species composition and growth parameters are inadequately covered. The current measures may be improved in the following ways:

- include an assessment of acceptability of seedlings/saplings that infers a probability of survival that is consistent with the evaluation standards
- include all stand components in assessment and evaluation of site occupancy in uneven-aged stands
- include species composition- an estimate of species coverage on each plot (at least the presence or absence of each species at each plot)
- growth could be incorporated through assessment at a later age when growth rates are more indicative of long term growth rate (eg 5 years). Integration with other Montreal Process indicators (eg soil indicators) could provide additional incentive and address the major cause of growth variation within intensively harvested areas in a cost efficient way. One could include tree quality in an assessment of growth
- there is the possibility of integrating the proposed 2.1(g) indicator with other Montreal Process indicators that are related and measured at the coupe scale, such as soil chemical and physical properties and related effects on growth at the sapling stage. Remote sensing methods may be used to assist in this process.
- inclusion of understorey- an acceptable approach may be to develop measures of a limited number of indicator species, which have particular biological attributes and represent broad plant groups. Theoretically the issue of species composition (including understorey) should be addressed in Montreal Process Criterion 1 (Conservation of Biological Diversity), but the indicators within this criterion will probably be applied at a broader scale than the coupe. However there may be a case for integrating criterion 1 indicators with criterion 2 and 4 indicators (see below).

Thus it is apparent that in order to meet sustainability monitoring requirements there needs to be modification of current methods. The review of regeneration processes and management objectives suggests that there is enough similarity between the major forest types to develop a set of standard parameters. However there is too much variation to develop a single system of regeneration monitoring to suit all forest types, although some groupings of forest types on the basis of regeneration processes may be possible. The following will vary between forest types/ forest type groups:

- acceptable stand components and attributes
- timing of surveys
- standards of site occupancy, species composition and growth

It is unlikely that new methods will be suddenly introduced, as there will be a cost associated with preparation and printing of new guidelines and retraining. In the first instance it may be feasible to present information from existing survey methods in a standardised way, thus meeting one of the objectives of the project. The major issue with standardising results from existing methods is the variably aggregated nature of natural regeneration which does not fit known statistical distributions. However there is potential that empirical relationships may be developed on the basis of the study of theoretical and actual seedling distributions. This is considered to be the highest R & D priority for the current project.

Other high research and development priorities are as follows:

- Determine useful measures of regeneration success (including density, species composition and growth).
- Identify the optimal timing of measurement of regeneration success, particularly for growth and species composition.
- Develop a process for evaluating regeneration success from the measures, including its relationship to the natural processes of regeneration.
- Identify critical components for the monitoring of stocking in uneven aged stands.

2.6.2 Regeneration Reference Sites (RRS)

The RRS concept

The detailed research proposal for this project specifies that further research and development be carried out on Regeneration Reference Sites (RRS). The main objective of the RRS is to provide information for the expression of regeneration success in terms of the degree of similarity between harvested and naturally regenerated stands. The proposal includes details of the plot types to be used and outlines the parameters to be measured and the analyses to be carried out. These are as follows:

- establish band-width measures of regeneration and early stand development (density, species composition, spatial distribution, growth and survival) for managed and natural stands
- establish relationships between initial seedling density and subsequent regeneration density and growth
- conduct desk top studies to establish the ability of different survey methods to accurately reflect relevant stand parameters
- develop and test a standardisation procedure for aggregation to regional and national levels which would include the use of stand parameter ratios of natural and managed stands.

Current experimental sites as RRSs

At present these regeneration reference sites do not exist, although there are a number of existing research sites which contain components which could be used for the purposes of the study. There are two main deficiencies in the existing research sites with respect to the proposal:

- They do not include natural stands
- The experimental design and monitoring method vary greatly between sites

There are a number of experimental sites designed to test the effects of silvicultural treatments which have data which would enable stand parameters to be calculated from an early age to sapling age and beyond. The time sequence of stand parameters would be useful for determining the relationships between initial seedling density and long term productivity. Some of these sites have data from permanent plots in which individual trees have been identified and measured over a period of time, which would be useful for evaluating the ability to identify potential successful or co/dominant seedlings at the regeneration survey stage. However, of particular note is the deficiency of stand maps at the stage at which regeneration surveys are carried out The only examples are from Brockley Rd in Tasmania from age 1 and data from the Central Highlands of Victoria from age 4 may be useful. Plot data without spatial coordinates of individual seedlings provides little information about the spatial distribution of regeneration which is a key component of site occupancy. Thus there is little information relating stocking at an early age to long term productivity. The two examples of sites with spatial distributions are based on a number of plots of 20 m x 20 m and 40 m x 20 m positioned to sample a relatively homogenous stand structure within each plot, which is deficient from the point of view of the aims of developing measures of regeneration success which are generally applied at the coupe scale.

The value of establishing RRSs

It would seem that none of the existing regeneration study sites meet the needs of an RRS, as conceptualised in the project proposal. The value of establishing the RRS in the current project needs to be questioned. The experience with establishing experimental plots in regeneration areas indicates that these sites could be expensive to establish ($10,000 to $1,000,000), the actual cost depending on the number of treatments, replication and sampling intensity of monitoring. If established , these sites would immediately provide valuable information about initial seedling spatial distribution, but it would be some years, probably after the completion of the current project, before they would provide useful information about stand dynamics. Given the resources available to the project the establishment of a number of RRSs should be along simple designs with few treatments and low intensity sampling, to enable important objectives such as developing relationships between initial stand parameters and long term productivity to be addressed. In contrast, the data from existing study sites could be added to at minimal cost and used to address most of the objectives of the current project within the allocated budget. The main exception would be the reference of managed stands to natural stands.

The concept and practicality of reference to natural stands

The concept of reference to a natural stand has merits from the ecological viewpoint in that over a period of time the departure from a natural process could be evaluated in terms of significance to long term ecological stability. Of particular interest would be the differences in spatial distribution that may occur between natural and some managed stands (eg the difference between a wildfire regenerated and planted *E. pilularis* forest). However there is some cause for concern over the prominence given to this aspect of the study in the proposal. The indicator 2.1(g) is within the criterion of maintenance of ecosystem productivity , whereas the question of the extent of the forest resource in a natural state in a particular growth stage might better be addressed by indicator 1.1(d), within the conservation of biological diversity criteria.

There are additional concerns about the ability to provide meaningful data about the development of stands under natural conditions within the time frame of the current project, as there are no data currently available and any new data would by necessity be retrospective and of dubious value. As mentioned in the previous section , any newly established sites would take some years to yield useful data. A further practical difficulty is that naturally regenerated stands may not occur near existing research sites or near areas of ongoing harvesting activity, which may make it necessary to compare data between remotely located natural and managed stands.

A new proposal for the role of RRSs

- In view of the conceptual and practical difficulties of the original RRS proposal it is proposed that the RRS concept be altered with respect to the current project. This change would be consistent with proposed changes to the objectives of the current project. The principle proposed change is the development of measures which enable regeneration success to be expressed in terms of long term productivity rather than in terms of similarity to natural stands. The objective can largely be met by using existing data and minimal collection of new data. The role of RRSs is considered to be a long term one, with some data contributing to the current project. The objective of RRSs will be to evaluate, develop and test measures of regeneration success.

- As written in the original RRS proposal the RRS could include two plot sizes. The sites could initially provide information about the spatial distribution of seedlings in large contiguous areas (eg 20m x 20m plots) and in smaller spatially dispersed plots (eg 16 m^2 plots on a 80m x 20m grid) and include areas of varying seedling density. These plots will be monitored over time to provide information about stand dynamics and long term productivity. The RRSs will be an integral part of ongoing R & D program to improve regeneration success. The source of funding for this proposal would need to be negotiated.

2.7. Conclusions

2.7.1 Regeneration success measures

Management objectives and silvicultural systems

- A regeneration monitoring system needs to incorporate measures of success that are related to the objectives of management and the silvicultural system being used to implement that objective.
- Measures need to be evaluated against standards that are related to the objective of management and are scientifically based.

Success measures

- Site occupancy, species composition and growth are general classes of regeneration success measures which are relevant to the objectives, management systems and ecosystems of Australian forests. Bole quality is also a measure applicable to high quality wood production.
- Within each class of measures there may be a number of specific measures, such as in the class of site occupancy which includes quadrat stocking, seedling density and/ or distribution measures. The stocked quadrat method is a sensitive, simple and scientifically valid measure, which includes minimum seedling density and distribution.
- Further research is needed to identify measures of species composition and growth.

Acceptable seedling definition

- Measures of regeneration success that are based on the seedlings that have a high probability of success are potentially more sensitive than one based on all seedlings, of which a highly variable number will survive. There is a need to determine the potential to identify successful seedlings and acceptability criteria that can be applied as a component of regeneration success measures that are applied at an early age.

2.7.2 Regeneration processes and silviculture

Variation with forest ecosystem type

- Regeneration processes vary with species and environmental factors
- Wet sclerophyll forests require extensive disturbance for successful regeneration from seed.
- Drier forests with dense understoreys require similar conditions.
- Drier forests and woodlands with lesser understorey development require minimal disturbance for regeneration from seed. Many species form lignotubers, persist as small seedlings in the understorey, and grow to sapling and pole stages after release from competition. Regeneration from coppice may be significant.
- The success of regeneration can vary greatly with seasonal variations in seed supply, germination, survival and growth in all forest types.
- There is a need to better understand the dynamics from seedling to senescence in order to determine long term ecosystem productivity in all forest types. The ability to identify successful seedlings at an early age would assist greatly with monitoring of regeneration success.

Variation with silvicultural system

- Silviculture varies with forest type and management objectives.
- Even aged systems (clearfelling, seedtree) are usually applied to wet sclerophyll forests, regeneration success being dependent on rapid establishment and initial growth rates.
- Uneven aged systems (single tree selection, group selection) are commonly applied to drier forests, although even-aged and multi-aged systems (shelterwood, retained overwood) are used and result in successful regeneration.
- The silvicultural systems applied in managed forests have elements in common with natural regeneration events in the ecosystems to which they are applied (eg clearfall and burn cf intense wildfire in wet forests, selective harvesting and partial ground disturbance cf low intensity wildfire in drier forests), but there are important differences in these systems that need to be understood and managed in order to maintain forest values such as wildlife habitat. However the variability in natural systems is probably much greater than in managed systems, which are inherently variable.
- There are basic measures of regeneration success applicable to all forest types, but variability in regeneration ecology and silviculture require development of specific monitoring and evaluation systems

2.7.3 Regeneration monitoring practices

Site occupancy

- Most states have well developed measures of site occupancy applicable to the range of silvicultural systems applied. Victoria and Tasmania use stocked quadrat methods whilst Western Australia uses a combination of density and stocking and New South Wales uses average seedling density.
- The primary research needs are: to establish the relationship between these regeneration measures of site occupancy and long term production outcomes and to develop methods for comparing results from the different systems.

Species composition

- Measures of species composition are in an early stage of development and are a high priority for research and development.

Growth and quality

- Routine monitoring of early growth and stem quality is not practised in any state. They are important measures of regeneration success particularly in meeting long term wood production objectives and require research and development.

Monitoring methods

- Measures applicable to the objectives of management require field based monitoring that is practical and cost-effective. Important considerations are timeliness, ability to provide clear management direction, statistical precision and training required to monitor the forest accurately.

- There is similarity between sampling approaches at the coupe level in Australia, which are generally statistically sound and cost effective. The approach of sampling less than 100% of all coupes at the regional level, may be a cost effective alternative for strategic level monitoring.

Evaluation standards

- The development of evaluation methods and standards requires a thorough understanding of stand dynamics from seedling through to maturity in order for measures to be indicative of long term ecosystem productivity.
- There is considerable variation between evaluation standards between states, but the variation in the measures, ecology and silviculture of the forests to which they apply make meaningful comparisons difficult.

2.8. Recommendations

2.8.1 Strata for Aggregation to National Level

Aggregation of regeneration results to the National level be based on strata that incorporate State (Regional), forest type and silvicultural differences. For example the following strata could be used:

- States
- Forest types
  - closed
  - eucalypt- wet intolerant
  - eucalypt- wet tolerant
  - eucalypt- dry mixed non-lignotuberous and lignotuberous
  - eucalypt- dry lignotuberous
  - woodland

  Alternatively use the National Forest Inventory forest types
- Silvicultural systems
  - even-aged
  - uneven-aged

2.8.2 Regeneration success measures

- Site occupancy, species composition and growth, including bole quality, be used as basic measures of regeneration success.
- Research and development be carried out into site occupancy, species composition and growth, as follows:

Site occupancy
- evaluate accuracy of measures of site occupancy, including those currently in use in Australian forests and feasible alternatives
- establish relationships between existing measures and standards and long term productivity
- determine the potential for identification (and the acceptability criteria, if applicable) of successful seedlings in the field
- establish the relationship between existing measures of site occupancy in use throughout Australia
- develop a procedure for comparing the results from different survey methods including a broad stratification of regeneration success based on management objective
- develop improved methods of stratifying and mapping stocking status at the coupe level
- evaluate measures of site occupancy for components of multi-aged and uneven-aged stands.

Tree species composition

Evaluate existing methods for monitoring of species and develop a method for use in both even and uneven aged stands.

Growth

- Develop field methods for identification and measurement of height and diameter of potential co-dominant and dominant trees.
- Develop and test height and basal area from seedling to sapling stages as measures of growth.
- Develop and test measures of bole quality, including:
  form, branching habit, potential for internal defect

2.8.3 Regeneration reference sites (RRS)

- RRSs should be established in the full range of forest types across Australia and include as the highest priority the range of silvicultural systems applied in that forest type, and as a secondary priority naturally regenerated areas where this opportunity is available.
- The objective of RRSs will be to evaluate, develop and test measures of regeneration success.
- RRSs will initially provide information about the spatial distribution of seedlings in large contiguous areas (eg 20m x 20m plots) and in smaller spatially dispersed plots (eg 16 m^2 plots on a 80m x 20m grid) and include areas of varying seedling density. These plots will be monitored over time to provide information about stand dynamics and long term productivity. The RRSs will be an integral part of ongoing R & D program to improve regeneration success.
- A pilot study should be established in one forest type to develop and test the RRS methodology.

2.8.4 Trial of national reporting procedure

- Aggregation to the regional and national level be tested by a desktop study involving all states. Regions should be included that enable aggregation of regeneration results from similar forest types and silvicultural systems but collected by different regeneration survey methods. A reporting format will need to be developed that is consistent with National reporting standards. This study should be funded separately by the Commonwealth but integrated with the present study.

3. Regeneration Reference Sites

3.1 Introduction

The main objectives for R & D, identified in the review, are given in the following paragraphs, along with proposed studies at RRSs to achieve those objectives. The RRS strategy includes the establishment of new sites (table 3.1, section 3.2), where existing sites (table 3.3, section 3.3) do not meet the study objectives.

Site occupancy

- evaluate accuracy of measures of site occupancy, including those currently in use in Australian forests, and feasible alternatives
- establish the relationship between existing measures of site occupancy in use throughout Australia
- develop a procedure for comparing the results from different survey methods including a broad stratification of regeneration success based on management objective

These objectives require study of the effect of spatial distribution on estimates of site occupancy by various methods. There were few stand maps available and further knowledge of spatial distributions in real stands was required to assist in developing relationships between site occupancy measures and conversion methods. This data was obtained at new RRSs from large contiguous plots (stand maps) and small plots dispersed across a regeneration area.

- *establish relationships between existing measures and standards and long term productivity*

This objective requires study of the variation in site occupancy over time and relationship between initial stocking and long term timber production. There are data available for dry eucalypt forests (Brockley Rd) and wet forests (pre-commercial thinning data) of Tasmania, *E. diversicolor* forests of Western Australia and *E. regnans* forests of Victoria. This objective can not be fully achieved in the time frame of the project, but RRSs will provide data for meeting this objective in the future. This objective should include the quality of stems produced at different levels of site occupancy.

- determine the potential for identification (and the acceptability criteria, if applicable) of successful seedlings in the field

This objective requires individual seedling growth to be measured intermittently over a long term. Such data are available for 3 forest types, lowland forest and E. regnans forest of Victoria and dry eucalypt forest of Tasmania. New RRSs will provide data to meet this objective in the future.

- develop improved methods of stratifying and mapping stocking status at the coupe level

This objective requires the long term monitoring of site occupancy across a discrete regeneration area. This is not the highest priority for the current project, but the study can be initiated by establishment of a survey grid and marking of plot centres for later monitoring at the new RRSs.

- evaluate measures of site occupancy for components of multi-aged and uneven-aged stands.

This objective can not be fully met within the time frame of the current project, because the existing studies do not include all components (ie regeneration, saplings, poles and mature trees). This project will concentrate on the regeneration component of group selection systems in E. pilularis forest of NSW , E. marginata forest of Western Australia and dry eucalypt forests of southern Queensland. Recommendations will be made for R&D into site occupancy based on all components in uneven-aged stands.

Tree species composition

- Evaluate existing methods for monitoring of species and develop a method for use in both even and uneven aged stands.

This objective involves the consideration of both methods and evaluation systems. Effect of spatial distribution on estimates of species composition by various methods can be studied in mixed species study sites for which there are stand maps. Currently there are stand maps for dry eucalypt forest of Tasmania. There will also be stand maps available for the new RRSs in a few additional mixed species forest types. The study of variation in species composition over time is a fundamental part of species evaluation systems. Currently there is data available for species dynamics to pole stage in dry eucalypt forest of Tasmania and to sapling stage in lowland forests in Victoria. Further data will be available in the long term from RRSs.

Growth

- Develop field methods for identification and measurement of height and diameter of potential co-dominant and dominant trees.

Currently measures of growth are not routinely applied at the time of regeneration surveys, but height and dbh of the most competitive seedlings could be useful indicators of long term stand growth. There are data available from regeneration studies in *E. regnans* and lowland forest of Victoria and dry eucalypt forest of Tasmania and *E. diversicolor* forest of Western Australia.

- Develop and test height and basal area from seedling to sapling stages as measures of growth.

Growth measures are potentially more usefully applied at a later stage than when regeneration surveys are currently conducted. The same sites as used for the first objective in the development of growth parameters can be used for this study.

- Develop and test measures of bole quality, including form, branching habit, potential for internal defect

This objective requires the measurement of bole quality from an early stage, although later than the timing of existing regeneration surveys. Such data does not currently exist but could be collected at existing regeneration study sites and at new RRSs after a suitable period of stand development..

3.2 New Regeneration Reference Sites

3.2.1 Objectives

- To characterise the spatial distribution and attributes (species composition, competitive position, growth) of seedlings at the time of regeneration surveys
- To test procedures for comparing results from different regeneration survey methods
- To monitor changes in spatial distribution and attributes over time in order to relate initial stocking to stand productivity over a rotation and refine standards of regeneration success.

3.2.2 Methods

As recommended in the review a pilot study was conducted in the lowland forest of Victoria to test the RRS plot methodology . The following methodology was applied.

Apply alternative methods of measuring site occupancy on a suitable sized sampling grid to fit the stand size (minimum 30 plots per stand is required)

Seedling density by a number of distance methods
Seedling density by triangular tessellation
Seedling density by 4 and 16 m^2 quadrat counts
Stocking by 4 and 16 m^2 quadrats
Stocking by triangular tessellation density
Seedling density of acceptable seedlings (Victorian rule *)
by triangular tessellation, distance methods, quadrat counts
Stocking of acceptable seedlings (Victorian rule)
by triangular tessellation density and stocked quadrat

Plots were mapped and the centre marked to enable relocation and re-measurement at suitable intervals (eg ages 1-2, 3, 5, 10).

Stand maps were prepared for 3 large continuous areas (eg 20 m x 20 m) representing the range of seedling densities in the stands sampled by the small plots. Seedlings on subplots were tagged, measured & attributes (e.g. species, dominance, competitive position, height, growth stage, form, "acceptability") were recorded. It is proposed that these be remeasured at same intervals as the small plots on the sampling grid and at age 10-15 to tag, measure dbhob, form, dominance of all trees and height of co-dominants.

In response to the pilot study the above methodology was modified to reduce the resources spent on this study. Thus the assessment of acceptable seedlings was only carried out at Victorian sites, ie only in the state where the criteria is routinely applied. Also stand maps were prepared at the Victorian, Tasmanian (the Warra sites) and Queensland sites only.

3.2.3 Study Sites

Stands varied from marginally regenerated to well stocked in order to test the ability of different survey methods to detect varying levels of regeneration performance. The key states and forest types were identified through the review but there were insufficient funds to cover all the important forest types. The forest types sampled were as follows:

- QLD *E. maculata*;
- NSW *E. pilularis*;
- WA *E. marginata*; *E. gomphocephala*
- VIC- low and high elevation mixed species,
- TAS Wet *E. obliqua*.

Resources also limited the of areas sampled (table 3.1) and the extent (no. of plots) of each sampled area.

Queensland sites

The dry sclerophyll forests of south-eastern Queensland are believed to be regenerated by lignotuberous seedlings, which are released when a gap in the overstorey is created by timber harvesting. The contribution of seedling regeneration, the adequacy of lignotuberous stock to provide regeneration and the ability of lignotubers to grow following release are not understood very well. Thus in addition to applying alternative survey methods, there will be detailed monitoring of germination, survival and growth in this forest type. At the RRS 100 plots will be established before harvesting and monitored again after harvesting. In 30 plots all seedlings were tagged for later identification, measurement of growth and survival, and to enable the monitoring of further recruitment. Pre-logging surveys were carried out in December 1999 and post-logging surveys in 2000.

New South Wales sites

Group selection, with gaps up to 40m in diameter, is the silvicultural system most commonly applied in the *E. pilularis* forests of the north coast of NSW. Plots were established in gaps at 3 sites, two with dense regeneration and one site with patchy and marginally dense regeneration. Four plots were systematically located in each gap. These plots were used to test alternative regeneration survey methods. Surveys were carried out in April and June 2000.

Western Australian Sites

E. marginata forest

Timber harvesting and associated stand treatment operations in *Eucalyptus marginata* (Jarrah) forest involve regeneration in one of two ways:

a) release of existing lignotuberous advance growth by means of gap creation, or
b) establishment of seedling regeneration beneath a shelterwood.

Regeneration survey grids were established at three sites (one gap, two shelterwood) each having a minimum of 30 survey points that are permanently marked and able to be relocated. Locations for study are:

- Kingston, north-east of Manjimup. A major integrated study investigating the impacts of timber harvesting on forest birds and terrestrial fauna, flora and soil physical properties has been underway in this area since 1995.
- Poole, 40 km south-east of Manjimup, in *E. marginata* / *E. calophylla* forest subject to shelterwood harvesting treatment.

Surveys were undertaken in the period May-July 2000 and September 2001.

E. gomphocephala forest

Eucalyptus gomphocephala (Tuart) occurs as an open forest or woodland on coastal soils derived from limestone. Timber harvesting has all but ceased in state-owned *E. gomphocephala* forest, but regeneration processes remain of interest in conservation reserves particularly for stands damaged by high intensity fires and boring insects.

Two regeneration survey grids were established in an area of the Yalgorup National Park damaged by a high intensity wildfire in March 1996. A preliminary field inspection confirmed the presence of some *E. gomphocephala* regeneration, but further detail about the stocking density, distribution and relationship to mature trees is required to determine whether the regeneration will be sufficient to replace the original stand. These grids are likely to be of particular value in assessing the merits and limitations of different site occupancy measures because the *E. gomphocephala* forest is less densely stocked than other forest types and is likely to have a strongly aggregated pattern of seedling regeneration.

Surveys were undertaken in the period May-July 2000.

Victorian Sites

The high elevation mixed species forest of East Gippsland consistently achieve lower stocking levels than other forest types in Victoria. Recent research has indicated that regeneration performance can be improved by retaining seed trees instead of clearfelling. Two high elevation mixed species coupes were chosen for the study, one clearfelled, slash-burnt and aerially sown and the other with seed tree retention, slash-burning and areial sowing. These sites will be useful for testing the current methods and standards in areas with marginal regeneration performance.

The regeneration of low elevation mixed species forests have been the subject of intensive research in eastern and central Victoria. However there is little information available about the relationship between initial seedling density and spatial distribution and long term growth. Three coupes were selected for study covering the range from low to high site occupancy and seedtree and shelterwood silvicultural systems.

Sites were surveyed in the period March to September 2000.

Tasmanian Sites

The Tasmanian sites were located at the Warra Long Term Ecological Reference site and cover 2 treatments in the silvicultural systems experiment, which have produced low and high density regeneration. The coupe names and treatments are as follows:

- Low density regeneration coupe Warra001B Dispersed Retention (10% BA), low intensity burn and naturally sown in March 1998
- High density regeneration coupes Warra008B Clearfell, high intensity burn and sown artificially in March 1999.

In addition surveys using the various measures of site occupancy were carried out on a portion of a routine coupe (clearfall, high intensity burn, sown in March 1998) in Geeveston District *(Picton 024A)*

3.2.4 Results

The results of the first measurement of the new RRSs are summarised in the appropriate tables in sections 4 and 5. The result tables are listed by objective in the following paragraphs:

- Characterise the spatial distribution and attributes (species composition, competitive position, growth) of seedlings at the time of regeneration surveys

The spatial distribution of seedlings as determined by the variation in sparsely sampled plots (table 4.4) and in mapped stands (table 4.2).

Density by species and stocking by species (table 5.1) and species association (table 5.2) in mapped stands. Density by species and stocking by species (table 5.4) and species association (table 5.3) in mapped stands.

- To test procedures for comparing results from different regeneration survey methods

Comparison of seedling density and stocking (table 4.4) and species composition (table 5.6) by different survey methods in sparsely sampled plots.

Table 3.1 The representation of forest types and silvicultural systems by new regeneration reference sites

Sites	Location	Forest type (associated species)	Silvicultural system
WayWay, Lower Bucca, Nambucca	North coast NSW	E. pilularis (tallowwwod, ironbark, flooded gum, red mahogany etc)	group selection
Exp 631 HWD	Coastal SE Qld	E. maculata (*grey ironbark, white mahogany, brush box etc*)	single tree selection
Picton 024A, Warra 001B & Warra 008B	South Tas	Wet *E. obliqua*	Clearfall Seedtree, Clearfall
Clarkeville Rd, Students Tk	East Gippsland, Vic	High Elevation Mixed Species (*E. fastigata, E.obliqua, E.denticulata, E.cypellocarpa*)	Clearfall Clearfall and seedtree
Steep Gully Mountain View Bellbird Tk	Midlands, Midlands, E. Gippsland, Vic	Lowland (*E. obliqua, E. radiata, E. ovata, E. rubida*) Lowland (*E. sieberi, E. globoidea, E. baxteri, E. cypellocarpa*)	Shelterwood Seedtree
Poole	S.W. WA	*E. marginata, E. callophylla)*	Shelterwood Gap
Yalgorup	S.W. WA	E. gomphocephala	Natural (wildfire)

3.3 *Existing regeneration study sites*

3.3.1 Tasmanian sites

Site: Pre-commercial Thinning Assessment (various sites)

The aim, methods and results are fully reported in LaSala and Dingle (2001).

Aim: To compare the original regeneration survey information (area mapped as stocked, $4m^2$ percent and $16m^2$ percent figures) with later age density (sph) to determine if regeneration surveys can be used to screen potential coupes prior to a pre-commercial thinning assessment.

The information collected for each coupe was:

1. percent of area mapped as stocked, $4m^2$ and $16m^2$ percent of plots stocked as reported by the district for each coupe
2. $4m^2$ and $16m^2$ percent using the mapping rules
3. $4m^2$ and $16m^2$ percent of the area assessed for pre-commercial thinning
4. sowing rate information (kg/ha)
5. stems per hectare (density), age, site index, sawlog percent and species composition

Regeneration survey information was collected from 52 coupes assessed for pre-commercial thinning in 6 districts around the state. From 2 to 19 pre-commercial thinning coupes per district were used. Stand age at PCT assessment varied from 8 to 27 years.

Regeneration Surveys

Plot layout: Strip lines were located at 100m intervals with plots spaced at 20m intervals along the strip lines.

Plot size: 4m^2 plots (radius = 1.13m) assessed for seedlings, where inspection of the 4m^2 plot indicated no seedlings present, a larger circular plot of 16m^2 (radius 2.26m) was searched.

Recorded at each plot:

1. Nature of seedbed, B (burnt), D (disturbed), U (unburnt and undisturbed).
2. Presence of one or more seedlings on the 4m^2 plot.
3. Only when the 4m^2 plot is not stocked, a search for seedlings was extended to the 16m^2 plot.

PCT Assessment Surveys

Plot layout: A 200m by 100m grid overlay was placed on a map with strip lines running across the majority slope. Strip lines were 200m apart with plot points spaced at 100m intervals along the strip lines.

Plot size: Plots were established using a 5.64m radius string, forming a plot that is 100m^2.

Recorded at each plot was:

1. The DBHOBs of all eucalypts and silver wattle trees greater than 2cm diameter were measured and recorded into diameter classes (diameter classes are in 1 cm increments). All trees with a diameter over 30cm were put into the 29cm-30cm diameter class
2. Whether trees were a potential sawlog tree or a pulp tree. All wattle was regarded as pulp
3. The major eucalypts species, but trees were not recorded as individual species. Blackwood trees were not measured.
4. The height of the tallest tree on the plot.
5. A measure of insect damage.
6. Five significant understorey species (that might impede operator movement in the stand).

Results:

Stocking by 4 m^2 and 16m^2 plots at age 2 varied from 21 to 100% and 31 to 100% respectively. Density at pre-commercial thinning age (10-27 years) varied from 375 to 4963 stems per ha. Later age density was positively correlated with initial stocking by 4m^2 and 16m^2 plots (R^2=0.5). However there was too much variation in the relationship to confidently identify those areas that would benefit from pre-commercial thinning. The variation is probably due to the different locations of the regeneration survey and PCT assessment plots combined with a low intensity of sampling (less than 1% by area) at both assessments. The results support use of regeneration reference sites that include a 100% sample (stand maps) and permanently marked plots.

Site: Brockley Road

Objectives:

To characterise the spatial distribution and attributes (species composition, competitive position, growth) of seedlings at the time of regeneration surveys

To determine if the $4m^2$ or $16m^2$ stocking can be correlated with density at age 20.
To determine which stocking produced the highest Estimated Standing Volume (ESV) or MAI at age 20.
To determine which density and stocking produced the highest sawlog percent.

The information collected for each plot was:
1. $4m^2$ percent and the $16m^2$ percent
2. sowing rate (kg/ha)
3. stems per hectare (density)
4. sawlog percent
5. Estimated Standing Volume and MAI

Site Information:
1. The study plots are spread over two adjoining coupes regenerated in 1978 and 1979.
2. The sowing rates used ranged from 0.1kg to 1.0kg/ha.
3. Species mixes were predominantly *E .obliqua*, with minor components of *E. globulus*, *E. viminalis*, and *E. amygdalina*
4. Earlier results have been previously reported by Lockett and Goodwin(1998) (see review 2.4.2).

	SW30	**SW29**
Forest type	Dry *E. obliqua*	Dry *E. obliqua*
Plots	5 x 20m x 20m	4 x 20m x 20m
Regeneration year	1978	1979
Regeneration System	Clearfell, burn and sow	Clearfell, burn and sow

Parameters recorded for each seedling were:
1. *species,*
2. *rectangular coordinates defining its location (x and y coordinates),*
3. *height,*
4. *diameter at 1.3m from age 13, and*
5. *dominance class at age 16 and 20(21) with trees allocated to one of four crown size classes relative to stem size.*

Most plots were scored once or twice in their first year following autumn sowing, once in each of their second to fifth years and then in years 7, 10, 13, 16 and 20 SW29 (21 for SW30).

Results:
Density of plots at 2 years of age varied from 400 seedlings per ha to 10,575 seedlings per ha and stocking by 16 m^2 plots varied from 44% to 100%. Basal area at age 20 varied from 4.7 to 29.0 m^2 ha^{-1}. The spatial distribution of seedlings is given in table4.2, early growth of seedlings in table 4.11, species composition and association of seedlings in tables 5.1 and 5.2. The relationship between initial stocking and density and growth at age 20 is given in section 4.5.7.

Site: Warra 011B

Objectives
To determine species dynamics from seedling to mature stages in order to develop measures of eucalypt species composition in mixed *E. delegatensis/ E. obliqua* stands

Site details
Warra 11B was harvested over an extended period. Harvesting of special species began in 1985. Clearfelling commenced in 1991 and continued through to 1996. The coupe was burnt on the 10th of March 1998. Sowing took place on the 26th of March 1998. The sowing mix comprised 38% *E. obliqua* and 62% *E. delegatensis,* calculated at a site weighting of 1.25 with 5% oversow added. This equates to 0.28kg/ha of *E. obliqua* seed and 0.55kg/ha of *E. delegatensis* seed per hectare.

The regeneration survey conducted on 27/01/99 indicated that the coupe was very well stocked at the time (97% mapped as stocked, 76% $4m^2$ plots stocked, 86% $16m^2$ plots stocked).

Method
Nine, ten metre by ten metre permanent plots were established at Warra 11B. The coupe was stratified into three zones, high (approx. 520 – 450m asl), middle (450 – 380m) and low (380 – 300m). Three plots were randomly located within each zone and permanently marked. Each plot was subdivided into ten subplots ten metres long and one metre wide. Within each sub-plot (10m by 1m) all seedlings were counted by species (eg 28 dele, 12 obl). The tallest *E. delegatensis* and *E. obliqua* seedlings on each sub-plot were mapped (x, y position), heighted, diameter over bark recorded at one third of top height, and permanently tagged using plastic string.

	Warra0011B
Forest type	*E. obliqua,* wet understorey
Area	165 ha
Regeneration System	Clearfell, high intensity burn and sow

Results:
Average seedling density was 26,422 seedlings per ha and species composition of the seedlings closely matched that of the seed mix at age 21 months (see review 2.4.2). The variation in species composition over time is given in section 5.5.

3.3.2 Victorian sites

Site: The Cabbage Tree Silvicultural Systems Project (SSP)

Objectives
The site was established to determine the feasibility of alternatives to clearfelling in the Lowland forests of East Gippsland. A major focus of the study has been the study of regeneration processes in the various silvicultural systems. The data will be used to meet the following objectives of the WAPIS study:

- Determine the variation in spatial distribution of regeneration.
- Determine variation in stocking over time.
- Determine the effect of applying acceptability criteria on stocking estimates.
- Determine the variation in species association of regeneration.

Site details:
The Cabbage Tree Creek SSP site is located in Cabbage Tree Block, Orbost District, East Gippsland FMA,Victoria. The average annual rainfall is approximately 1100 mm and elevation

is 70-200 m ASL. The main vegetation community is Lowland forest (4 sub-communities dominated by *E . sieberi, E. globoidea, E. baxteri or E. consideniana*) with minor occurrence of Damp forest (dominated by *E. obliqua* in association with *E. botryoides, E. globoidea* and *E. cypellocarpa*). *E. croajingalensis* and *E.muelleriana* are also present on the site. The mature forest varied in height from 24 to 47 m and stand basal area from 10 to 80 m^2ha^{-1}.

Experimental design:

- Harvesting: retained overwood (0, 10, 30, 50, 100 %) and gap (0.0, 0.03, 0.25, 1.0, 4.0, 10.0 ha)
- Site preparation: burnt or mechanically disturbed (only burnt in 10.0 ha/ 0%)
- Replication: harvesting x site preparation replication variable (2 to 11 coupes per treatment) established over 1989 and 1990

Monitoring

- *Regeneration surveys.* Regeneration surveys were carried out in each coupe at 2.5 years after site preparation by the stocked quadrat and triangular tessellation methods.
- *Operational plots.* For up to 4 years after site preparation eucalypt germination, survival and height growth were monitored with a system of 2m x 1m plots. During monitoring the plot area was thoroughly searched and newly observed eucalypts were tagged, and species and height of all eucalypts on the plot recorded. Location of seedlings was recorded to the subplot level (25cm x 25cm subplot in the 2 x 1 m plots). Understorey cover by height class and life form was recorded up until year 3.
- *Growth plots.* Beginning at four years after regeneration, density and growth of eucalypt regeneration was monitored with a system of 2 m radius growth plots. Monitoring was carried out at ages 4, 5, 6 and 10 years. Up until age 6 the same procedure was applied as in the operational plots. At age 10, , dbhob of all trees > 1.59 m tall, dominance class of all eucalypts and the total and green level height of the fattest eucalypt in each plot was measured. In addition, in a 15 m radius plot (co-located with each 2 m radius plot) the 5 fattest eucalypts were assessed for total and green level height, dbhob and dominance class. Basal area was also determined at each plot point by basal area sweep with a 1 factor wedge.
- *Future monitoring.* The SSP monitoring strategy includes establishment of 20m x 20m long term monitoring plots in the next 5 years to continue studies of stand development over the range of treatments, over which period the monitoring of the current set of growth plots will cease.

Results:

Stocking by $16m^2$ plots of intensively harvested coupes at 2.5 years after site preparation varied from 65% to 100%. The spatial distribution of seedlings is given in table 4.3, the effect of applying acceptability criteria in tables 4.9 and 4.10, the relationship between seedling height at ages 1 to 4 and dominance at age 10 in figure 4.19 and species association in table 5.3.

Site: Young Ash Scattered Density Plots (various sites)

Objective:

To study the variation in spatial distribution of mountain forest regrowth over time.

Methods:

Three 40 m x 20 m plots were established in 4 year old regrowth mountain forest in 1973. All sites were regenerated by clearfalling, followed by a hot slash burn and aerial sowing.

	Bunyip Rd	Dowey Spur Rd	Starvation Creek
Species mix	***E. regnans, E. delegatensis, E. nitens***	***E. regnans, E. delegatensis***	***E. regnans, E. delegatensis, E. cypellocarpa***
Elevation	700	680	800
Site Index (dominant height at age 50)	37.1	37.6	32

Each tree within the plots was tagged and location coordinates recorded at the first measurement. These trees were relocated at approximately 2 yearly intervals and remeasured. Dbhob, dominance class, species and dominant height were routinely measured and recorded.

Results:
Density at age 4 varied from 3900 to 7000 seedlings per ha and stocking by 16 m^2 plots from 80 to 100%. The spatial distribution of seedlings is given in table 4.2, species composition and association of seedlings in tables 5.1 and 5.2. The variation in spatial distribution up until age 12 was reported by Hamilton (1984) (see section 2.4.1).

Site: Victoria Range Nelder Design Plots

Objective:
To study the effect of spacing on growth of mountain forest regrowth.

Methods:
A spacing trial using a nelder design (see figure 3.1) covering a density range of 420 to 6725 trees/ha was planted with *E. regnans* in 1966 near Toolangi in the Central Highlands of Victoria.

Dbhob, dominance class, and dominant height were routinely measured and recorded at approximately 2 yearly intervals.

Results:
Density and basal area after 26 years decreased with initial seedling density, varying from 375 to 2423 stems per ha and 38 to 74 m^2 per ha respectively. The relationship between initial stocking and density and growth up until age 28 is given in section 4.5.7.

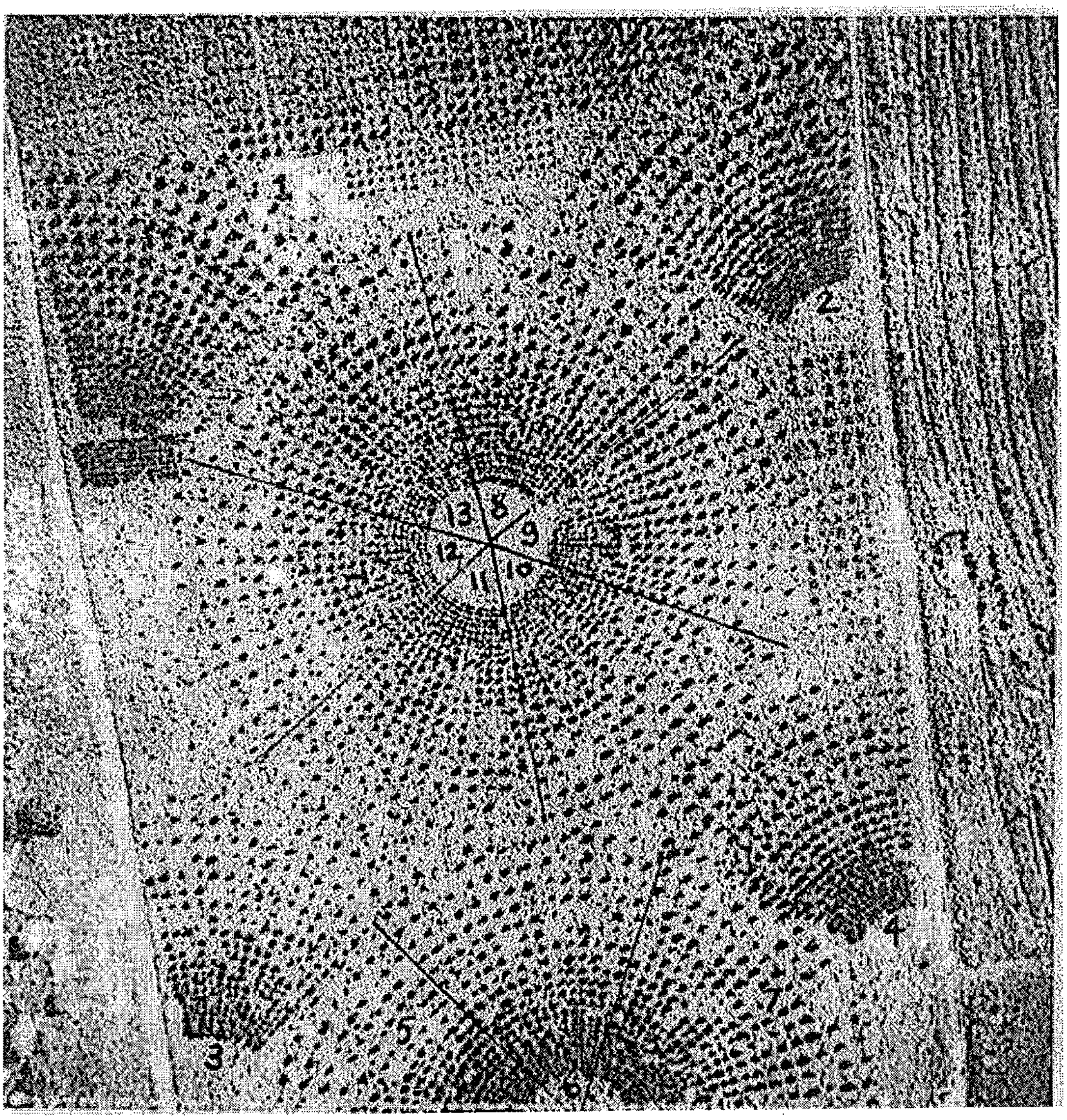


Figure 3.1 Aerial photo of the Victoria Range Nelder trial, containing 13 segments, segments 1-4 are separate, 5-7 in a half circle and 8-13 in a full circle. In each segment trees are aligned radially and concentrically so that seedling density of each ring decreases from 6750 trees per ha at the centre to 420 trees per ha at the outside.

3.3.3 WA sites

Site: Wheatley Block spacing trial

Objective:
To validate the recommended initial stocking levels of planted *E. diversicolor* seedlings to confirm that these are adequate to ensure full site occupancy and optimum bole length development in the longer term.

Method:
The Wheatley block trial was established in 1990 and includes planting densities from 2 x 1 m (5000/ha) to 4 x 3 m (833/ha). The Wheatley trial also has a smaller number of plots in adjacent

forest established using the seed tree method, some of which have been thinned to equivalent density to selected treatments in the planted stand. The density of seedling regeneration was assessed one year after regeneration burning using both fixed quadrats and the triangular tessellation method. Survival & height have been assessed at ages of 4 months, 12 months, and 15 months. Subsequently, height and diameter have been assessed at ages of 3 and 5 years.

Re-measurement work was carried out during the period June-September 2000, and included assessment of height, diameter, form and branching characteristics. Branching was assessed by measuring the height to the lowest persistent live and dead branches exceeding 50 mm in diameter. Growth and form was compared between seed tree regeneration and planted regeneration of equivalent density.

Results:
Survival of planted seedlings at age 10 varied from 70% (3500 seedlings per ha) for the highest density plantings to over 90% (800 trees per ha) for the lowest density planting, whereas density of un-spaced seed tree regeneration was 6300 trees per ha at age 10. The effect of initial density and source of regeneration (planted or seed tree) on growth and branching at age 10 is given in section 4.5.7.

Summary of studies on Regeneration Reference Sites

The RRS strategy involved the use of existing information and collection of new information at established regeneration study sites where possible. Six previously established sites representing regeneration after clearfalling of dry to wet forest were utilised in the current project. The information has been (will be) used to meet the following objectives:

- Effect of spatial distribution on estimates of site occupancy by various methods
- Variation in site occupancy over time, relationship between initial stocking and long term timber production
- Effect of spatial distribution on estimates of species composition by various methods
- Variation in species composition over time
- Initial height as a measure of long term site productivity

New sites were established to increase the range of forest types and silviculture covered by detailed studies of spatial distribution and early stand development. 18 sites have been established in eucalypt regeneration covering wet forests of south-eastern Australia, dry forests of north-eastern Australia, south-eastern and south-western Australia. Silvicultural systems includes clearfalling, seedtree, shelterwood and group selection systems.

Table 3.2 The representation of forest types and silvicultural systems and WAPIS study objectives by existing regeneration reference sites

Sites	**Location**	**Forest type (silvicultural system)**	**Study objective**
Warra 011B	South Tas	Wet E. obliqua / E. delegatensis (clearfall)	Species composition- variation in species composition over time
Brockley Rd Cabbage Tree SSP	East Tas East Gippsland, Vic	Dry *E.obliqua* mixed species (clearfall) Lowland mixed species (clearfall, seedtree)	Site occupancy - Effect of spatial distribution on estimates of site occupancy by various methods Variation in site occupancy over time, relationship between initial stocking and long term timber production Effect of spatial distribution on estimates of species composition by various methods Variation in species composition over time Initial height as a measure of long term site productivity
Young scattered density plots	Central Highlands, Vic	*E. regnans, E.delegatensis, E. nitens* (clearfall)	Site occupancy - Effect of spatial distribution on estimates of site occupancy by various methods Variation in site occupancy over time, relationship between initial stocking and long term timber production
Victoria Range Nelder plots Wheatley Block	Central Highlands, Vic Manjimup, WA	*E. regnans* (clearfall) *E. diversicolor* (clearfall)	Variation in site occupancy over time, relationship between initial stocking and long term timber production

4 Measures of site occupancy

4.1 Introduction

The review identified the following priorities in the development of measures of site occupancy.

- evaluate accuracy of measures of site occupancy, including those currently in use in Australian forests and feasible alternatives
- establish relationships between existing measures and standards and long term productivity
- determine the potential for identification (and the acceptability criteria, if applicable) of successful seedlings in the field
- establish the relationship between existing measures of site occupancy in use throughout Australia
- develop a procedure for comparing the results from different survey methods including a broad stratification of regeneration success based on management objective
- develop improved methods of stratifying and mapping stocking status at the coupe level
- evaluate measures of site occupancy for components of multi-aged and uneven-aged stands.

The progress with these priority tasks is presented in the following sections. The general approach has utilised a limited amount of real stand information, which has been multiplied by applying simulation methods. In this way more precise statistical comparisons could be made.

4.2 Seedling spatial distribution

4.2.1 Introduction

In the review the importance of the spatial distribution of seedlings to measures of site occupancy was discussed. In this study the general approach is by simulation of stand structures at the regeneration stage and application of the various measures to these stands. The simulation approach enables an estimate of a measure and its error to be madė empirically through applying the measures to a large number of stands with similar spatial characteristics. The structural variable of most interest in the statistical sense is the degree of clustering or aggregation of seedlings, which can be quantified by a number of spatial point pattern statistics. For the simulation approach to be valid the simulated stands must be shown to be similar to the real stands to which the measures will be applied. In this section the available data about spatial distributions is compared to simulated distributions.

4.2.2 Methods

Measures of spatial distribution

Mapped distributions were characterised using seedling to seedling and point to seedling distances, namely:

- Pielou's index based on distance from each seedling to its nearest neighbour (Pielou nearest neighbour) (Pielou 1959)
  $\alpha_i = \pi\rho\varpi_i$ where ρ is the density in no.trees per unit area ϖ_i is the mean of the squared distances from all seedlings to their nearest neighbours
  α_i=1 for random, <1 for uniform, >1 for aggregated

- Pielou's index based on distance from a set of nx by ny grid points to the nearest seedling (Pielou point to nearest neighbour).

$\alpha_p = \pi\rho\varpi_p$ where ρ is the density in no.trees per unit area, nx and ny = $\sqrt{\rho}$, ϖ_p is the mean squared distance from the n points to their nearest neighbours
α_p=1 for random, >1 for uniform, <1 for aggregated

- The empirical distribution functions of the nearest neighbour distances (Diggle 1983) When plotted against the nearest neighbour empirical distribution function for random, the function for uniform distribution shows a deficit of small distances and excess of larger distances, the aggregated distribution shows an excess of smaller distances and a deficit of larger distances.

In addition, two spatial statistics based on quadrat counts were determined:

- Variance:mean ratio of quadrat counts for a number of quadrat sizes (Kershaw 1964) Quadrat counts for random distributions have a Poisson distribution, where variance= mean, thus variance:mean = 1 for random, <1 for more uniform, and >1 for more aggregated distributions.

- Heterogeneity factor (Mount 1961) for a number of quadrat sizes
  The heterogeneity factor relates the density or count to the frequency of stocked plots, ie $h = (d_o - d_m) / (d_r - d_m)$ where d_o is observed density, d_m is the minimum density for the measured frequency (f %) of stocked plots, d_r is the random density for the measured frequency (f %) of stocked plots
  ie d_m= f/100 $d_r = \log_e(100/100\text{-}f)$ from the Poisson distribution
  h = 1 for random, <1 for uniform, and >1 for aggregated distributions

Quadrat size was varied to enable the analysis of the scale of spatial pattern. In homogeneous patterns the variance:mean ratio plotted against quadrat size peaks at the quadrat size that is equivalent to half the mean area of the clumps in aggregated distributions (Kershaw 1964). The quadrat based statistics were able to be used with sparsely sampled regeneration data, as well as with fully enumerated stand data.

Statistical significance of the departure from complete random spatial distribution (CSR) was determined by a Monte Carlo approach (Manly 1991). This process involved generating a large number of random distributions of the same density and calculating spatial statistics for each distribution and the 95% confidence interval from the 5^{th} and 95^{th} % ile values of each statistic. The statistics of the real stands were compared to the upper and lower 95 % confidence intervals of the random distribution of the same density. This process was particularly important for the nearest neighbour analysis of stand map data because in small plots the distance to the nearest neighbour can be biased by a large proportion of the nearest neighbour distances being affected by the edge of the plot. The Monte Carlo approach has been used to remove the edge effect in other studies of spatial point processes (Diggle 1983).

Study sites

As indicated in the discussion of RRSs stand maps consisting of seedlings with positions identified as x, y coordinates were obtained from 9 experimental areas (table 4.1).

Table 4.1 Details of sites with stand maps

Site name	Location	Forest type	Silviculture	No. plots x plot size
Young Ash Scattered Density Plots	near Powelltown, Victoria	*E. regnans, E.delegatensis, E. nitens*	Clearfall, burn, sow	3 x 40m x 20m
Brockley Rd Experiment nos SW29 & SW30	near Triabunna, Tasmania	Dry *E. obliqua* mixed species	Clearfall, burn, sow	9 x 20m x 20m
Warra Cpt 001B Warra Cpt 008B	near Geeveston, Tasmania	Wet *E. obliqua*	Seedtree, low intensity burn Clearfall, burn, sow	3 x 20m x 20m 3 x 20m x 20m
Clarkeville Rd Students Tk	East Gippsland, Vic	High Elevation Mixed Species (*E. fastigata, E.obliqua, E.denticulata, E.cypellocarpa*)	Clearfall Clearfall and seedtree	3 x 20m x 20m 3 x 20m x 20m
Steep Gully Mountain View	Midlands, Vic	Lowland (*E. obliqua, E. radiata, E. ovata, E. rubida*)	Shelterwood	3 x 20m x 20m 6 x 20m x 20m
Bellbird Tk	E. Gippsland, Vic	Lowland (*E. sieberi, E. globoidea, E. baxteri, E. cypellocarpa)*	Seedtree	3 x 20m x 20m

In addition to stand maps, information on spatial distribution in real stands was obtained from sparsely sampled regeneration at 16 study sites across a broader range of forest types (tables 4.3 & 4.4).

Simulated seedling distributions

Random and aggregated stands were generated in the SPLUS Spatial Stats module (SPLUS 1999) using the make.pattern command. This command specifies the total number of seedlings in an area bounded by a rectangle, effectively setting the true seedling density. For aggregated distributions, the spatial distribution is controlled by a Poisson parent-daughter process, the Matern cluster process. The number of clusters or parents is determined by the Poisson distribution with a specified mean, the seedlings or daughters are uniformly positioned in the clusters within a specified radius. Computationally, a seedling in the cluster is generated in radians and then it is placed randomly in one of the clusters, so the number of seedlings per cluster varies. The uniform stands were made by constructing a square grid of seedling positions, then applying random mortality of approximately 10% to retain the total number of seedlings required. In addition stands were generated using a mixed process; ie a random process was superimposed over a cluster process to reduce the number of voids but still maintain a high degree of aggregation.
500 stands with seedling density of 1000 or 2500 seedlings per ha and stand area of 4.0 ha

(200m x 200m) were created using each process (table 4.5).

4.2.3 Spatial characteristics of real and simulated stands

The plots in mapped stands in all forest types varied from showing no evidence for departure from random distribution to highly aggregated, with aggregated distributions being more common than random (table 4.2). The 95% confidence intervals for random seedling distributions obtained by simulation indicated that there was some inconsistency between indices of departure from complete spatial randomness (CSR). For example a number of stands were not significantly different from CSR for one or two indices, but were clearly aggregated for most of the measures. In contrast, in the lowest density plots at 3 of the sites there was a significant difference from CSR for one measure only. This measure differed between sites. Regardless of the inconsistencies with significance, there was a high degree of correlation between the indices of spatial distribution (table 4.2b). Quadrat data from small dispersed plots at the Cabbage Tree SSP experimental site (table 4.3) and at the new RRSs (table 4.4) showed a similar range of spatial distribution as occurred in the mapped plots.

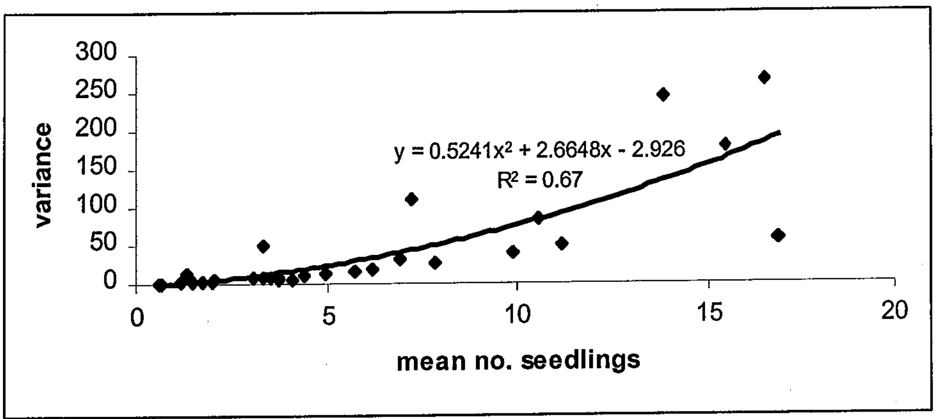


Figure 4.1 The variation in variance with seedling density in 16 m^2 quadrats within mapped stands

Table 4.2 Density, stocking, Pielou nearest neighbour, Pielou point to nearest neighbour, variance:mean ratio ($4m^2$ to $100m^2$), heterogeneity factor ($4m^2$ to $100m^2$) in fully enumerated plots with stand maps at age 2 years.

	Density	Pielou		Variance:mean ratios				H factors			
	(Stocking % $16m^2$)	α_i	α_p	$2m^2$	$4m^2$	$16m^2$	$100m^2$	$2m^2$	$4m^2$	$16m^2$	$100m^2$
Brockley Rd											
sw291	400(44)	*1.61	*1.42	*0.92	0.85	*1.16	*1.17	*0.00	*0.00	*1.43	nd
sw292	2225(88)	2.04	0.85	1.57	1.54	2.34	*0.49	2.21	1.73	2.16	nd
sw293	2550(96)	1.75	0.73	1.28	1.56	1.55	*1.69	1.86	2.18	*1.38	nd
sw297	9675(100)	2.39	*0.99	3.13	4.35	11.50	19.08	2.88	3.05	nd	nd
sw301	2350(92)	1.99	*1.03	*1.05	*1.01	1.56	*2.45	*1.18	*1.16	*1.77	nd
sw303	925(72)	*1.51	0.75	1.20	*1.24	*1.13	*0.96	*2.24	2.24	*1.37	nd
sw304	825(44)	2.97	0.74	2.48	4.10	10.02	15.14	14.52	14.38	6.29	nd
sw305	10575(96)	*1.85	0.84	1.94	2.25	3.43	8.88	1.92	1.45	7.07	nd
sw3011	2750(92)	1.96	0.84	1.48	1.85	2.23	*2.10	2.48	2.71	2.17	nd
Mountain Ash Scattered Density Plots											
Plot1-B	4525(80)	4.77	0.88	4.16	6.76	15.17	52.56	7.32	7.42	7.96	nd
Plot2-D	3888(96)	2.10	0.93	1.42	1.58	2.80	7.65	1.64	1.75	2.33	nd
Plot3-S	6988(100)	1.70	0.94	1.66	2.14	4.48	7.77	1.68	1.64	nd	nd
Warra 001B RRS											
Plot1-lo	725(56)	*1.73	*0.81	*0.93	*1.07	*1.41	*1.05	*0.46	*1.06	2.30	nd
Plot2me	2075(84)	2.42	0.89	1.31	1.78	2.50	5.47	2.20	2.37	2.50	nd
Plot3-hi	4900(96)	2.44	0.75	1.80	2.36	3.41	11.34	2.83	3.15	2.96	nd
Warra 008B RRS											
Plot1-lo	1650(80)	1.83	*0.97	1.22	1.41	1.98	2.36	2.12	2.13	2.27	nd
Plot2-me	4225(100)	1.7	0.84	1.4	1.71	2.62	2.31	1.46	1.56	nd	nd
Plot3-hi	6125(100)	1.61	0.83	1.4	1.78	2.34	0.27	1.63	1.72	nd	nd
Bellbird Tk RRS											
Plot1-lo	1100(80)	*1.57	*1.08	*1.16	*1.23	*1.19	4.49	*1.53	*1.19	*1.14	nd
Plot2me	6175(100)	2.13	*1.01	1.77	2.34	4.10	5.86	1.87	2.29	nd	nd
Steep gully RRS											
plot 1	8650(84)	4.81	0.89	4.56	7.54	17.71	88.82	4.52	5.38	12.90	nd
plot 2	46725(100)	1.69	0.87	3.04	4.02	8.22	6.60	1.88	0.00	0.00	nd
plot 3	10350(76)	10.68	0.70	3.10	5.03	16.11	69.57	4.92	7.57	22.78	nd
Mountain View RRS											
plot 2	425(36)	1.00	0.83	0.93	1.01	1.35	1.05	0.00	1.08	2.32	nd
plot 5	900(52)	2.94	0.49	1.81	2.04	3.04	5.44	7.02	4.57	4.11	nd
plot 4	1250(84)	1.42	0.98	1.00	1.05	1.30	0.89	1.11	1.30	1.13	nd
plot 3	2075(52)	8.54	0.83	4.60	6.41	14.69	34.23	14.08	16.26	12.53	nd
plot 6	3100(96)	2.32	0.87	1.64	1.72	2.86	1.63	2.22	2.09	1.74	nd
plot 1	3600(100)	1.67	1.00	1.50	1.84	2.91	5.77	2.16	2.33	0.00	nd
Clarkeville Rd RRS											
Plot1-lo	1275(72)	2	1.05	1.73	2.32	2.96	9.54	4.06	3.71	2.39	nd
Plot2me	1925(76)	2.62	0.96	2.07	2.77	4.88	13.64	5.27	4.83	3.3	nd
Plot1-hi	6600(68)	13.65	0.36	5.03	7.89	15.67	65.54	11.97	17.16	20.81	nd
Students Track RRS											
Plot1-lo	750(56)	2.01	1.56	1.32	1.72	2.64	5.47	3.83	5.31	2.45	nd
Plot2me	2350(80)	2.42	0.86	1.71	2.21	5.97	16.5	4.19	4.17	3.66	nd

Plot3-hi	4325(84)	3.18	0.81	2.86	4.58	9.77	12.51	4.46	4.16	6.04	nd

* not significantly different from randomly distributed stands at the same density
nd: not defined-the h factor has no meaning for stands with 100% stocking.

Table 4.2b Correlation between measures of aggregation: Pielou nearest neighbour (pnn), Pielou point to nearest neighbour (ppn), variance:mean ratio for 2m^2 to 100m^2 plots (vm2-100), heterogeneity factor for 2m2 to 16 m2 plots(h2 to h16) in fully enumerated plots with stand maps at age 2 years.

	pnn	ppn	vm2	vm4	vm16	vm100	h2	h4	h16
pnn	1.00								
ppn	-0.52	1.00							
vm2	0.84	-0.41	1.00						
vm4	0.84	-0.39	0.99	1.00					
vm16	0.85	-0.37	0.95	0.97	1.00				
vm100	0.79	-0.34	0.86	0.90	0.94	1.00			
h2	0.78	-0.36	0.83	0.77	0.70	0.54	1.00		
h4	0.89	-0.36	0.87	0.83	0.77	0.63	0.96	1.00	
h16	0.96	-0.48	0.84	0.86	0.92	0.90	0.66	0.78	1.00

Table 4.3 Variance:mean ratios and heterogeneity factors for all seedlings in 2m^2 operational plots and seedlings meeting regeneration criteria in 16m^2 regeneration survey plots at 2.5 years after site preparation of 20 coupes at the Cabbage Tree Creek SSP site, East Gippsland, Victoria.

Coupe details			Operational plots				Regeneration surveys			
Coupe	Harvest *	site prep *	density 2m^2 (spha)	stocking 2m^2 (%)	Var/mean 2m^2	h factor 2m^2	density 16m^2 & tri tess (spha)2	stocking 16m^2 (%)	Var/mean 16m^2 2	h factor 16m^2
51001	LCF	B	1625	23	1.64	3.35	1044	69	na	2.04
51020	LCF	B	4900	55	1.68	1.79	1142	69	na	2.36
51056	LCF	B	3158	47	0.89	0.94	2170	76	5.34	3.99
51102	LCF	B	4744	36	4.05	6.88	1239	76	2.44	1.79
50919	O10	B	16061	85	3.44	2.28	4799	82	19.18	7.61
51019	O10	B	18971	88	2.62	2.32	4496	94	na	3.34
51027	O10	B	8824	62	2.68	3.34	4507	92	na	3.92
51051	O10	B	22500	87	7.66	3.16	6016	100	5.23	nd
51005	O10	D	10143	80	1.93	1.52	2521	81	na	3.79
51013	O10	D	16833	77	3.55	3.78	3965	85	na	5.25
51048	O10	D	18704	89	3.53	2.18	3944	79	6.33	7.05
51101	O10	D	5833	43	2.43	5.45	2038	78	3.32	3.33
50922	SCF	B	19714	60	14.99	10.57	3571	81	14.34	5.78
51016	SCF	B	8108	51	2.96	5.35	1828	91	na	1.35
51023	SCF	B	9146	54	7.30	5.56	1639	65	na	4.93
51040	SCF	B	9667	70	1.67	2.45	2583	83	4.47	3.44
50904	SCF	D	11026	74	2.27	2.37	1903	79	na	2.93
51002	SCF	D	13088	65	5.39	5.00	2187	88	na	2.11
51058	SCF	D	26167	70	20.74	9.00	4667	90	5.17	4.68
51105	SCF	D	10000	55	6.93	5.78	1646	77	4.83	2.71

*LCF = large clearfall (10.0ha), O10 = 10% retained overwood (seedtree),
SCF = small clearfall (4.0 ha), B = burnt, D = disturbed. na = not avaliable

Variance:mean ratio was used as the measure of aggregation to test the relationship between seedling density and aggregation. There was increasing aggregation with increasing density in the aggregated stand map data and in the sparsely sampled Cabbage Tree plots (figure 4.1 & figure 4.2). It is apparent from the combined data sets that very aggregated stands do occur at low to medium seedling density, but the trend is to increasing aggregation with increasing density. This result is probably the effect of the limited distribution of suitable seedbed types, where seedlings tend to aggregate, as other factors become more favourable for regeneration.

The other consistent trend is that the variance:mean ratio increased at a greater rate than heterogeneity factor with quadrat size. When plot size was increased to $16m^2$, the h factor was less than the variance:mean ratio in most of the real stands. The key difference between the two statistics is that the variance:mean ratio is very sensitive to variation in density between plots, whereas the h factor is sensitive to variation in density between plots only when plot density falls to zero. The biological explanation of the pattern may be that the occurrence of favourable seedbeds occurs at a number of overlapping scales. For example there may be large areas of good seedbed associated with concentrated soil disturbance and accumulations of logging slash which were burnt later produced topsoil disturbed and moderately burnt seedbeds which are most favourable for regeneration. Superimposed on this pattern may be smaller scale variation in favourable seedbeds such as microsites provided by logs and moisture accumulating depressions. Another possibility is that seed supply interacted with seedbed, with favourable seedbeds being well dispersed across the harvested area, but seed supply varied producing areas of low and high density, but not distinct clusters and voids. One may argue that many of the real stands should have received uniform seedfall because they were aerially sown after a high intensity slash-burn. However the seed dispersal from aerial sowing has been shown to be not uniform (pers. comm. M. Lutze).

Table 4.4 Variance:mean ratios and heterogeneity factors for all seedlings in $4m^2$ and 16 m^2 plots in sparsely sampled RRSs

Coupe details	$4m^2$ plots				16 m^2 plots			
Coupe	density (spha)	stocking (%)	Var/ mean	h factor	density (spha)	stocking (%)	Var/ mean	h factor
E. pilularis NE NSW								
WayWay	7083	71	4.59	4.06	5547	92	7.39	5.07
Lower Bucca	1510	35	1.46	3.01	1380	69	3.31	3.20
Nambucca	11146	79	7.06	4.72	10052	96	14.99	6.81
E. maculata SE Qld								
Exp 631 HWD	2400	55	1.47	1.65	2369	93	2.54	1.65
Wet E. obliqua Southern Tas								
Picton 024A	10925	73	5.87	5.41	9918	93	8.64	14.42
Warra 001B	2300	40	2.61	4.69	2075	73	6.85	4.40
Warra 008B	3606	59	1.77	2.76	3182	82	5.70	4.87
High Elevation Mixed Species E.Gipps., Vic								
Clarkeville Rd	5000	47	6.96	9.16	4045	69	16.85	11.76
Students Tk	3942	33	7.07	17.24	3518	54	21.10	21.68
E. marginata SW WA								
Poole	2083	47	2.16	2.26	1521	77	6.23	2.42
Kingston shelterwood	2250	57	1.18	1.24	2354	97	2.63	1.15
Kingston gap	3375	75	1.16	0.94	2875	98	1.80	1.34
Yalgorup	1333	33	1.39	2.77	750	60	2.15	1.90
Lowland Vic								
Bellbird Tk	6958	70	6.33	4.13	5219	87	21.08	6.52
Steep Gully	23474	88	12.60	3.14	14635	97	15.90	6.68

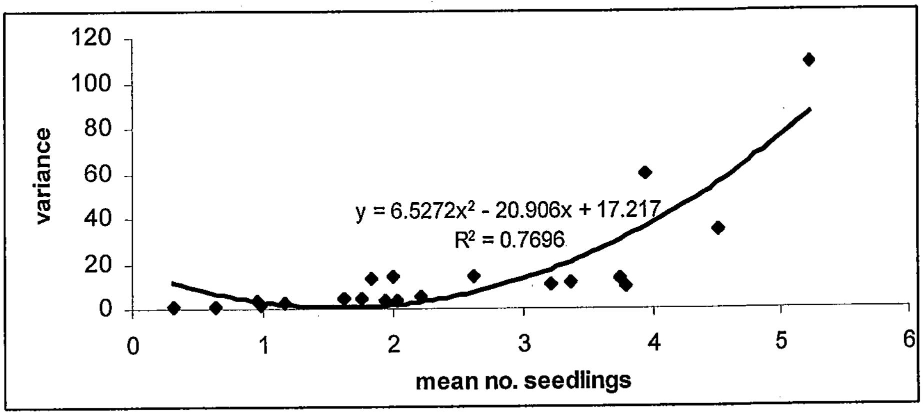


Figure 4.2 The variation in variance with seedling density in 2 m^2 plots at intensively harvested coupes at the Cabbage Tee Tree Creek SSP experiment

The aggregation at small scale is well illustrated by the empirical distribution functions of nearest neighbour distances in 3 plots over the range of seedling density and aggregation at Brockley Rd (figure 4.3 and figure 4.4). As degree of aggregation increased (as indicated by Pielou, variance:mean and h factor statistics) the frequency of short nearest neighbour distances increased relative to the 95% confidence envelope of random distributions of the same density.

In the very highly aggregated stand of high density approximately 90% of seedlings were outside the upper 95% envelope, ie at shorter distances, than CSR. In the moderately aggregated of medium density approximately 80% of seedlings were at shorter distances than CSR. The low density stand with low degree of aggregation all seedling probabilities fell in the middle of the 95% confidence envelope.

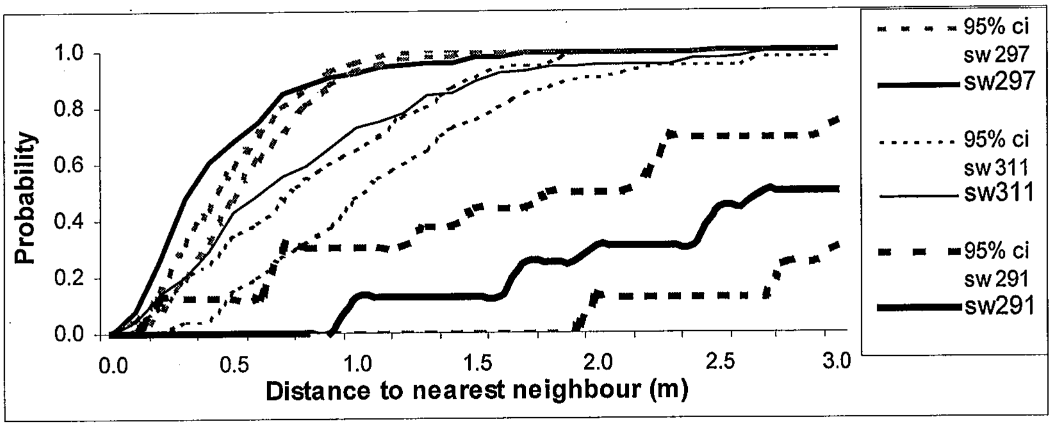


Figure 4.3 The empirical distribution functions of nearest neighbour distances in 3 mapped plots of varying aggregation at Brockley Rd at age 2 years and 95% confidence envelopes of random distributions with the same seedling density.

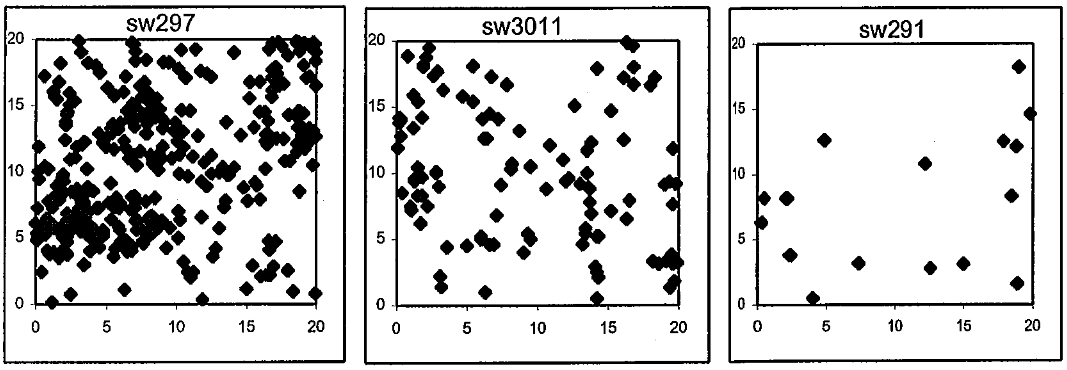


Figure 4.4 Stand maps for 3 of the 20m x 20m plots at Brockley Rd at age 2 years (the same 3 stands with nearest neighbour distributions shown in figure 4.3)

Further evidence of the scale of aggregation is provided by the scale at which the variance:mean ratio is maximised in the total enumeration of the mapped stands (table 4.2). The variance:mean ratio tended to increase with plot size in the Young Ash Scattered Density plots, the Bellbird Tk RRS, 2 of the Warra 001b plots, 5 of the Brockley Rd plots, Clarkeville Rd RRS and Students Rd RRS plots, which suggested that the scale of aggregation was greater than the largest sub-plot size tested (ie 100 m^2). In sparsely sampled coupes the variance:mean ratio increased with increasing plot size at Cabbage Tree SSP (table 4.3) and at the new RRSs (table 4.4). The increasing aggregation up to the scale of 100m^2 is consistent with the larger pattern of disturbance, eg areas of convergence of snig tracks and landings. However it is likely that aggregation is occurring at a smaller scale than that because the distribution of favourable seedbeds, such as moderately burnt or disturbed soil, is often at a scale of several metres, and of favourable microsites such as logs and water holding depressions at the scale of centimetres. The peak of variance:mean ratios at 2, 4 and 16 m^2 in the remainder of the plots is consistent with smaller scale seedbed factors. The inability to detect peaks in variance:mean ratio at the smaller scale on the remainder of the plots is probably a result of the interaction of patterns at a number of different scales. Another factor is the distribution of seed, which can be extremely variable under both natural and artificial seed supply.

Spatial characteristics of simulated stands

By simulation of random distributions and aggregated distributions with decreasing cluster radius and increasing number of clusters, the aggregation varied over a similar range as that occurring in real stands (table 4.5). In addition, simulated uniform distributions indicate the spatial arrangement of planted stands at high (2,500 seedlings per ha) and medium (1000 seedlings per ha) planting density. The density of simulated stands was limited to 2,500 seedlings per ha, because higher density stands tend to be very well stocked, regardless of spatial distribution, and not very useful for testing the accuracy of different survey methods. The simulation study did not cover the very high variance:mean ratios encountered in very dense stands.

One difference between the simulated and real stand spatial statistics is that the h factor invariably exceeded the variance:mean ratio for simulated stands generated by the moderate to high cluster processes, but the h factor was less than the variance:mean ratio in most of the real stands. The difference could not be attributed to the difference in scales of enumeration between real and simulated stands, because the real stand data included data at both the 20m x 20m stand map and small dispersed plot scales. Additionally, calculation of the variance:mean ratios and h factors from the 50 plots per stand indicated the same trend as obtained from the full enumeration of the simulated stands. The reason for the difference between real and simulated stand statistics was that the number of zero plots was lower in the real stands than in the simulated stands for a given variance:mean ratio. Thus it appears that the aggregation in the simulated spatial point processes were more extreme than natural processes in the creation of voids, and the lower range of stocking of the simulated stands is probably lower than that normally encountered in real stands. The testing of survey methods under more extreme stand conditions should enhance the evaluation of the robustness of the survey methods.

In order to provide a better evaluation of the performance of measures under real stand conditions, stands were generated using a mixed process; ie a random process was superimposed over a cluster process to reduce the number of null plots but still maintain a high degree of aggregation. Thus the "mixed" process in table 4.5 produced a moderate stocking level, but a high variance:mean ratio. Furthermore the variance: mean ratio was greater than the h factor for 16m^2 plots, reproducing the usual situation in real stands.

Table 4.5 Density, stocking, Pielou nearest neighbour, Pielou point to nearest neighbour, variance:mean ratio (2, 4, 16 & 100m^2), and heterogeneity factor (2, 4, 16 & 100m^2) of stands produced by uniform, random and aggregated spatial point processes

		Pielou		Variance:mean ratios				H factors			
Process* Cluster radius & mean no.	**Stocking (16 m^2)**	**point to nearest neighbour**	**nearest neighbour**	**2m^2**	**4m^2**	**16m^2**	**100m^2**	**2m^2**	**4m^2**	**16m^2**	**100m^2**
Density=2500 seedlings per ha											
Uniform*	99.99	0.57	2.84	0.59	0.18	0.26	0.43	0.13	0.05	0.07	nd
Random	98.19	1.04	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	nd
20m, 500	89.18	3.71	0.95	1.17	1.34	2.33	8.48	1.45	1.56	2.34	7.95
13m, 200	76.28	11.08	0.77	1.36	1.71	3.70	15.26	2.04	2.38	4.85	16.61
Mixed*	70.20	3.62	0.97	1.97	2.91	8.24	39.07	4.42	5.51	6.54	nd
13m, 50	54.72	50.50	0.50	1.74	2.46	6.55	na	3.65	5.07	14.69	na
10m, 50	39.55	78.70	0.33	2.29	3.54	10.47	47.50	7.13	11.63	35.18	89.73
Density=1000 seedlings per ha											
Uniform*	94.90	0.57	2.83	0.80	0.60	0.53	0.53	0.00	0.00	0.32	nd
Random	79.83	1.06	1.02	1.00	1.00	1.00	1.00	1.01	1.00	1.00	0.05
20m, 200	71.16	2.60	0.96	1.07	1.14	1.52	3.96	1.38	1.42	1.68	3.73
13m, 80	58.49	9.46	0.69	1.18	1.36	2.38	8.30	2.10	2.29	3.51	10.35
10m, 20	18.45	118.00	0.15	2.31	3.58	10.59	48.08	16.31	27.51	84.01	202

*for uniform process 1.9m x 1.9m grid with 9.3% random mortality, 3.0m x 3.0m with 8.2% random mortality; Mixed- two overlapping processes 80% seedlings aggregated (13m, 25) and 20% seedlings with random distribution.
na - not available; nd - not able to be determined

The empirical distribution functions showed the same trend in nearest neighbour distances with degree of aggregation as occurred in the natural stands (figures 4.6 & 4.7). The probability of short nearest neighbour distances increased with increasing aggregation and the probability of far nearest neighbour distances was high for the uniform process. In the mixed process there was a greater probability of short nearest neighbour distances within 1.5 m but a lower probability at further distances than the random process. This can be explained by the sparsity of the pattern outside the dense clusters in the mixed process (figure 4.7).

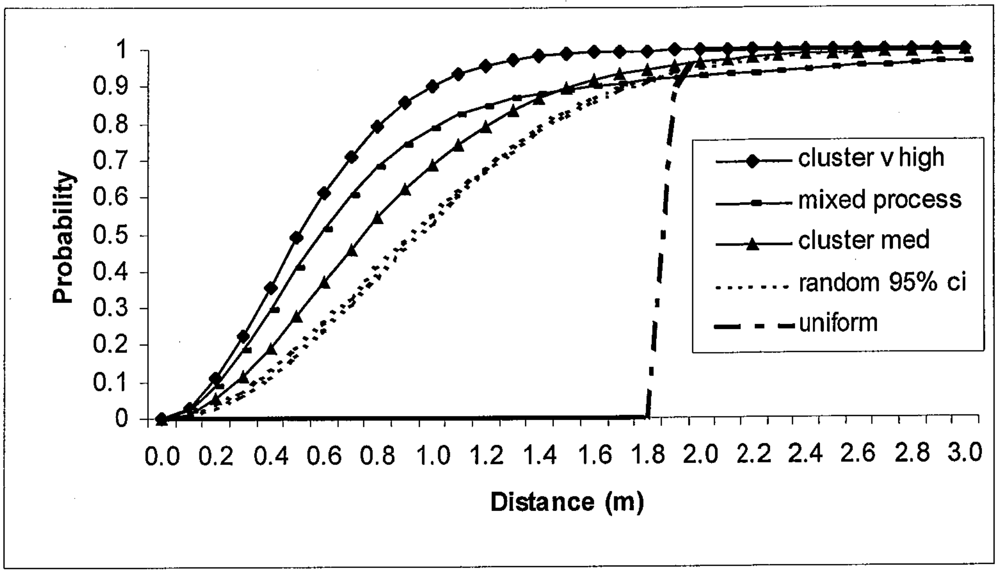


Figure 4.6 The empirical distribution functions of nearest neighbour distances in simulated stands with density of 2500 seedlings per ha and varying degrees of aggregation and 95% confidence envelopes of random distributions with the same seedling density.

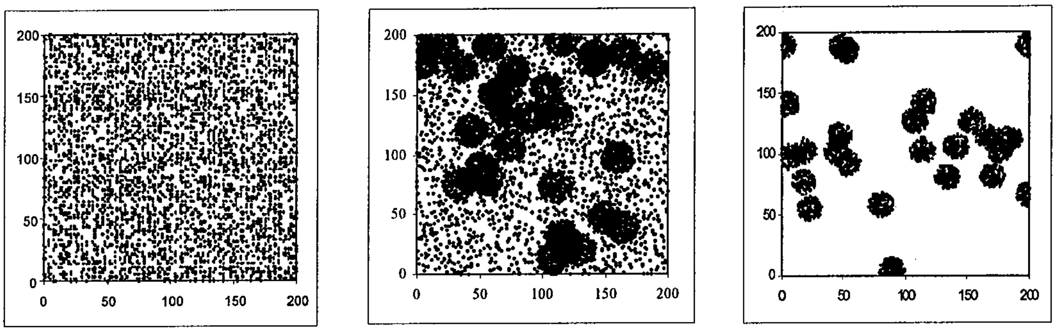


Figure 4.7 Stand maps for 3 of the simulation processes. Left: random; middle: mixed; right: very high aggregation. Each map shows the location of 10000 seedlings over 4 ha (ie 2500 seedlings per ha). Markers represent seedling locations.

4.2.4 Summary of spatial distributions

The analysis of mapped plots varying from 0.04 to 0.08 ha in size and small dispersed plots indicated that by a number of nearest neighbour distance and quadrat based indices :

- Spatial distribution in real stands established by clearfelling and artificial sowing or by retention of seed trees were random to very aggregated
- Aggregation increased with increasing seedling density

In the absence of stand maps for planted stands, they were assumed to have a uniform spatial distribution.

500 x 4.0 ha stands were simulated for each of 6 spatial point processes at 2500 seedlings per ha and 5 spatial point processes at 1000 seedlings per ha. Analysis of the simulated stands indicated that the spatial point processes covered the range of aggregation encountered in the real stands.

The relationship between variance:mean ratio and h factor varied between real and simulated stands, because there was a greater proportion of voids in the simulated stands. This difference was considered to enhance the ability of the simulated stands to test the robustness of the survey methods.

4.3. Evaluation of accuracy of measures of site occupancy

4.3.1 Introduction

There are a number of historical approaches to measuring site occupancy, including various ways of quantifying seedling density and stocking. These measures are based on quadrat counts, distance to a closest individual or triangular tessellation. The measures used in Australia cover the range of possible approaches, although there are so many variations in details of how they are applied that they only represent a subset of the available measures. The measures that will be evaluated are as follows:

- Seedling density by quadrat count (4 m^2 and 16 m^2 circular plot)

The quadrat count measure of density has been widely applied in ecological surveys. The statistical properties of count data including the effects of varying spatial distributions are well understood. There is also considerable information concerning the utility of the method in the field. The plot sizes chosen for this evaluation, 4 and 16 m^2 , correspond to the 1 and 4 milacre plots which have been routinely applied in forest regeneration studies in Victoria, Tasmania and other countries.

- Seedling density by triangular tessellation

The triangular tessellation measure is based on the theory that each seedling has its own domain bounded by a polygon which is nearer to that seedling than any other (ie Dirichlet tessellation). From the tessellations a Delauney triangulation is formed, consisting of triangles joining the points or seedlings for which the associated polygons have an edge in common. It follows that the triangles thus formed represent <u>half</u> the areas occupied by the seedlings and the inverse of the triangle area surrounding a sample point is directly proportional to seedling density at that point. Thus D (seedlings ha^{-1}) = 10000 (m^2/ha) / area (m^2) / 2 = 5000 / area (m^2). The arithmetic mean of the point density estimates can provide an unbiased estimate of seedling density.

- Seedling density by point to plant (distance to the closest seedling)

Seedling density is inversely proportional to the square of distance from a sample point to the nearest seedling. It has been reported that this measure tends to be biased for all but random seedling distributions. A number of variations upon the distance method have been tested, requiring more than one distance at each point or measuring the distance of the n^{th} closest seedling (where n>1). However none of the variations have been shown to be unbiased for a large range of spatial distributions. Thus the basic method as applied in NSW will be the one evaluated here.

- Stocking by quadrat (% of 4 m^2 and 16 m^2 plots stocked)

The stocking by quadrat or proportion of plots that contain a seedling is the most common stocking measure. Historically this measure has been applied in preference to the seedling density by quadrat count, because it is simple to apply and interpret. Although there has been a trend to seedling density measures or a combination of stocking and seedling density, stocking by quadrat is still the main measure of success used in Tasmania and Victoria.

- Stocking by triangular tessellation (% of plots where triangular tessellation density exceeds plot minimum density)

In Western Australia the triangular tessellation approach has been extended to measure the spatial distribution of seedling density. The proportion of plots that exceed a specified point seedling density standard is the measure of success. This approach is unique to Western Australia, where there has been considerable refinement in terms of variation in point standards with forest type and the growth stage of the trees.

Accuracy of these measures can be quantified in terms of bias and precision. Inaccuracy or error can be the result of a number factors, including sampling error and human error associated with the field monitoring procedure. This section is primarily concerned with quantifying sampling bias and precision, through empirical and theoretical means. The stand structures to which the measures will be applied to were presented in section 4.2. In addition, error due to field monitoring systems will be addressed, but on the basis of a literature review and a limited number of field observations.

4.3.2 Methods-Simulation of survey methods

Simulation of survey methods was replicated twice for each stand, using a systematic grid of sample points, as routinely applied in Australian forests. The procedure involved the random selection of the first plot point in the south-western corner of the stand. Subsequent plot points were spaced at 20 m intervals in the east-west direction and at 40 m intervals in the north-south direction. This spatial arrangement of plots was similar to that applied in intensive surveys in Victoria, where survey transects are spaced at 40 m intervals and plots are spaced at 20 m intervals along them. Thus 50 plots were systematically located in each 4.0 ha stand. The first plot was located within limits so that the outside row of plots occurred at a maximum of 15.0 m and a minimum of 2.0 m from the stand boundary. The closeness of the minimum distance could have caused a negative bias of 0.02% in the estimated mean seedling density by the 16 m^2 quadrat, and thus was considered negligible.

The following data were calculated at each plot point using an SPLUS (SPLUS 1999) script program for the various measures of site occupancy (figure 4.8).

- Seedling density by quadrat count (16 m^2 and 4 m^2 circular plots)
  - Count of all seedlings within 2.26 m radius was converted to seedling density using the formula: D (seedlings ha^{-1}) = 625 x seedling count
  - Count of all seedlings within 1.13 m radius was converted to seedling density using the formula: D (seedlings ha^{-1}) = 2500 x seedling count

- Seedling density by triangular tessellation
  - Delauney triangles were created for a 10m x 10m area surrounding each plot point. The area of the tessellation containing the plot point was determined and converted to an equivalent density using the formula:
    D (seedlings ha^{-1}) = 5000 / area (m^2)

- Seedling density by point to plant (distance to the closest seedling)
  - The distance (m) to the closest individual was determined.

- Stocking by quadrat method (% of 4 m^2 and 16 m^2 plots stocked)
  - Presence or absence of a seedling within 1.13 m and 2.26 m were determined.

- Stocking by triangular tessellation (% of plots where triangular tessellation density exceeds plot minimum density)
  - True or false response to whether point seedling density exceeds standard of 1666 seedlings ha^{-1} or 625 seedlings ha^{-1}.

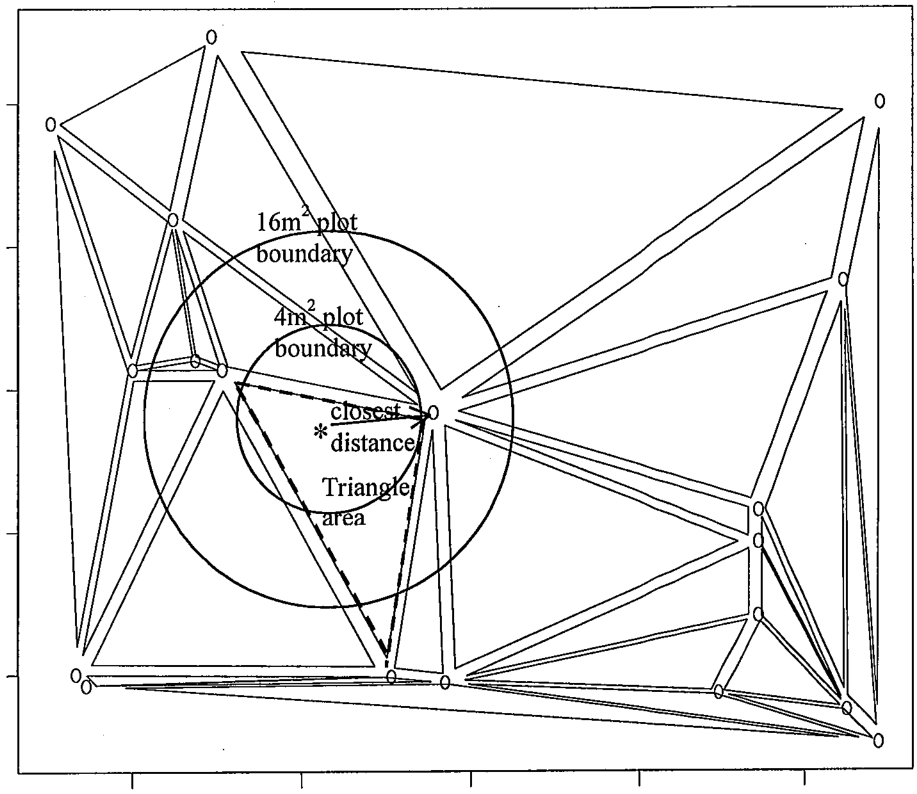


Figure 4.8 The 10m x 10m portion in the centre of one of the aggregated 200m x 200 m stands of density 2500 seedlings per ha showing the location of seedlings (o), the sample point (*)and plot measurements by quadrat, distance and triangular tessellation

Stand level measures were calculated for each simulation of the sampling of each stand (ie two observations per stand) as follows:

- Seedling density by quadrat count and triangular tessellation
  - Mean and variance of plot seedling density estimates.

- Seedling density by point to plant (distance to the closest seedling)
  - The seedling density was calculated by the following formula:
    D (seedlings ha^{-1}) = 10000 / (2 x mean distance(m))^2
    A correction factor was applied for nil plots.

- Stocking by quadrat and triangular tessellation
  - The percentage of stocked plots was calculated.

The stability of the estimate and its variation was tested using the triangular tessellation and quadrat measure on 1000 stands of the uniform, random and most aggregated processes at 2500 seedlings per ha. On the basis of the results (see 4.3.3.2 and 4.3.4.1) comparison of measures was limited to 500 stands per process.

True values of seedling density and stocking were calculated by a full enumeration of the simulated stands:

- Seedling density was calculated by counting all the seedlings within the boundary of the stand and dividing by stand area (seedling density was set exactly by the stand generating process).
- Stocking by quadrat was determined by dividing the total stand into squares of 4 m^2 and 16 m^2 and calculating the percentage of those squares that contained a seedling.
- Stocking by triangular tessellation was determined by Delauney triangulation of the entire pattern of seedlings in the stand and calculating the percentage of the area occupied by triangles that were less than the area corresponding to the seedling density standard (ie 625 seedlings per ha = 8 m^2, 1666 seedlings per ha = 3 m^2).

4.3.3 Accuracy of estimates of seedling density

4.3.3.1 Variation within stands

The variance of the stand seedling density estimates varied with the method of measuring density, the true value of seedling density and the degree of aggregation (figure 4.9). The mean variance by triangular tessellation was greater than by quadrat for random to aggregated distributions. For uniform distributions the variance by quadrat was greater than by triangular tessellation. For a given degree of aggregation the variance increased with seedling density. The relatively low variance by quadrat compared to triangular tessellation is probably a result of the averageing of seedling density over a larger area at each plot point.

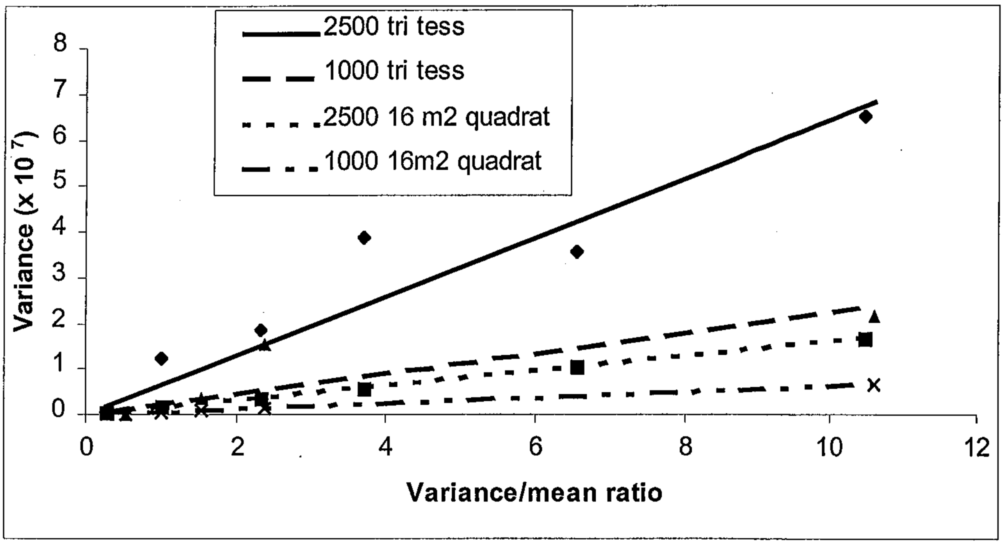


Figure 4.9 Variance (and least squares fitted trend lines) of stand seedling density estimates by quadrat count and triangular tessellation in simulated stands with density of 1000 and 2500 seedlings per ha and aggregation varying from uniform to very aggregated. Variance is the mean of 2 estimates x 500 stands per seedling density x aggregation combination.

4.3.3.2 Variation between stands

After 200 simulations, estimates of seedling density were within 2% of the true values. After

500 simulations the cumulative estimates did not vary by more than 1% of the true value. Standard deviation estimates took longer to stabilise, but after 500 simulations the standard deviation of mean seedling density did not vary by more than 1%. For a given process the triangular tessellation results were more variable and took longer to stabilise than other methods (see standard deviations in table 4.6). The estimates of the mean and standard deviation of the mean of seedling density by triangular tessellation took longest to stabilise in the most aggregated stand type (figures 4.10 & 4.11). Thus, on the basis of the results with triangular tessellation in the 3 test processes, it was decided that systematic sampling with 500 stands per spatial point process was sufficient to compare the estimates and variation of different survey methods.

The variability of the triangular tessellation method is indicated by the very low estimates of seedling density for the first few stands and it was not until some correspondingly high estimates were made for subsequent stands that cumulative mean density approached the true value of 2500 per ha after about 60 stands estimates. In contrast the estimates by 16 m^2 quadrats exceeded the true value over the same stands. The possibility of very high variance of seedling density estimates by triangular tessellation is well demonstrated by stand no. 121 in figure 4.10. One of the systematic samples had an extremely high density estimate and variance and this caused a large jump in the cumulative mean seedling density and standard deviation. The estimate by 16 m^2 quadrats for the same systematic sample was not unusually high.

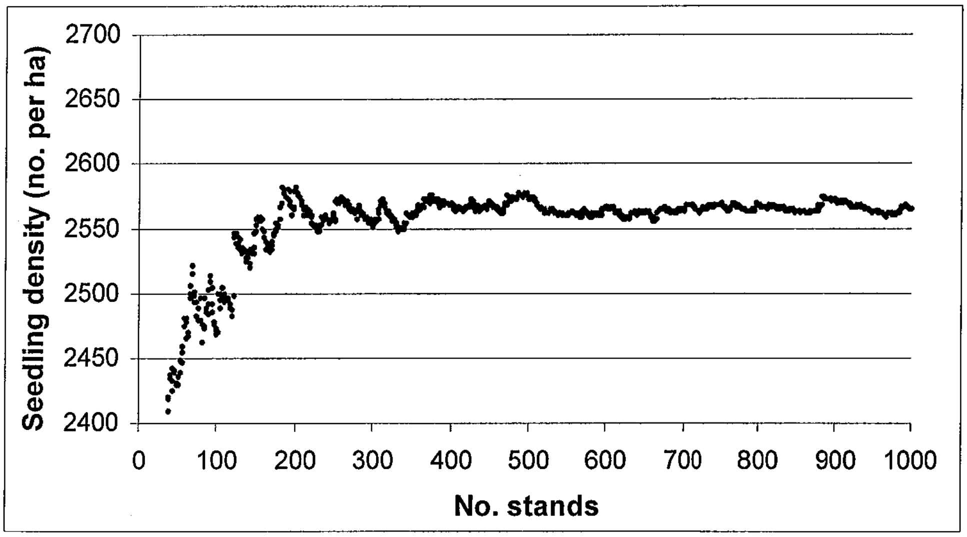


Figure 4.10Cumulative mean (of 2) seedling density by systematic sampling (50 points per stand) after 1 to 1000 realisations of an extremely aggregated process.

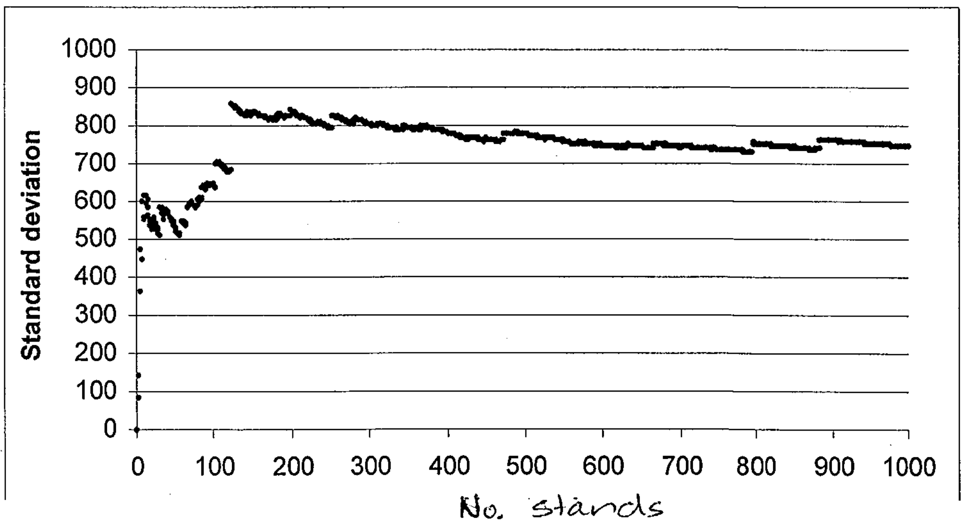


Figure 4.11Cumulative standard deviation of mean seedling density by systematic sampling after 1 to 1000 realisations of an extremely aggregated process.

The larger variation between plots by triangular tessellation than by quadrat methods resulted in a larger standard deviation of the mean seedling density for the 500 stands simulated by each spatial point process (Table 4.6).

Table 4.6 Mean (standard deviation of mean) seedling density, estimated by two systematic surveys of 500 stands per process

Process* Cluster radius & mean no.	Variance/ mean ratio ($16m^2$)	Seedling density $16\ m^2$ quadrat	Triangular tessellation	Closest individual
Density=2500 seedlings per ha				
uniform	0.26	2514 (109)	2516 (52)	4436(1221)
random	1.00	2518(127)	2505(360)	2549(278)
R=20m, n=500	2.33	2540(144)	2517(413)	1872(259)
R=13m, n=200	3.70	2548(196)	2541(582)	1270(242)
R=13m, n=50	6.55	2548(274)	2513(573)	744(191)
mixed	8.24	2532(417)	2514(837)	905(182)
R=10m, n=50	10.47	2562(336)	2565(748)	444(124)
Density=1000 seedlings per ha				
uniform	0.53	1016 (58)	998(44)	1663(172)
random	1.00	999(81)	990(139)	1012(110)
R=20m, n=200	1.52	1018(80)	1015(178)	814(104)
R=13m,n= 80	2.38	1015(110)	1020(380)	566(91)
R=10m, n=20	10.59	1027(204)	991(435)	183(78)

The standard deviation of mean seedling density by closest individual varied with the estimate of seedling density which varied with the degree of aggregation. For random stands where the estimate was approximately equal to that by the other measures, the standard deviation was intermediate to the other two measures.

4.3.3.3 Comparison of estimates with true seedling density

Estimates of mean seedling density by triangular tessellation and quadrat tended to be marginally greater than the true values (up to 2.5% of the true value and just significant at the 95% confidence interval for some distributions). Density by distance measurement greatly over-estimated the true value for uniform processes and under-estimated the true value for aggregated processes, the amount of bias increasing with degree of aggregation (Table 4.6). The bias by closest individual is consistent with reports on distance methods in the literature (Cox 1976). The small error of the other 2 methods is probably a result of insufficient replication to completely bring seedling density to equilibrium. The location of sample plots close to the stand boundary could not have produced the positive bias in the estimate. The spatial point process produced the specified number of seedlings without exception. The Matern cluster process locates the centre of clusters at random and places seedlings at random in the clusters, and thus there should be not have been bias in the location of seedlings relative to the stand edge or the systematically located sample points. The interaction of the process with the sampling method should not have produced bias in the estimate of seedling density.

4.3.4 Accuracy of estimates of stocking

4.3.4.1 Variation between stands

As for seedling density, after 200 simulations, estimates of stocking were within 2% of the true values. After 500 simulations the cumulative estimates did not vary by more than 1% of the true value. Standard deviation estimates were more variable and, after 500 simulations, there were variations of up to 4% of the value of the standard deviation after 1000 simulations. The standard deviation of the mean stocking estimates varied with the method of measuring stocking, the true value of stocking and with the degree of aggregation (figure 4.12). Direct comparison of variation between methods was made difficult because the methods gave different estimates and the variation is related to the value of the estimate or proportion, according to the theory of the binomial distribution. In order to vary the stocking estimate, the plot standard by triangular tessellation was reduced to 625 seedlings per ha. The plot size by quadrat was also varied to produce estimates of similar value- the plot size of 9.5 m^2 was usually chosen. The standard deviation of the mean stocking was similar for the two methods when similar estimates were compared (table 4.7).

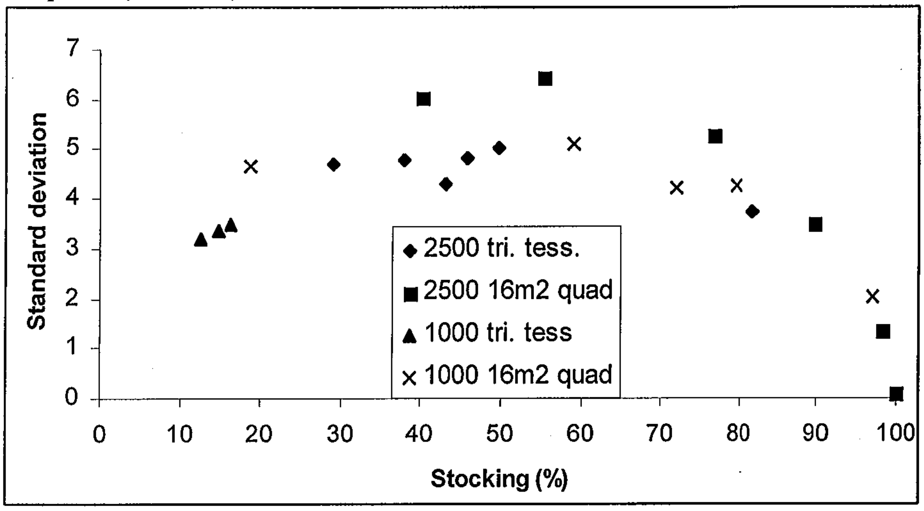


Figure 4.12 Standard deviation of stocking estimates by quadrat count(16m2) and triangular tessellation in stands with density of 1000 and 2500 seedlings per ha and varying stocking.

4.3.4.2 Comparison of estimates with true stocking

As for seedling density, stocking by triangular tessellation and quadrat tended to be marginally greater than the true values (up to 2.8 % of the true value), also probably a result of insufficient replication to completely bring stocking to equilibrium (table 4.7).

4.3.5 Effect of variation in sampling intensity on the confidence interval of estimates

The comparison of the mean variance of seedling density between quadrat and triangular tessellation indicated that variance of the triangular tessellation was greater, except for the uniform seedling distributions. The 95% confidence intervals of the seedling density estimates by triangular tessellation was approximately 3.4 times the interval by the 16 m^2 quadrat. Confidence intervals for 4m^2 quadrats were intermediate to the triangular tessellation and 16 m^2 quadrat. In order to equalise the confidence intervals by triangular tessellation and 16m^2 quadrat, sample size of the triangular tessellation would need to increased to a value equal to the ratio of the variances, which according to the fitted trendlines in figure 4.7 is by a factor of 300%.

The precision often aimed for in inventory of forests is 15% sampling error, where the sampling error is calculated as the standard error of the mean/ mean (ie se = $s/\sqrt{n}$ where s and s^2 are the standard deviation and variance of the sample statistic respectively and n is the sample size). The sampling intensity used in the simulation study was adequate for uniform to highly aggregated seedling distributions to achieve a sampling error of 15% for estimates of seedling density by the quadrat method. As the sampling intensity was marginal for the highly aggregated distribution it would be necessary to increase the sampling intensity by a factor of 300% to achieve a 15% sampling error by triangular tessellation in the 4 ha stand using a 40 m x 20 m sampling grid.

Halfing the sampling intensity to the level routinely carried out in regeneration surveys (ie 80 m x 20 m sampling grid) would mean that the 15% sampling error would only be achieved by quadrats for uniform to slightly aggregated distributions in 4 ha stands. The triangular tessellation would achieve less than 15% sampling error for all distributions, including uniform distributions. However, regeneration surveys are generally carried out in coupes ranging from 10 to 100 ha in area, which greatly increases the number of plots sampled and reduces the sampling error. In Victoria and Tasmania, where highly aggregated regeneration may result from clearfelling or seedtree systems, coupe size often is greater than 30 ha. To cover these coupes, the number of sample plots would exceed the 150 needed to reduce sampling error by triangular tessellation to 15%. In *E. diversicolor* forests of Western Australia, planting is the most common method of establishment and measuring seedling density by triangular tessellation of the uniform distributions would commonly achieve a sampling error of less than 15%.

Table 4.7 Mean (standard deviation of mean) stocking, estimated by two systematic surveys of 500 stands per process and true stocking by triangular tessellation (plot standards= 1666 and 625 spha) and quadrat (plot size= 4 to 16 m^2).

	True stock quad.	Stocking estimate by quadrat (std dev)			True stocking by triangular tessellation		Stocking estimate by tri. tess. (std dev)	
Process	**16m^2**	**6m^2***	**16m^2**	**Equiv plot size**	**std = 1666**	**std = 625**	**std= 1666**	**std= 625**
2500 seedlings per ha								
uniform	99.99	na	100 (0.08)		79.63	97.60	81.8 (3.74)	na
random	98.19	na	98.2 (1.32)		49.41	94.25	49.7 (5.00)	na
R=20m, n=500	89.18	na	89.7 (3.47)		45.10	79.91	45.8 (4.82)	na
R=13m, n=200	76.28	61.3 (4.89)	76.6 (5.25)	69.6 (5.02) 9.5 m^2	42.28	67.43	43.2 (4.27)	68.7 (5.11)
R=13m, n=50	54.72	47.1 (5.64)	55.3 (6.43)	48.8 (5.87) 9.5 m^2	37.07	47.43	38.0 (4.79)	48.6 (6.34)
R=13m, n=25 80% Random 20%	70.20	47.7 (7.2)	70.2 (6.6)		29.0	46.2	29.3 (6.34)	46.4 (7.4)
R=10m, n=50	39.55		40.2 (6.04)		28.09	32.19	29.1 (4.69)	na
1000 seedlings per ha								
uniform	94.90	60.4 (8.77)	97.0 (2.02)	85.0 (5.40) 9.2 m^2	0.0		0 (0)	82.0 (4.90)
random	79.83	44.8 (5.97)	79.6 (4.26)	54.9 (5.15) 9.5 m^2	12.70	52.89	12.6 (3.21)	53.1 (5.07)
R=20m, n=200	71.16	42.5 (4.58)	72.0 (4.21)	51.1 (4.96) 9.5 m^2	14.33	47.68	14.8 (3.37)	48.5 (4.55)
R=13m,n= 80	58.49	37.4 (4.33)	59.1 (5.10)	44.4 (4.95) 9.5 m^2	16.11	42.26	16.3 (3.50)	43.3 (4.57)
R=10m, n=20	18.45	15.7 (3.88)	18.8 (4.64)	14.4 (3.51) 4.0 m^2	12.16	13.81	12.6 (3.21)	14.2 (3.86)

na not available

The comparison of the standard deviation of stocking by triangular tessellation and quadrat methods showed that they were similar when the plot seedling density standard and quadrat size were varied to give a similar stocking value. This result is in accordance with stocking having a binomial distribution, where the error depends on the sample size and the proportion of stocked plots. The relationship between 95% confidence interval and sampling size and the proportion of stocked plots indicates that confidence interval increases from a minimum at 0% of stocked plots to a maximum at 50% of stocked plots then decreases to a minimum at 100% of stocked plots (figure 4.13). In accordance with the underlying binomial distribution, the standard deviations of the mean stocking by triangular tessellation and stocked quadrat followed the same trend. The effect of halving the sampling intensity, to the level routinely carried out in most forest types, can be predicted from figure 4.14. For proportions of around 50%, sampling error (ie standard error/mean) could be maintained at less than 15% by ensuring that sample size does not drop to less than 50. Theoretically the sampling intensity could be reduced as coupe size increases, provided that the total number of plots is not reduced. However as coupe size increases the heterogeneity is likely to increase which would decrease the precision of the estimate.

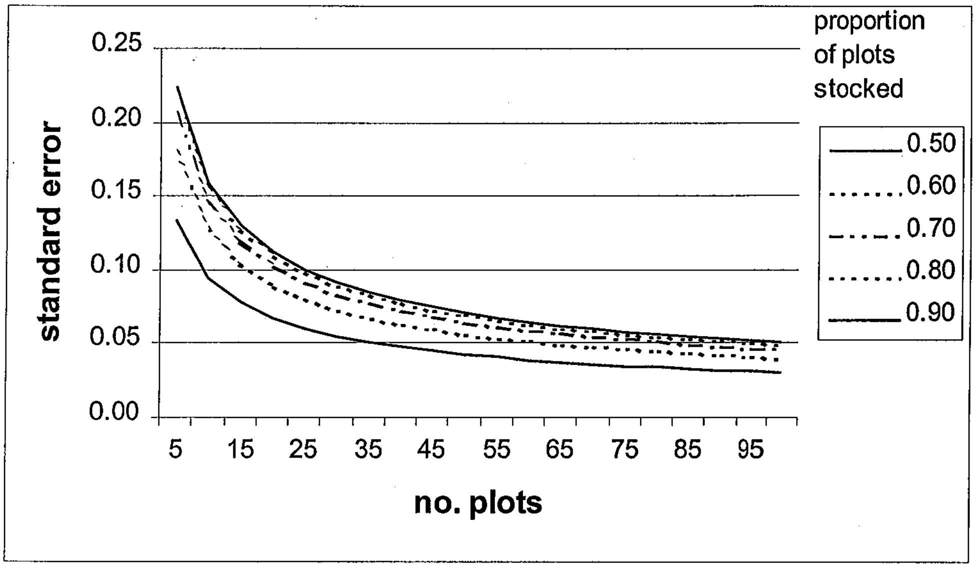


Figure 4.13 Variation in the standard error of mean stocking estimates with variation in sample size (predicted from the binomial distribution)

4.3.6 Inaccuracies introduced through practical application of measures

There appears to be little bias in the quadrat and triangular tessellation measures whereas the closest individual method is inherently biased. However the closest individual measure is so simple and easy to apply that there is low potential to introduce error through field procedures. Recent field investigations showed that seedling density estimates by the closest individual were consistently less than estimates by 4 and 16 m^2 quadrats, which provided further evidence of the inherent bias in the closest individual method (table 4.8).

Quadrat measures may be inaccurate due to error in identifying the boundary of the plots. As the name implies the method initially utilised square plots, but circular plots are generally used now, because it is more operationally efficient to determine the plot edge and search the plot. Ghent (1963) found that there was a positive bias in stocked quadrat methods because of a tendency to include seedlings on or just outside the plot boundary. However there may be a tendency to underestimate seedling density, because seedlings may be missed, particularly in very dense stands, where counting is tedious or where visibility is poor due to vegetation cover. One approach to overcome the difficulty of high seedling density is to target the seedlings that are most likely to survive the establishment phase or have potential to become part of the mature stand. The acceptable seedlings would be less dense than the total seedling population. If numbers were still high then an estimate could be made of seedling numbers in dense plots. In such cases one could reduce the plot size to reduce the size of the task, but this would decrease the precision of the estimate, if the number of plots is not increased.

The accuracy of the triangular tessellation method depends on the identification of the seedlings that form the Delauney triangle around the sample point. The practical guidelines on triangle selection attempt to cover the variability in seedling distributions. Recent field investigations have shown that the triangular tessellation method may produce an estimate of seedling density that is lower than the estimate by the quadrat method (table 4.8). The possibility of positive bias in the quadrat method was ruled out because the same thing happened at low and high seedling density and the positive bias by quadrat would not be expected to occur at high seedling density, where there is a low probability of missing seedlings. The negative bias by the triangular tessellation method may be the result of selecting a triangle larger than the Delauney triangle in order to select a triangle close to equilateral in shape.

Table 4.8 The variation in seedling density and stocking estimates by triangular tessellation, quadrat and distance measures by systematic surveys at RRS s

	Seedling density				Stocking by quadrat		Stocking by tri tess	
	Quad. 4m^2	Quad. 16m^2	Tri tess	Closest dist.	4m^2	16 m^2	1666 spha	312.5 spha
E. pilularis NE NSW								
WayWay	7083	5547	5301	2790	71	92	50	71
Lower Bucca	1510	1380	1948	719	35	69	33	71
Nambucca	11146	10052	22128	3281	79	96	71	96
E. maculata SE Qld								
Exp 631 HWD	2400	2369	1426	1342	55	93	33	79
Wet E. obliqua Southern Tas								
Picton 024A	10925	9918	6263	2733	73	93	60	91
Warra 001B	2300	2075	1550	754	40	73	15	53
Warra 008B	3606	3182	2848	1261	59	82		
High Elevation Mixed Species E.Gipps., Vic								
Clarkeville Rd	5000	4045	5024	600	47	69	33	58
Students Tk	3942	3518	2606	290	33	54	32	38
E. marginata SW WA								
Kingston SW	2250	2354	2312	1935	57	97	50	93
Kingston gap	3375	2875	3114	997	75	98	70	98
Poole	2083	1521	1619	1136	47	77	17	83
Yalgorup	1333	750	472	445	33	60	10	47
Lowland Vic								
Steep Gully	23474	14635	21081	919	88	97	88	97
Bellbird Tk	6958	5219	5139	1888	70	87	58	88

Other sources of error in the triangular tessellation method are lack of precision by estimating distances to a low level of accuracy (eg to the nearest 0.5m) and limiting the search area (eg to 5 m). At low seedling density, especially where there is dense understorey, it is difficult to locate seedlings and it may be incorrectly determined that there is no triangle within the search area. In such cases a nominal value may be given to the point (eg 200 seedlings per ha). These practical variations to the method, as applied in Western Australia, may have little practical significance as the frequency of borderline coupes is generally low in the forest type to which it is applied (pers. comm. L. McCaw CALM)

In practice average plot density by both quadrat and triangular tessellation may overestimate stand density because of the skewed distribution of the plot densities. The transformation of plot estimates by the log transformation may provide a better estimate of seedling density.

Human error has the potential to effect stocking estimates in a similar way to seedling density estimates.

4.3.7 Summary of accuracy of measures of site occupancy

Simulation of two systematic surveys of 1000 stands of the uniform, random and most aggregated spatial point processes at 2500 seedlings per ha and application of the triangular tessellation and quadrat measures of site occupancy indicated that:

- Variance of the estimate was greater by triangular tessellation than by quadrat
- Variation increased with aggregation
- The estimates and variation in estimates by triangular tessellation applied to the most aggregated process became very stable after approximately 500 stands were measured

On the basis of the simulation in the 1000 stands, 500 stands of each process were used to compare the measures of site occupancy. By simulation of two systematic surveys of 500 stands per process and application of a range of site occupancy measures it was found that :

- Seedling density by triangular tessellation and quadrat measures were unbiased for the range of seedling distributions tested
- Seedling density by the closest individual was biased for all but random distributions
- Seedling density by triangular tessellation had approximately 3 times the variance of seedling density by 16m^2 quadrat
- Stocking by triangular tessellation and 16m^2 stocked quadrat were unbiased, but the stocking estimate and its variation varied with the measure. When the triangular tessellation plot standard and quadrat size were varied so that the stocking estimates were similar, the variation of the measures were similar.
- The width of the confidence intervals of the stocking measures peaked when stocking was around 50% , reflecting the underlying binomial distribution of stocking. Sampling error could be reduced to 15% if a minimum sample size of 50 was chosen.

Thus sampling intensity would need to be increased by a factor of 300% to reduce variation in seedling density by triangular tessellation to that by 16 m^2 quadrat. Any time advantage of applying triangular tessellation compared to the seedling count in the quadrat method would be negated by the extra sampling effort required.

In order to achieve a sampling error of less than or equal to 15% in aggregated stands, sampling intensity of triangular tessellation would need to be greatly increased in small stands. However acceptable sampling error may be achieved in larger stands with a sampling grid of 80 m x 20 m.

In practice seedling density and stocking estimates by the quadrat method may be less precise or biased, because of inclusion of seedlings outside the quadrat or missing seedlings within the quadrat. Error in estimates by triangular tessellation could occur as a result of mis-identification of the Delauney triangle seedlings, missing seedlings, imprecise measurement of the triangle sides and limiting the search area.

4.4. Relationship between measures of site occupancy

4.4.1 Introduction

In section 4.3 the sampling error associated with 4 measures of site occupancy were compared, on the basis of simulation of survey methods in a range of stand types. In this section the estimates obtained by the various measures will be compared on the basis of the same simulations used in comparing accuracy and a limited number of field investigations. The objective of the comparison of the measures is to assist in the development of a standardised indicator of regeneration success. As discussed in the review the major tasks are the identification of the most sensitive measures and methods of conversion between measures

The review has drawn attention to the relationship between seedling density and stocking, because there is potential efficiency in measuring one and using it as an indicator of the other. Alternatively there may be a case for measuring both. The relationship can be derived theoretically with quadrat methods and this relationship will be compared with empirically derived relationships.

Stocking measures are designed to vary in response to the extent of voids in the seedling distribution. In this section the estimates of the extent of voids by triangular tessellation and quadrat methods are compared, including their sensitivity to changes in stand spatial distribution. The rules concerning what is a measurable void are also analysed to explain differences in estimates.

The closest individual measure of seedling density was shown to be biased varying with the extent of seedling aggregation, in a similar way to stocking measures. Thus this measure will be analysed in the context of its sensitivity as a stocking measure.

It was shown in the previous section that two measures of seedling density, quadrat and triangular tessellation, provided estimates that were very close to the true population values. It follows that the estimates of these two measures are statistically equivalent and no further comparison is necessary. However there is variation in how the quadrat and triangular tessellation measures of seedling density are applied, including variation in timing of the measurement and the application of acceptability criteria. The effect of these variations are covered in this chapter.

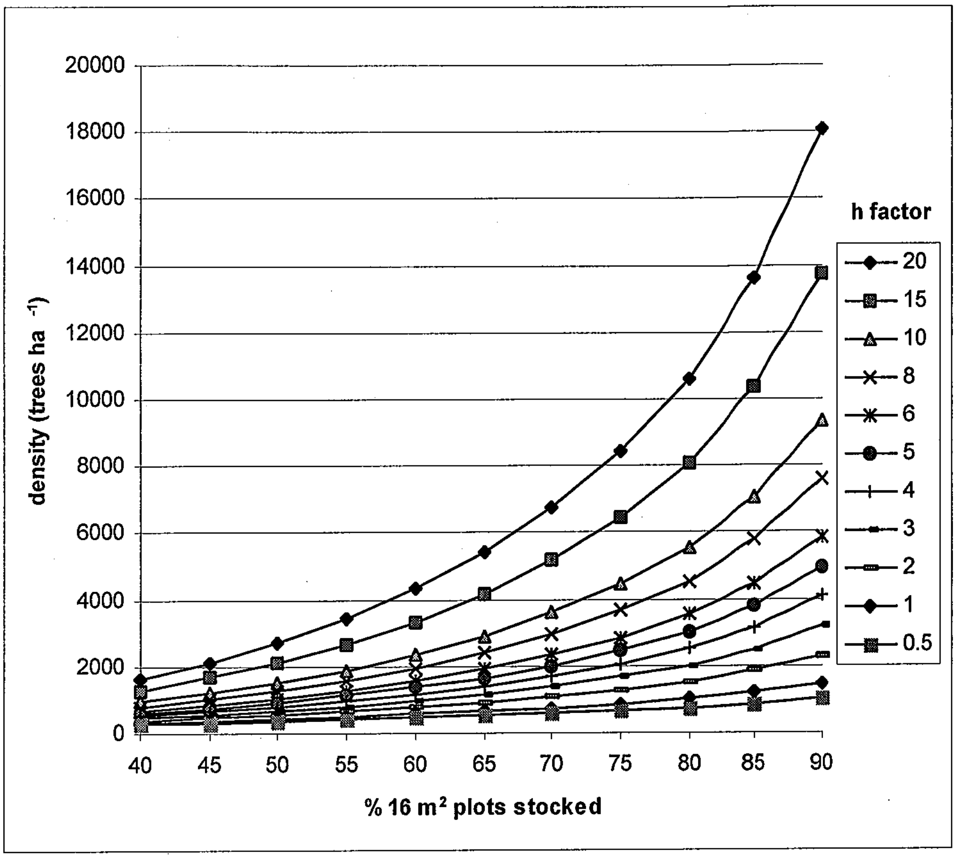
4.4.2 Variation in stocking with seedling density

4.4.2.1 The effect of aggregation of seedling distributions

When seedling density was held constant, stocking estimates decreased as stands became increasingly aggregated (table 4.5 & 4.7). The rate of decrease varied with the measure (quadrat or triangular tessellation) and quadrat size or plot stocking standard. It is immediately evident that some measure of heterogeneity may be needed to predict seedling density from stocking or vice versa.

4.4.2.2 Heterogeneity factors suitable for quadrat data

Seedling density and stocking by quadrat can be related through the theoretical distribution of quadrat counts for a random distribution (the Poisson distribution). Mount (1961) proposed the use of a heterogeneity factor that uses the departure from the Poisson distribution and the departure from the minimum density corresponding to the frequency of stocked plots. The derived set of curves (figure 4.14) can be used to predict seedling density or stocking, if one of these variables and heterogeneity are known. The simulation results confirmed that Mount's heterogeneity factor was sensitive to the variation in processes that caused aggregation. Figure



4.14 Indicates that the variation in density at a given stocking is large over the range of heterogeneity found in real stands (ie h=0.5 to 20 as per section 4.2.3).

Figure 4.14 The relationship between seedling density, stocking and heterogeneity factor for quadrat size of 16 m^2

4.4.2.3 Quantifying heterogeneity with triangular tessellation methods

The relationship between seedling density and stocking by triangular tessellation is conceptually different from quadrat relationships. The variation in the statistical distributions of the Delauney triangle areas and derived densities have not been studied. This is probably the result of the measure being relatively new to the field of ecological studies. Further study of the statistical properties could be by simulation comparing stands of varying degrees of aggregation with randomly distributed stands.

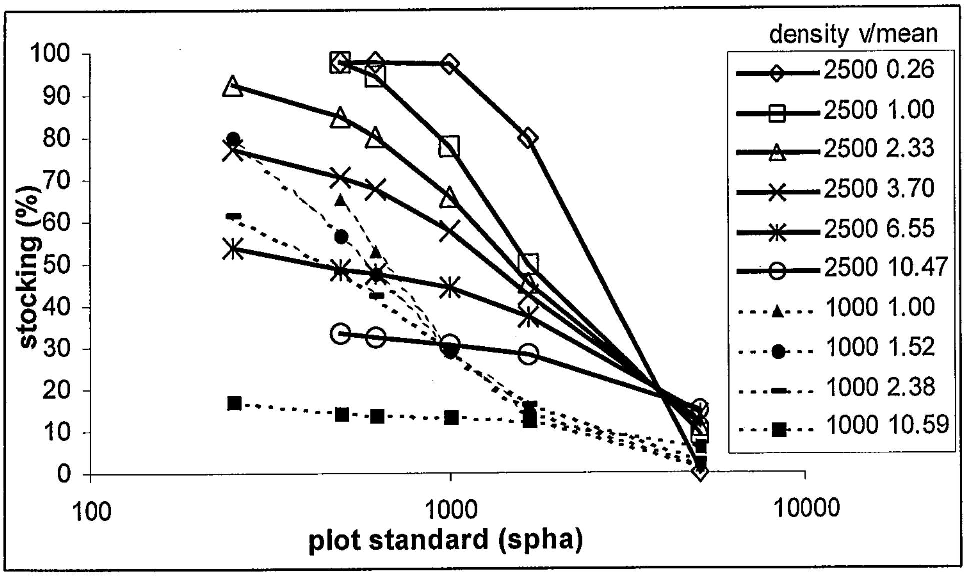
4.4.3 Comparison of stocking estimates by triangular tessellation and quadrat methods

4.4.3.1 Effect of varying the triangular tessellation plot standard and quadrat size

True stocking by triangular tessellation decreased with increasing plot standard, but the variation in stocking with the plot standard was not linear (figure 4.15a). In contrast, true stocking by quadrat decreased with increasing plot size, but like triangular tessellation, the change in stocking with plot size was not linear. Log transformation of the plot standard and plot size axes made the relationship more linear for a limited range of seedling density x aggregation (figure 4.15b).

It was also apparent that the response of stocking to variation in plot size differed from the response to variation in plot standard (figure 4.15). For example, in stands with a density of 1000 seedlings per ha and a variance:mean ratio of 2.38 stocking was approximately equivalent at 60 % by both measures, at a plot standard of 250 seedlings per ha by triangular tessellation and a plot size of 16m^2 (corresponding to a minimum seedling density of 625 seedlings per ha) by quadrat. When the triangular tessellation plot standard was doubled to 500 seedlings per ha, stocking decreased to 50 %. However when the plot size was halved to 8m^2, to effectively double the minimum seedling density standard to 1250 seedlings per ha, the stocking decreased to 45 %. The difference in responses can be explained by the inherent difference in the plot standard, which is based on actual seedling density in the triangular tessellation but on minimum seedling density in the quadrat measure. It has been shown by Mount (1961) that the relationship between minimum and actual seedling density is non-linear.

A practical relationship between the stocked plot and triangular tessellation method might be derived by consideration of the area of the void or unstocked plot. For example, the minimum sized void that can be detected by the commonly used quadrat method is the 16m^2 circular plot. Consider an equivalent sized void of 16m^2 formed by a triangle with seedlings at the three vertices, resulting from the Delauney triangulation of a seedling pattern. The corresponding plot density for the triangulation method would be 312.5 (5000/16) stems per ha. When the plot standard of 312.5 was used, then the difference in stocking between the triangulation and quadrat methods only exceeded 5% for the extremely aggregated process (table 4.9), a spatial arrangement rarely encountered in real stands.



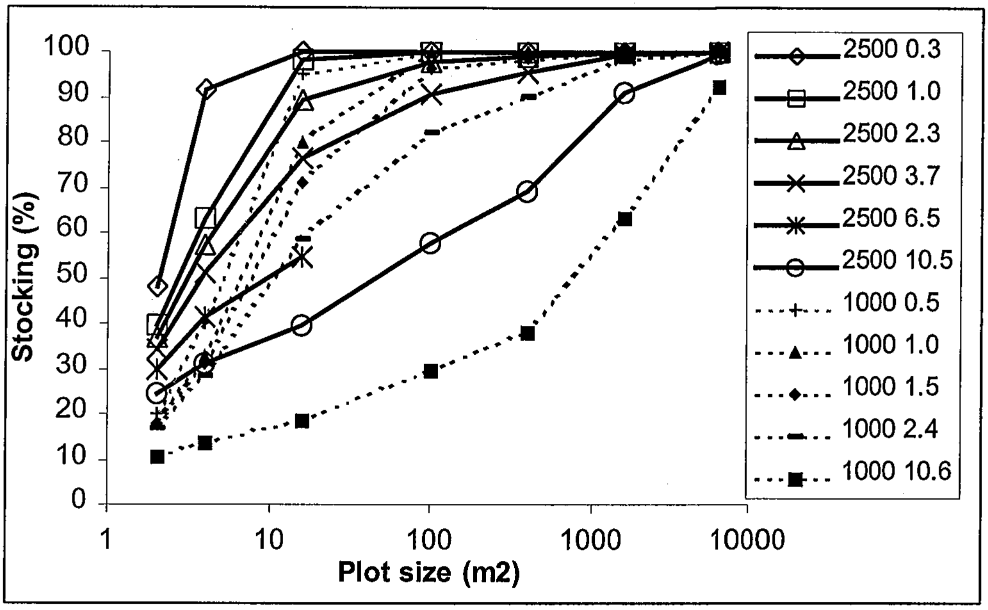


Figure 4.15 The relationship between stocking by (a)triangular tessellation and (b)quadrat and plot standard and plot size for simulated stands of 1000 and 2500 stems per ha and variance:mean ratios ($16m^2$) varying from 0.3 to 10.6.

Table 4.9 The $16m^2$ stocking and plot standard to give equivalent stocking by triangular tessellation); stocking by triangular tessellation using a plot standard of 312.5 stems per ha in simulated stands of 2500 seedlings per ha

process	$16m^2$ stocking	plot std for equiv. stocking	stocking with plot std=312.5	% difference if 312.5 used
uniform	100	<1385	100	0
random	98	500	100	2
20m, 500	89	350	91	2
13m, 200	76	300	75	1
13m,25&random20 %	70	312.5	70	0
13m, 50	55	250	52	5
10m, 50	40	250	37	8

4.4.3.2 Variation in relative values with degree of aggregation

Stocking by both triangular tessellation and quadrat decreased with increasing aggregation. However the relationship between stocking and aggregation also varied between triangular tessellation and quadrat (figure 4.16).

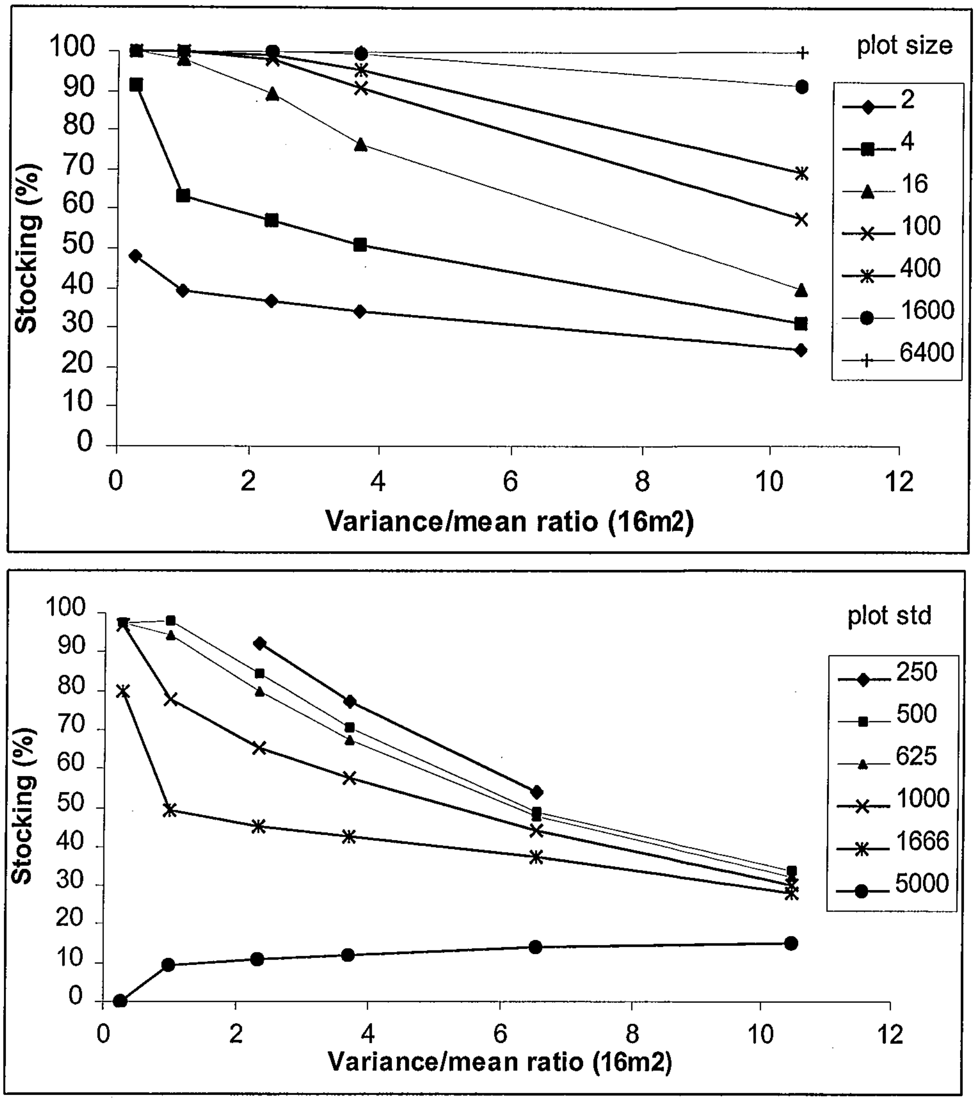


Figure 4.16 The variation in stocking by (a) quadrat (16m^2) and (b) triangular tessellation with variation in aggregation (variance:mean ratio) in simulated stands of 2500 seedlings per ha with varying plot standard (stems per ha) and plot size (m^2).

The response of triangular tessellation tended to be binary in stands of 2500 seedlings per ha when a plot standard of 1666 stems per ha was applied. The stocking was high for uniform stands then abruptly decreased to a relatively steady stocking for random and aggregated distributions. The response became more linear as the plot standard was decreased. A similar response was observed with the stocked quadrat method, the response became more linear as the plot size was increased (decreasing the minimum seedling density standard). The binary response at high plot standards is related to the statistical distribution of the Delauney triangle areas and point to nearest neighbour distances. For regular distributions the frequency distribution of triangle areas and point to nearest neighbour distances has a very small range and either a very high or very low proportion of plots meet the plot standard. The frequency distribution of random to aggregated stands is more widespread and the probability of plots meeting the plot standard is relatively low . There is clearly a case for matching plot standards to increase sensitivity to site occupancy levels around the point where decision making is required.

4.4.4 Seedling density by distance methods

Density by the distance to the closest individual decreased with increasing aggregation. The rate at which the density estimate decreased was greater than the rate of decrease in stocking by the quadrat method (figure 4.17). The reason for this difference is that density by the closest individual is inversely related to the square of the distance to the nearest seedling, whereas stocking by quadrat is inversely related to distance to the closest seedling.

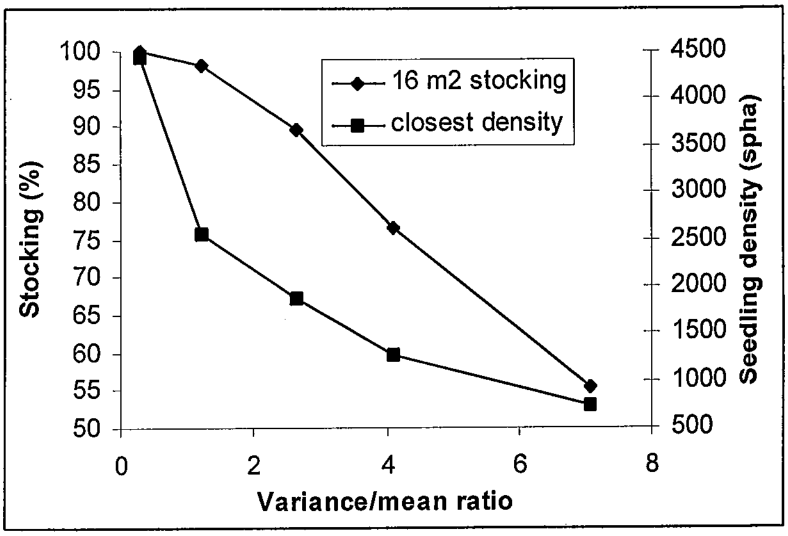


Figure 4.17 The variation in density by the closest individual and stocking by 16m^2 quadrat with variation in seedling aggregation (variance:mean (16m^2)) in simulated stands of 2500 seedlings per ha.

4.4.5 The effect of stand age on estimates of seedling density and stocking

There have been a number of studies into the variation in seedling density and stocking with time since disturbance and seed supply. The majority of these have included a study of the regeneration processes of germination and survival. In the following paragraphs the same approach will be taken as in the review: ie a discussion of the response of the major forest types within ecological groups. Before commencing the discussion, it would be useful to consider one principle that applies to eucalypt forests, that eucalypt seed is relatively short-lived. Once seed has been shed from capsules and in contact with the soil it will usually germinate or die within 12 months, although some delayed germination up to 18 months has been reported. Thus, over the period of 1 to 3 years after site preparation when regeneration surveys are carried out, usually there will not be any additional germination, unless there has been an on-going supply of seed after the site preparation. Thus in clearfall systems, where sowing/planting closely follows site preparation, the survival rate of the germinants from the first year determines the variation in seedling density and stocking over time.

4.4.5.1 Wet eucalypt forests

As described in the review, wet forests are usually regenerated using the clearfall system. In *E. regnans* of the Central Highlands of Victoria Dignan *et al* (1995) found that seedling density decreased by approximately 30% in intensively monitored plots over the period 1 to 3 years after site preparation. (Neyland and Dingle 2001) found that from 21 months to 33 months after sowing in wet *E. obliqua* / *E. delegatensis* forest in southern Tasmania, seedling density decreased by 4% overall, seedling density decreasing on most plots but increasing on others. These results contrasts with the findings of Wehner(1984) that average stocking by 4 milacre plots determined by standard regeneration surveys on 5 coupes increased from 74% to 92% over the same period since site preparation. The height class distribution suggested that the increase was not a result of continuing germination. Reasons given for the apparent increase include operator error (failure to observe all the seedlings at the earlier measurement) and limitations of the survey method. The method only assessed seedlings that were beyond the 2-leaf stage and it is possible that a number of seedlings less than the 2-leaf stage grew on and were counted at the subsequent measurement. Similarly Featherstone and Squire (1989) reported an increase in stocking in the majority of High Elevation Mixed Species coupes of East Gippsland, Victoria, that had more than one survey in the period 1962 to 1980. In *E. diversicolor* forests where seed trees were removed 9-10 months after the slash-burn, stocking remained relatively constant after the middle of the first summer following the slash burn (White 1974). However there were variations in plot counts which could be attributed to germination of dormant seed or seed blown in from the coupe edge, and deaths by various means.

Thus intensive regeneration studies suggest that seedling density may remain constant or decrease marginally over the period 1 to 3 years. However the decrease may not be measurable for a number of reasons. Firstly the decrease in seedling density would result in a smaller proportional decrease in stocking, because of the aggregated distribution of seedlings. Part of the mortality probably consists of seedlings that would not be included as part of a regeneration survey, because they would not be considered to be developed sufficiently. Also operationally it is more difficult to observe seedlings at the earlier measurement, even if they are beyond the two-leaf stage. The regeneration survey results indicate that one could consider stocking to be stable or even marginally increasing over the period 1 to 3 years after site preparation and sowing in cleafallen wet forest. Where planting is the source of seedlings, such as in *E. diversicolor* and *E. grandis*, seedlings become established or die over the first summer, and mortality is low under relatively low levels of competition over the period 1 to 3 years after site preparation.

Where there has been a potential source of continued germination of seed from retained trees, there have been mixed results. Mount (1964) reported that average stocking by milacre plots increased from 9 to 11% over the period 1 to 3 years after variable disturbance including logging by tractor or cable and burning or no burning of slash in *E. regnans* forest of the Florentine Valley, Tasmania. Grose (1960) reported an increase in stocking from 1 to 2 years after slash-burning in *E. delegatensis* in the Central Highlands of Victoria, primarily as a result of on-going germination from retained seed trees. Edwards (2001) reported an increase in seedling density of up to 33% from 2 to 3 years after slash-burning where there was 10% dispersed retention of overwood in wet *E.obliqua* in southern Tasmania. However Dignan *et al* (1995) reported a decrease in *E. regnans* seedling density of approximately 30% from 1 to 3 years after site preparation under 50% retained overwood, with a small amount of ongoing germination being exceeded by seedling mortality. McCaw *et al* (2000) reported that stocking of *E. diversicolor* by $1m^2$ plots decreased from 43% to 23 % in the period 6 months to 2.5 years after a moderate fuel reduction burn under a mixed stand of *E. jacksonii* and *E. diversicolor*. Thus although there may be an increase in stocking from continued germination this may be offset by high mortality under high levels of retained overwood, ie above approximately 10 % as retained by seed tree systems. In practice high mortality is not likely to occur in wet forests, where retention of greater than seed tree levels are generally not applied. Under the seed tree system there may be a marginal increase in stocking as a result of ongoing germination, but this is limited by the rapid recolonisation of seedbeds.

4.4.5.2 Dry eucalypt forests

Dry eucalypt forests are usually regenerated by seed tree, shelterwood or group selection silviculture. In the lowland forest of East Gippsland, Victoria, (ie Cabbage Tree SSP) seedling density remained relatively constant over the period 1 to 3 years after a range of harvesting intensities from small gaps to clearfelling and overwood retention of up to 50% and site preparation by fire or mechanical disturbance. Although there was profuse germination over this period, density stayed constant or decreased up to 10% as a result of heavy mortality (Faunt *et al*) (table 4.10). Most of the germination from 12 months after site preparation died or became sick within a few months as a result of excessive competition, and approximately 75% of the survivors at year 2.5 were seedlings that germinated in the first year.

Lockett and Goodwin (1998) reported that stocking by $4m^2$ plots reached a maximum somewhere between 2 and 5 years after sowing in dry eucalypt forest of Eastern Tasmania (ie Brockley Rd). It is not known whether the increase in stocking was a result of germination from seed blown in from outside the sowing plots, delayed germination or failure to observe seedlings at earlier measurements.

Abbot and Lonergan (1984) reported that 86% of *E. marginata* seedlings present one year after fire died over the following 5 years in SW Western Australia. However the level of retained overwood was not reported. Stoneman *et al* (1994) reported mortality of *E. marginata* of up to 30% during the second summer following overwood removal, site preparation and sowing. However both of these studies did not include the role of on-going germination in stabilising seedling density, which is possible in the silvicultural systems applied in *E. marginata* forests. This issue may be of little practical significance in the *E. marginata* forest that is cut to gaps, because they are likely to contain lignotuberous stages of regeneration that will provide the main contribution to stand growth in the following decades. Lignotuberous *E. marginata* have high survival potential (Abbott and Lonergan 1984) and stocking is unlikely to vary much in the 1 to 3 years following gap creation.

Thus in dry eucalypt forest mortality of regeneration is likely to be offset by on-going germination and stocking will be relatively stable over the period 1 to 3 years after site preparation. Finally there should be no limitations on the timing of regeneration surveys in either wet or dry eucalypt forests, provided that they are carried out in the period 1 to 3 years after site preparation and sowing.

4.4.6 The effect of acceptability criteria on estimates of seedling density and stocking

The concept of the acceptable seedling was introduced in the review. The intention of applying the acceptability criteria, is to measure the seedlings that provide a significant contribution to stand development. As discussed in the review a large proportion of seedlings will not survive, provide very little competition and could be considered irrelevant to the decision about whether the area is successfully regenerated. Thus in most native forests established from seed or in situ vegetative reproductive structures the application of acceptability criteria will reduce the estimate of seedling density. However the effect on stocking may not be as great as the effect on seedling density, because the distribution of unacceptable seedlings tends to be more aggregated than the distribution of acceptable seedlings. That is, there is a high probability that the rejection of a seedling does not vary the stocking because there is an acceptable seedling nearby which maintains site occupancy.

The effect of applying the Victorian acceptability criteria in the lowland forests of Victoria was investigated by analysing the results of intensively monitored plots in some of the Silvicultural Systems Project experimental coupes. The experimental coupes included harvesting by 4.0 and 10.0 ha clearfall and seed tree retention, with site preparation by burning or mechanical disturbance, and artificial sowing in the clearfall coupes (Table 4.10). Growth and survival of eucalypt seedlings and competing non-eucalypt vegetation on operational plots up until 4 years after site preparation was analysed to determine the effect of applying the acceptability criteria.

The Victorian acceptability criteria are as follows

- Vigour- healthy vigorous growing tip
- Origin- seedlings, lignotubers or coppice attached below 20cm
- Stem damage- free of severe damage, growing clear of obstructions which cause damage
- Height and competitive position- at least 40 cm tall and above competing understorey, but intermediate seedlings could be included if field experience indicates they may outgrow their competitors.

Investigation of a sample of the plot data indicated that at 2.5 years after site preparation, the average age when regeneration assessment is carried out in this forest type in Victoria, that seedlings greater than 40 cm tall were generally healthy and in a favourable position relative to the understorey. Thus only the 40cm height criteria was applied in order to simplify the analysis of the density and spatial distribution (variance:mean ratio) of acceptable seedlings.

Table 4.10 The variation in density (2 m^2) of all and ratio of acceptable to all seedlings with stand age and variance:mean ratio of all and acceptable seedlings at age 2 years at the Cabbage Tree Creek SSP site

Coupe details				Density of acceptable seedlings/ density of all seedlings			Density of all seedlings		Variance : mean at 2.0 yrs	
Coupe harvest		Site prep	year	2.0 yrs	2.5 yrs	3.0 yrs	1.0 yrs	3.0 yrs	acceptable	all
51001	LCF	B	89	0.38	0.62	0.5	2,375	2,250	1.7	1.6
51020	LCF	B	89	0.34	0.52	0.64	3,500	4,400	1.2	1.6
51056	LCF	B	90	0.43	0.71	0.74	3,816	3,026	1.2	0.9
51102	LCF	B	90	0.51	0.7	0.86	11,538	4,744	3.0	4.1
50919	O10	B	90	0.45	0.58	0.63	17,879	16,061	3.5	3.7
51019	O10	B	89	0.24	0.34	0.48	16,176	17,206	1.7	2.6
51027	O10	B	89	0.38	0.45	0.52	8,971	8,529	2.4	2.8
51051	O10	B	90	0.5	0.61	0.78	24,000	20,167	2.3	7.9
51005	O10	D	89	0.17	0.18	0.28	7,143	8,714	1.6	2.3
51013	O10	D	89	0.21	0.26	0.41	17,000	14,667	2.2	3.3
51048	O10	D	90	0.17	0.16	0.19	17,778	19,630	1.1	3.6
51101	O10	D	90	0.09	0.09	0.21	5,000	5,500	0.9	2.3
50922	SCF	B	90	0.17	0.2	0.26	23,714	18,571	2.3	16.9
51016	SCF	B	89	0.27	0.3	0.45	7,973	7,162	1.7	2.9
51023	SCF	B	89	0.14	0.19	0.26	6,829	8,537	1.3	7.2
51040	SCF	B	90	0.35	0.47	0.53	11,833	8,833	1.0	1.9
50904	SCF	D	89	0.21	0.26	0.33	11,282	10,128	1.4	2.3
51002	SCF	D	89	0.17	0.24	0.31	9,412	12,794	1.3	5.4
51058	SCF	D	90	0.2	0.24	0.37	27,333	25,000	2.2	20.6
51105	SCF	D	90	0.18	0.33	0.36	7,414	9,655	3.8	7.0

LCF=10.0 ha clearfall SCF=4.0 clearfall O10=seed tree retention, B=burnt D=mechanical disturbance

Table 4.11 The variation in density of all and ratio of acceptable to all seedlings with stand age at Brockley Rd

Site	Density acceptable/ all seedlings		Density of all seedlings			Variance:mean at age 2.0 yrs	
Plot	2.0 yrs	3.0 yrs	1.0 yrs	2.0 yrs	3.0 yrs	acceptabl	all

						e	
sw291	0.27	0.76	325	375	425	0.97	0.85
sw292	0.3	0.72	1950	2225	2525	1.26	1.59
sw293	0.15	0.66	1850	2550	2900	1.4	1.56
sw297	0.59	0.82	9300	9675	9900	3.47	4.24
sw301	0.19	0.49		2350	2725	1.28	1.03
sw303	0.51	0.63		925	1025	1.14	1.24
sw304	0.23	0.48		775	825	1.23	4.1
sw305	0.29	0.59		10550	11275	1.35	2.23
sw311	0.24	0.54	2600	2750	3025	1.06	1.92

The variance:mean ratio of all seedlings tended to be greater than the variance:mean ratio of the acceptable seedlings (table 4.10). The stocking by 2 m^2 quadrats was reduced by 59% (from 67% to 37%) whereas the density was reduced by 63% by applying the acceptability criteria at 2.5 years. The effect of applying the acceptability criteria was similar at Brockley Rd to at Cabbage Tree Creek. At Brockley Rd variance:mean ratio tended to be greater for all seedlings than for acceptable seedlings at age 2 (table 4.11). Stocking by 16 m^2 quadrats was reduced by 31% (from 77% to 53%) whereas the density was reduced by 69% by applying the acceptability criteria at age 2 (table 4.11).

4.4.7 Effect of stand age and seedling density on the relationship between all and acceptable seedlings

Application of the acceptability criteria, that is based on height caused an increase in the stocking with age. Over the period 2 to 3 years after site preparation the density of seedlings was relatively constant at Cabbage Tree Creek, but the ratio of acceptable to all seedlings and thus density of acceptable seedlings increased as more of the less competitive seedlings grew above 40cm. At Brockley Rd there was a larger increase in the proportion of seedlings meeting the acceptability criteria over the period 2 to 3 years after sowing, which combined with an increase in overall seedling density produced a larger proportional increase in the density of acceptable seedlings (tables 4.10 & 4.11).

Variance:mean ratio of all seedlings remained relatively constant over this period at Cabbage Tree Creek and at Brockley Rd. The variance:mean ratio of acceptable seedlings marginally increased at both locations, which is consistent with the increase in density of acceptable seedlings (tables 4.10 & 4.11).

4.4.8 Options for conversion between measures

There are two unbiased and sensitive measures of site occupancy that might be used as a reference measure of regeneration success, stocking by quadrat and triangular tessellation. Seedling density by quadrat and triangular tessellation are unbiased, but not sensitive enough to spatial variation of seedlings, to be used as a reference. The analysis of the relationships between measures indicates that accurate conversion between measures will require some measurement of the spatial distribution of seedlings, which would be included as one of the variables in a set of conversion functions (table 4.12). Current methods should enable the calculation of spatial distribution through additional analysis of the data already being collected. Stocking together with seedling counts are sometimes obtained in Victoria, and enable the calculation of the heterogeneity factor (Mount 1964). Alternatively, Mount (1964) states that the heterogeneity factor can be reliably determined from the ratio of $4m^2/16m^2$ stocking, which is available by the Tasmanian method. However the ratio of 4 m^2 to 16 m^2 stocking only provides an accurate measure of h, if h is constant with plot size. RRS data (tables 4.2 & 4.4) indicate that h varies with plot size. More optimistically, a number of measures of spatial distribution based on nearest neighbour distances can be calculated from data which are collected using the NSW method. Measures of spatial distribution would need to be specifically developed for triangular tessellation on the basis of empirical studies.

One of the major difficulties with conversion between measures is the variability in acceptable stocking with stand age. Inclusion of stand age as a factor in the conversion function will not be sufficient, as the variation in seedling acceptability is also dependent on site quality, seasonal conditions and silvicultural treatment. Thus in order to empirically develop the relationship between all seedlings and acceptable seedlings a study needs to be carried out across a range of sites over a number of years.

Functions have been developed for the simpler of the two reference measures (ie 16 m^2 quadrat stocking) (table 4.12). The development of the function for Victorian 16m^2 acceptable stocking to 16m^2 stocking is not possible at this stage. As an interim approach it could be assumed that 16m^2 stocking is equivalent to acceptable stocking and there would be no need for conversion. This approach would understate the regeneration performance in Victorian forests.

The conversion could also be further simplified by converting data at each plot rather than at the stand level. For example, the WA method could adopt a point density standard of 312.5 stems per ha, and the NSW method could include a comparison of the distance to the standard of 2.26 m, to provide comparable measures of stocking to the 16m^2 stocking . However, the difficulty with comparison of acceptable with all seedlings in Victoria can not be overcome this way, and it may be better to collect more information at each plot, ie if stocked by any seedling.

Table 4.12 Conversion functions for reporting regeneration success according to selected reference measures

Reference	WA conversion	Victorian conversion	Tasmanian conversion	NSW conversion
WA triangular tessellation Stocking (percentage of points where seedling density>plot standard)	NA	**WA tri tess stocking = fn(h, 16m^2 stocking)** h= fn(f %, d_o) Stocking (16 m^2) = fn(h, age, acceptable stocking).	**WA tri tess stocking = fn(h,16m^2 stocking)** h = fn(f % 4m^2, f % 16m^2).	**WA tri tess stocking = fn(H,16m^2 stocking)** Stocking (16m^2)= fn(H,density). See ** below H =fn(*Distances*).
Tasmanian Quadrat Stocking (percentage of 16 m^2 plots containing a seedling)	**Stocking (16m^2) = fn(h,tri tess density)** h= fn(ttVariance, tri tess density). See * below	**Stocking (16m^2) = fn(h, age, acceptable stocking)** h= fn(f %, d_o)	NA	**Stocking (16 m^2)= fn (H,density)** See ** below H= fn(*Distances*).

Where

- h is the heterogeneity factor; h = $(d_o - d_m) / (d_r - d_m)$
  where d_o is observed density, d_m is the minimum density for the measured frequency (f %) of stocked plots, d_r is the random density for the measured frequency (f %) of stocked plots
  d_m= f/100 $d_r = \log_e(100/100\text{-}f)$

- H is the Pielou point to nearest neighbour statistic; $\alpha_p = \pi\rho\varpi_p$
  where ρ is the density in no.trees per unit area, ϖ_p is the mean squared *Distances* from a grid of points to their nearest neigbours

* $Log_e(h+1)=1.8351+0.0000000671(ttVariance)-0.0008(density)$ $r^2=0.69$ $p<0.01$

** $Stocking\ \%(16m^2) = 19.72(log_e(density))-0.2355(H)-60.03$ $r^2=0.97$ $p<0.001$

4.4.9 Summary of relationship between measures of site occupancy

The analysis of simulated and real stands indicated the following:

- Seedling density and stocking by quadrat can be related by the heterogeneity factor, which is based on the departure from the theoretical distribution of quadrat counts for a random distribution (the Poisson distribution)
- The stocking by triangular tessellation and stocking by quadrat responded differently to changes in site occupancy. The difference in responses can be explained by the inherent difference in the plot standard, which is based on actual seedling density in the triangular tesssellation but on minimum seedling density in the quadrat measure.
- Density by the distance to the closest individual decreased with increasing aggregation. The rate at which the density estimate decreased was greater than the rate of decrease in stocking by the quadrat method.
- The relationship between all and acceptable seedlings by the Victorian acceptability criteria varied with stand, seedling density and stand age. Further study of variation in acceptability is necessary before conversions to equivalent stocking of all seedlings is possible.
- Conversions have been developed for converting seedling density by triangular tessellation (WA method) and seedling density by closest individual (NSW method) to $16m^2$ stocking (Tasmanian method). Other options for reference measures requires further development of conversion methods.
- More precise conversion from WA triangular tessellation stocking and NSW closest individual density to Tasmanian $16m^2$ stocking is possible by altering evaluation at the plot level.

4.5. Comparison of evaluation systems

4.5.1 Introduction

The evaluation system is usually comprised of a method of summarising the measure to the required scale, the standard(s) or desirable level(s) to which the measure is compared and decision rules to determine appropriate action on the basis of the comparison of the measure with the standard. In this chapter the central part of the system, the objective of management, is firstly introduced, then the system described. The performance of the system is assessed in terms of how sensitive it is to changes in the level of site occupancy that effect the management objective. It is also assessed in terms of how robust the system is to variations in the practical application of the measure such as the sampling method.

The systems described cover the range currently in use throughout Australia and alternative systems are introduced.

4.5.2 Mapping rule system

Mapping rule systems are based on the objective of maximising the area available for timber production by identifying and treating extensive areas of low site occupancy. The system can be applied as the main evaluation of site occupancy as in Tasmania or as an adjunct to other evaluation systems such as in Victoria and Tasmania. The following discussion is about the Tasmanian system.

The system takes the basic measure, the stocked quadrat, and partitions the coupe into stocked and unstocked areas. An unstocked area consists of the area surrounding 3 or more consecutive unstocked plots or groups of 3 or more consecutive unstocked plots separated by 1 or 2 stocked plots. The percentage of the area of the coupe that is mapped as stocked is then compared to the standard of 80% of the coupe mapped as stocked. If the measure falls below the standard, corrective action may be applied to bring the coupe up to standard.

The measure is sensitive to reductions in site occupancy, with there being a gradual reduction in the value of the measure with increases in stand aggregation for a given seedling density (figure 4.18) and a reduction with decreasing seedling density for a given degree of aggregation. The measure is less sensitive than the basic measure from which it is derived, the stocked quadrat, at low to medium levels of aggregation.

When sampling intensity is varied by changing the distance between plots within the transect there is a large effect on the area mapped as stocked (figure 4.18). For aggregated distributions, as the distance between plots is increased the area mapped as stocked increases, because there is a reduction in the probability of 3 or more consecutive plots being unstocked, the unstocked plots being aggregated. If sampling intensity is varied by changing the distance between transects then there is little effect on the area mapped as stocked. This sensitivity to sampling design needs to be taken into account, by varying the standard with sampling design.

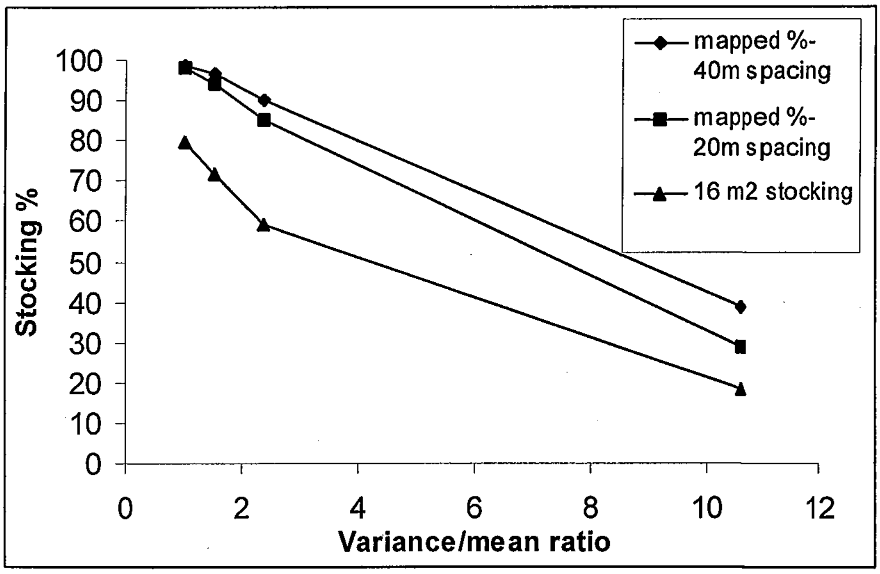


Figure 4.18 The variation in the percentage of area mapped as stocked with the variation in aggregation and distance between plots within transects in simulated stands with a density of 1000 spha

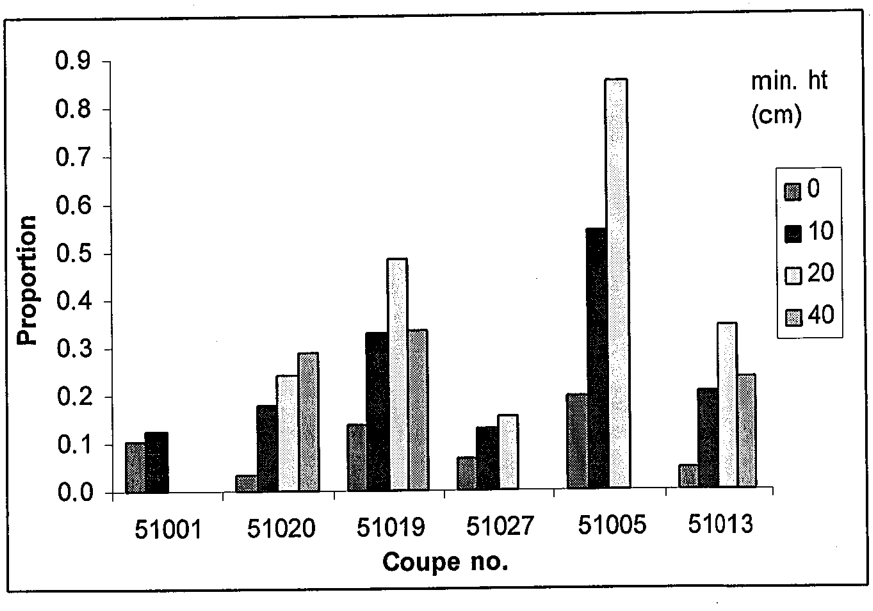
4.5.3 Stocking of acceptable seedlings

Evaluation of acceptable seedlings is based on the objective of maximising timber production by ensuring there are sufficient well established seedlings that are capable of attaining a codominant or dominant position in the stand.

The main evaluation occurs as part of the field monitoring system, where decisions are made about the health and competitive position of individual seedlings. The acceptable seedlings only are measured for site occupancy. The acceptable seedling system as applied in Victoria compares the percentage of 16 m^2 plots stocked with acceptable seedlings with a coupe level standard of 65%. If the coupe fails to meet the standard, the understocked part of the coupe may be excised for further treatment and the stocking in the remaining area compared to the stocking standard. Another feature is the reduction of the stocking standard to 55% if sampling intensity is doubled. This is a result of the error allowance being included in the stocking standard. If sampling intensity is increased the error of the estimate is reduced and this is accounted for by comparing the estimate to a lower standard. Coupes or portions that do not meet the standard are scheduled for further regeneration treatment.

The response of the 16 m^2 quadrat measure to changes in site occupancy, as seedling distributions become more aggregated, has been demonstrated to be relatively linear about the decision point of 50 to 65% (figure 4.16b). Such an evaluation system enables the degree of site occupancy to be readily determined. However of fundamental importance is the sensitivity of the plot level and individual seedling evaluation. The sensitivity of the acceptability criterion was tested using data from the Cabbage Tree SSP experiment. Seedlings were classed according to their height at age 1 and age 4 and their dominance at age 10. Thus the predictive ability of seedling height at the age range when regeneration would be assessed, was determined from its relationship with dominance at sapling stage.

(a)



(b)

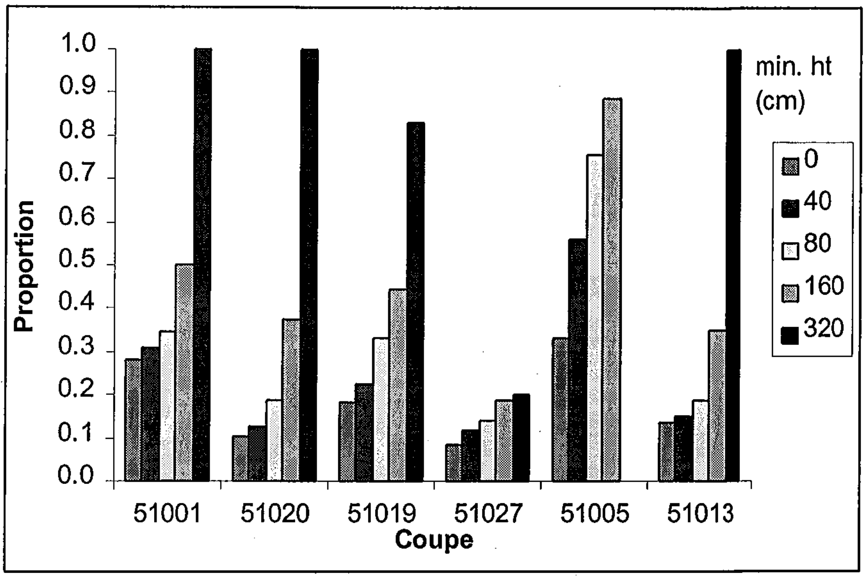


Figure 4.19 The proportion of seedlings that reached subdominant to dominant class by minimum height class at (a)age 1 and (b) age 4 in 6 intensively harvested coupes at the Cabbage Tree SSP site

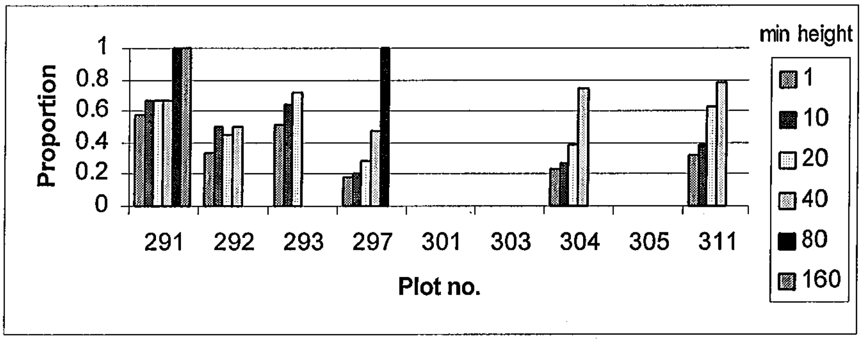
It was apparent that at age 10 there were insufficient trees in the co-dominant and dominant crown classes to fully stock some coupes and that sub-dominant trees were considered to be competitive still. Thus the proportion of seedlings reaching sub-dominant to dominant status was analysed and it was found that proportion of seedlings reaching that status varied greatly between coupes (figure 4.19). Generally less than 40% of the seedlings that were greater than 40cm at age 4 reached the sub-dominant status at age 10. The analysis showed that the proportion of seedlings reaching sub-dominant class increased with minimum height standard, with generally more than 80% of seedlings greater than 320cm at age 4 becoming sub-dominant at age 10. The relationship at age 1 was not as clear, because the proportion of seedlings that reached sub-dominant class was less in the tallest height class than the second tallest height class. In addition the proportion of seedlings that reached sub-dominance was generally less than 50% for all the minimum height classes.

Analysis of the application of the seedling acceptability criteria to the Brockley Rd stands indicated a similar trend to the Cabbage tree data, the proportion of seedlings reaching the sub-dominant class increasing with minimum height standard. In contrast to the Cabbage Tree results the trend was also clear at age 1, with the greatest proportion of seedlings in the tallest class reaching sub-dominant to dominant status at age 20 (figure 4.20).

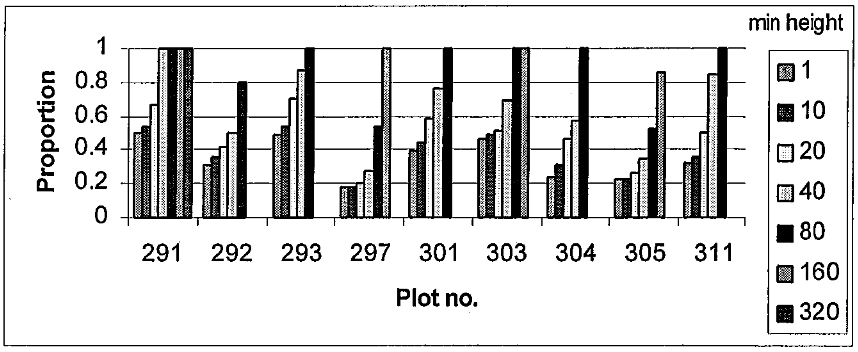
It is apparent that delaying the regeneration survey to age 4 years increased the predictive ability of the minimum height criteria at both sites, as there was a steeper increase in the proportion of seedlings reaching the sub-dominant to dominant status as minimum height increased, and in some stands nearly all seedlings that met the height standard at age 4 were at least sub-dominant. Thus the sensitivity of the seedling acceptability criteria increased with the age of assessment. All seedlings above the 40 cm height criterion at age 3 to 4 at Cabbage Tree Creek and Brockley Rd did not reach sub-dominant to dominant status. However applying a more stringent height criterion excluded some of the faster growing trees. For example at age 4, up to 15% of seedlings less than 80 cm tall reached sub-dominance at Cabbage Tree, and up to 60% of seedlings less than 80cm at age 3 reached sub-dominance at Brockley Rd .

In order to reduce the exclusion of potentially acceptable seedlings the height criteria may be set lower, but this will probably result in inclusion of seedlings that will not reach acceptable dominance at a later age. For example the proportion of seedlings greater than 80 cm at age 3 to 4 that reached sub-dominance was as low as 15% at Cabbage Tree Creek and 25 % at Brockley Rd (figures 4.19 and 4.20). In view of the competing demands of inclusion of better performing seedlings of a low height and exclusion of poorer performing seedlings of a greater height it is not possible to set a minimum height criterion, that accurately segregates seedlings of good potential from poor potential. However it may be possible to set a minimum height criterion which includes an equal number of seedlings that will not perform to balance the number that were missed from lower height that would reach acceptable dominance. At Brockley Rd the density of sub-dominant to dominant trees was intermediate to the density of seedlings greater than 40cm at ages 2 and 3 for stands of low to moderate density. In stands of high density the density of seedlings meeting the height criteria greatly exceeded the density of sub-dominant to dominant trees (figure 4.20). However the 16 m^2 stocking was similar for the acceptable seedlings at year 3 and the subdominant to dominant trees at age 20, because the variance:mean ratio of the subdominants to dominants at age 20 was much lower than the variance:mean ratio of acceptable seedlings at year 3 (table 4.13).

(a)



(b)



(c)

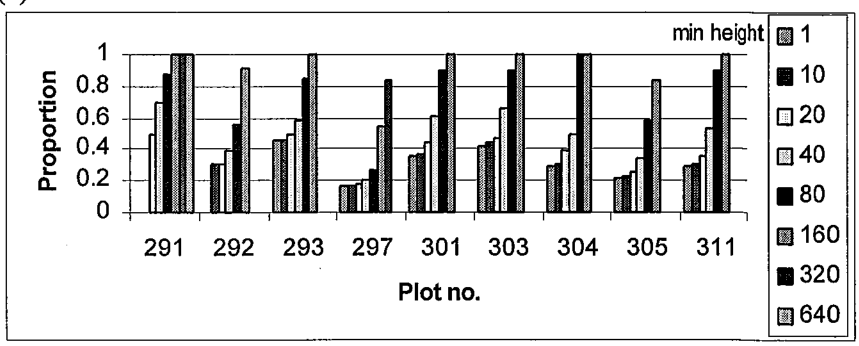


Figure 4.20 The proportion of seedlings that reached subdominant to dominant class by minimum height class (cm)at (a)age 1 (b) age 2 and (c) age 3-4 in stand mapped plots at Brockley Rd

Thus it appears that stocking of acceptable seedlings at some time during the period 2 to 3 years after sowing indicated the stocking of trees with long term survival potential at 20 years after sowing. However the timing of the indicator probably varied between plots and the large difference between year 2 and 3 stocking of acceptable seedlings suggests that a measure based on acceptable seedlings would have poor predictive power.

In contrast to the mapping rule the sampling design or grid layout does not influence the value of this measure and does not need to be considered in its evaluation. The variation in the confidence interval with sampling intensity is implicit in the variation of the standard with sampling intensity.

Table 4.13 Stocking and variance:mean ratio (16m^2) of sub-dominants to dominants at year 20 and acceptable seedlings at year 2 and 3 at Brockley Rd

	Stocking (16 m^2)			Variance:mean (16 m^2)		
Plot	Year 20	Year 2	Year 3	Year 20	Year 2	Year 3
sw291	32	16	40	0.9	0.87	0.98
sw292	80	56	84	0.83	1.61	1.94
sw293	96	40	100	0.76	1.39	0.97
sw297	92	92	100	2.26	9.34	10.45
sw301	76	44	76	1.21	1.68	1.74
sw303	48	48	60	0.95	1.35	1.16
sw304	32	24	36	1.15	1.05	3.24
sw305	96	96	96	0.79	1.64	2.37
sw311	76	64	88	0.95	1	1.28

4.5.4 Stocking by triangular tessellation

Regeneration assessment by triangular tessellation is aimed at providing a basis for predicting future yield and for determining the extent of infill planting required.

The system involves firstly an evaluation at the plot level, the plot level standard reflecting the management objective at the stand level. Secondly a stand level standard that sets the minimum proportion of the stand that meets the plot level standards. The details of the system varies between the two forest types to which it is routinely applied, ie the Karri and Jarrah forests. The following discussion will focus on the system used in Karri.

The plot level standard has 3 levels in the Karri forest:

- Optimal stocking: at which crop trees develop the maximum clean bole length (density greater than 3000 spha at age 1)
- Adequate stocking: at which crop trees will develop less than the maximum possible clean bole length but still provide a full stocking of acceptable crop trees at first thinning. (density of 1666-3000 spha).
- Understocked: at which the bole length of crop trees at first thinning will be unacceptable (density less than 1666 spha at age 1).

The assessment area is divided into cells on the basis of any features that are related to obvious changes in regeneration success. For each cell, the percentage of plots that have adequate and acceptable seedling density is compared to the standard of 85%. The location and stocking status of all plots are mapped and the area requiring infill planting is determined. The mean seedling densities of the understocked areas are calculated to determine the density of infill planting required.

The analysis of the triangular tessellation response in section 4.4 indicated that it tended to be binary in stands of 2500 seedlings per ha when a plot standard of 1666 stems per ha was applied. The stocking was high for uniform stands then abruptly decreased to a relatively steady stocking for random and aggregated distributions. In uniform stands planted at a density of 1666 to 6664 spha a 1% increase in random mortality equated to a 2 % decrease in the percentage of stocked plots, which means that the standard equates to a survival standard of 92.5%. In denser stands with a random to aggregated distribution, as would occur in stands established by seed trees, the response to changes in site occupancy is likely to be more linear, such as shown for the 500 spha plot standard at the stand density of 2500 seedlings per ha in figure 4.16a.

As for stocking of acceptable seedlings, the variation in the confidence interval with sampling intensity is implicit in the binomial distribution of plot stocking status. Thus the number of plots will affect the precision of the result, but the layout of the sampling grid should have little effect.

4.5.5 Seedling density by closest individual

The purpose of the closest individual system is to provide a stand level estimate of seedling density to aid the better achievement of management objectives. The evaluation system involves comparison of the coupe or strata density estimate to a standard of 500 stems per ha in NSW. The analysis of the variation in the estimate with variation in seedling distribution, indicates that the overwhelming response to aggregation would undermine its response to seedling density in most native forest stands. However the system may be considered to provide a sensitive indicator of site occupancy, regardless of whether it provides an accurate estimate of density. Figure 4.17 indicated that it had a more curvilinear response than the 16m^2 quadrat stocking to changes in aggregation and site occupancy at 2500 seedlings per ha. The confidence interval of the estimate is proportional to the inverse of the square root of the sample size and changing the sample size should have an effect on the confidence interval but not the mean of the estimates. Varying the layout of the sampling grid would not effect the value or the confidence interval of the estimate. The confidence of the estimate varies with the value of the estimate itself (see standard deviations in table 4.7), which needs to be considered in the minimum standard. For example, if the standard is increased a greater margin would need to be included for error.

4.5.6 Comparison of existing systems

The sensitivity of existing systems of measuring and evaluating site occupancy is compared graphically in figure 4.21. At a density of 2500 seedlings per ha and the levels of site occupancy tested, the most linear response was by the 16m^2 stocked quadrat measure. Triangular tessellation and closest individual were very sensitive to variation from uniform to random but then became less sensitive. In contrast, the mapped as stocked was only sensitive to high degrees of aggregation (ie very low levels of site occupancy).

Field monitoring methods, in particular the sampling design, had a major effect on the sensitivity using the mapped as stocked approach. The sensitivity increases with increasing plot spacing and decreases with increasing plot spacing. All other systems respond to an increasing sampling intensity with a decrease in confidence interval, but there was no response to other aspects of the sampling design.

The review included a simplistic comparison of the standards in use throughout Australia. However the comparison is so dependent on the actual measure and its variation with spatial distribution of the stand that the simulation was necessary to provide a meaningful comparison. The comparison in simulated stands with a density of 2500 seedlings per ha (figure 4.21) indicates that the triangular tessellation standard of 85% is the highest, with none of the stands meeting the standard. The 65% stocking of acceptable seedlings was the next highest standard, the moderately to highly aggregated stand not meeting the standard. (nb the acceptable stocking was derived from the ratio of acceptable to all seedlings at year 2.5 across a range of coupes at the Cabbage Tree Creek SSP site). The 80% mapped as stocked standard was a lower standard, because even the most aggregated stand, with the lowest site occupancy, almost met the standard. The 500 seedlings per ha by the closest individual standard was the lowest, with all stands meeting the standard.

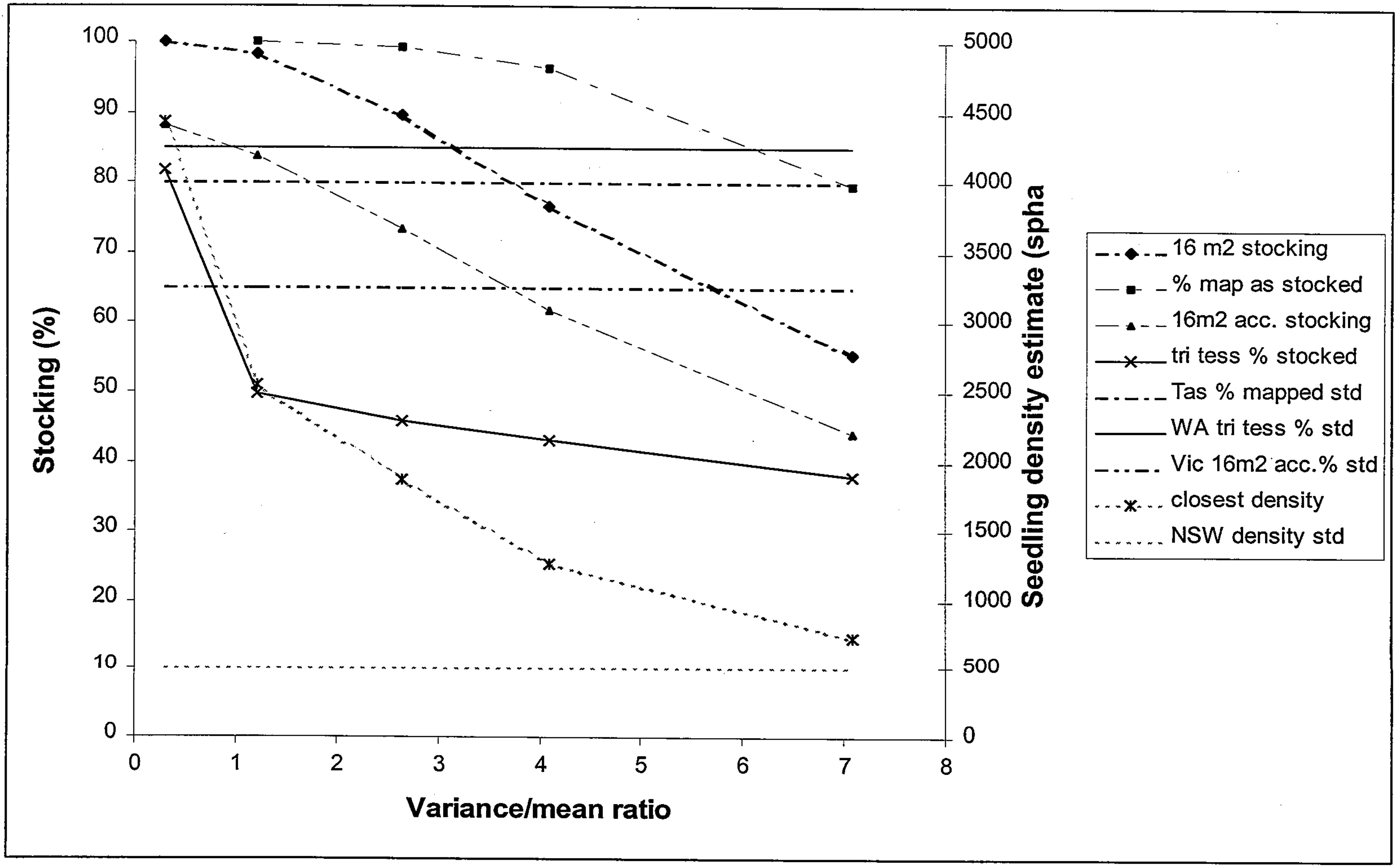


Figure 4.21 Comparison of the variation in measures of site occupancy with variance:mean ratio and evaluation standards in simulated stands with a seedling density of 2500 spha

4.5.7 Validation of existing standards

As discussed in the review of the scientific basis of the standards, there has been a variable amount of extrapolation from experimental data to the more general forest estate. The major sources of error in such an approach are the variation in stand dynamics with forest type and species, and variation with site and silvicultural treatment. The other important basis of the standard is the management objective which is generally concerned with providing a range of timber products from native forests.

The comparison in section 4.5.6 indicates that a very high standard is applied in the *E. diversicolor* forest of Western Australia. To further emphasise this difference, a plot standard of 312.5 stems per ha by triangular tessellation is roughly equivalent to a minimum density of 625 seedlings per ha by 16 m^2 quadrat. Clearly an adequate density of 1666 and optimal density of 3000 stems per ha by triangular tessellation is well in excess of the minimum density by quadrat standard. The high standard is based on the growth characteristics of the species, observed during a retrospective study, which indicated that this species needs to be established at a density well above final crop tree density to have good form at first thinning age (Bradshaw and Gorddard 1991). This may be partly attributed to the sparsity of non-eucalypt trees and large shrubs that play a role in maintaining tree form in other wet forest types. However there is a clear emphasis on obtaining the maximum wood quality from the forest, perhaps a greater emphasis on this than in the other standards tested. The standard was tested by remeasurement and analysis of the Wheatley Block spacing trial at age 10 years (section 3.3.3).

It was found that total standing volume increased in proportion to initial stocking, with a difference in volume of almost 50% between the volume in the lowest and highest stocked treatments (figure 4.22). The seed tree plots that were unspaced or spaced to 2500 trees per ha went against this trend with standing volume approximately equal to the planting density of 1000 stems per ha. Dbhob of the largest 333 stems per ha decreased with increasing initial density, the difference between highest and lowest initial density for planted trees was about 5cm (figure 4.23). Average height to the lowest live branch varied from 8m at the lowest initial planting density to 10 m at the highest planting density, and the spaced seed tree treatments were not consistently higher than the equivalent planted density. There was a high frequency of persistent dead branches>50mm diameter on the lower stem in all planted trees but there were markedly fewer in trees regenerated from seedtrees (figure 4.24). The results support the current guideline of planting *E. diversicolor* at density of 2250 stems per ha to provide an acceptable combination of diameter and standing volume. The results for stem quality are less clear, the presence of persistent dead branches not being very sensitive to planting density. The results indicate that seed tree regeneration spaced to 1250 stems per ha would give an acceptably low incidence of large branches and a reasonably high standing volume. In the absence of data for seed tree regeneration established at lower density it is not possible to determine the minimum standard for *E. diversicolor* regenerated from seed trees.

The lower standard applied to most forest types in Victoria has a historical basis in silvicultural trials in the ash eucalypt forests of the Central Highlands (Cunningham 1960, Grose 1960) with some verification by growth modelling (Edgar and Opie 1967, Hamilton 1989, West 1991). However the growth models that relate stand density to volume by diameter class, assume that the stand approximates to even spacing at all times, and do not include tree quality as a variable. The Victorian standard translates to an even distribution of approximately 400 trees per ha, and doubts have been raised over the timber quality of ash stands which might just meet the Victorian standard.

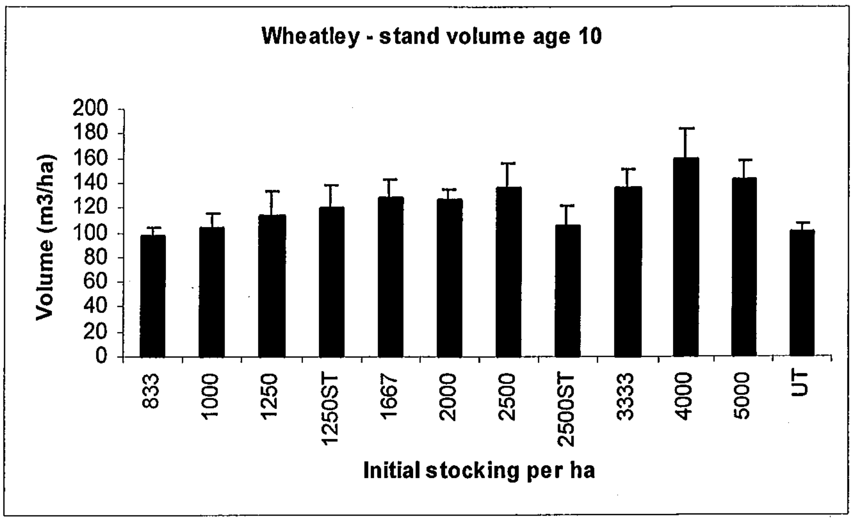


Figure 4.22 Variation in volume at age 10 with initial seedling density at the Wheatley Block trial (ST=seed tree spaced UT=unspaced seed tree)

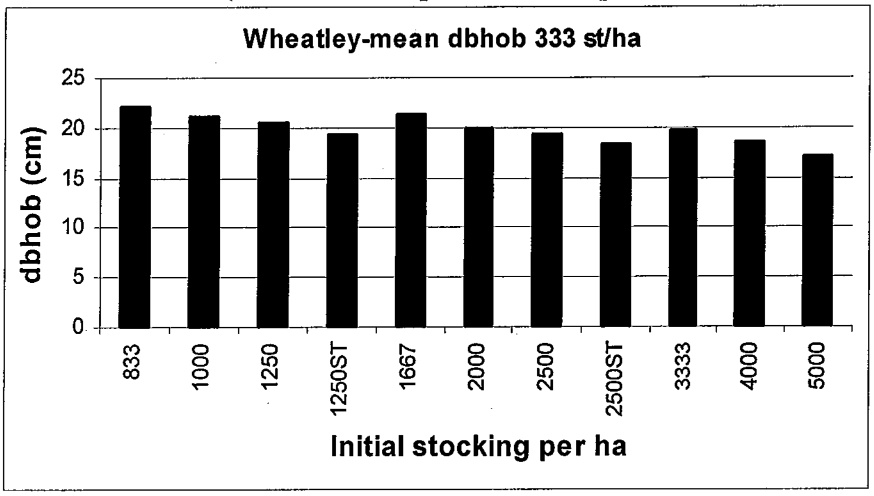


Figure 4.23 Variation in mean DBH of largest 333 stems per ha at age 10 with initial seedling density at the Wheatley Block trial

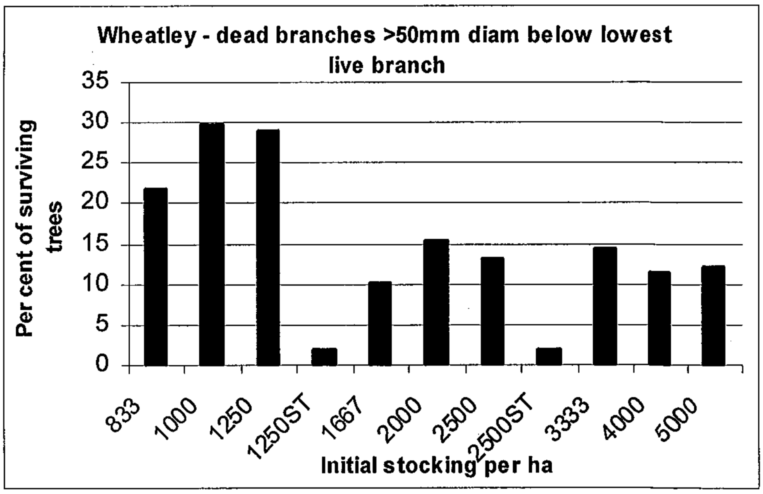
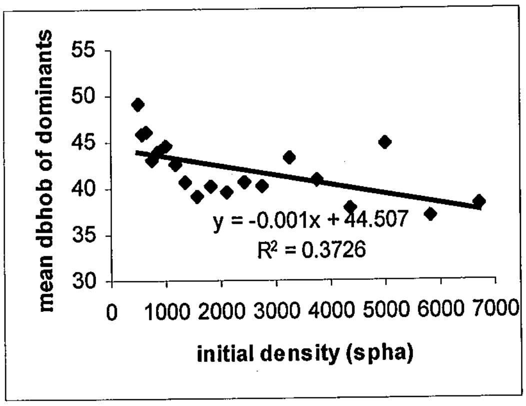


Figure 4.24 Variation in percentage of large dead branches below green height at age 10 with initial seedling density at the Wheatley Block trial

In order to test the standard the results from the last measurement of the Victoria Range Nelder trial (see section 3.3.2) were analysed and are summarised below:

- At age 26 (1992) density and basal area decreased with decreasing initial stand density.
- At age 26 mean dbh and mean dbh of dominants (fattest 62.5 per ha) increased with decreasing initial stand density (figure 4.25a)
- Top height increased with increasing tree dbhob.
- In contrast green height (height to the lowest green limb) decreased with increasing dbhob (and height) at large diameters (ie in dominant trees). Green height increased with increasing tree dbhob and total height for suppressed to subdominant trees (figure 4.25b)
- At age 28 tree volume (sawlog, pulp and total merchantable) increased with increasing dbhob.
- However merchantable stand volume did not vary significantly with initial seedling density (figure 4.26)- lower stand density balanced higher mean tree volume in the wider spaced stands.

Thus the Nelder trial results tend to support the relatively low initial stocking standard for *E. regnans* and the predictions of the Standsim model up until age 28. That is, acceptable stem quality and volume and superior dbh increment have been achieved at low planting density. It should be noted that the stem quality predictions are based on observations of green height and the assessment of sawlog length from visual indicators on standing trees and that there could be much higher levels of internal defect at low planting density. Further monitoring will indicate whether the yield declines with increasing initial density because mortality from mid-rotation age greatly increases with initial density, as predicted by Standsim (figure 4.27).



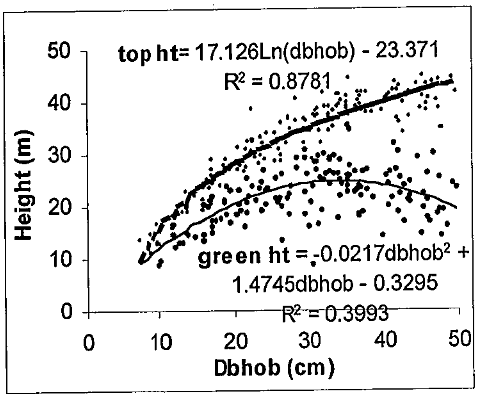


Figure 4.25The variation in (a) mean dbhob of dominants with initial seedling density and (b) height (top and green) with dbhob at age 26 at the Victoria Range Nelder trial

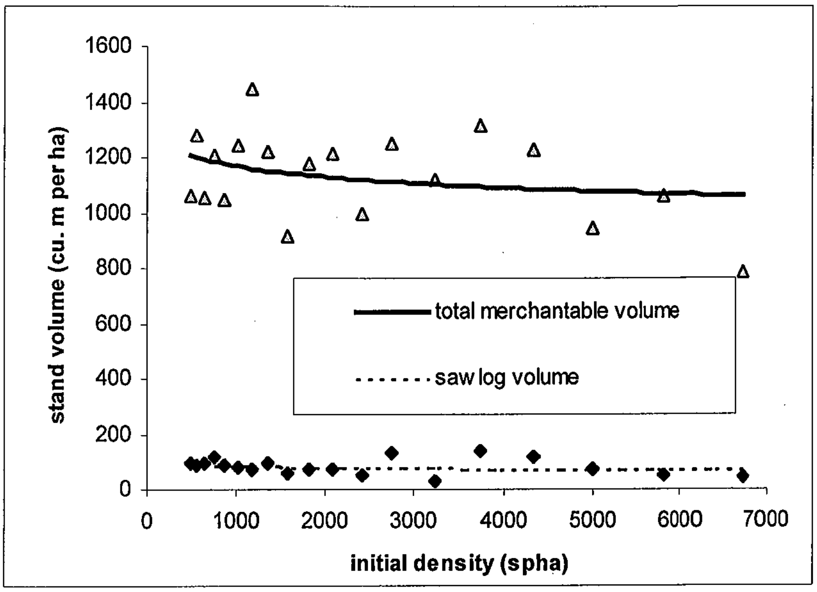


Figure 4.26The variation in merchantable volume (total and sawlog) at age 28 with initial seedling density at the Victoria Range Nelder trial

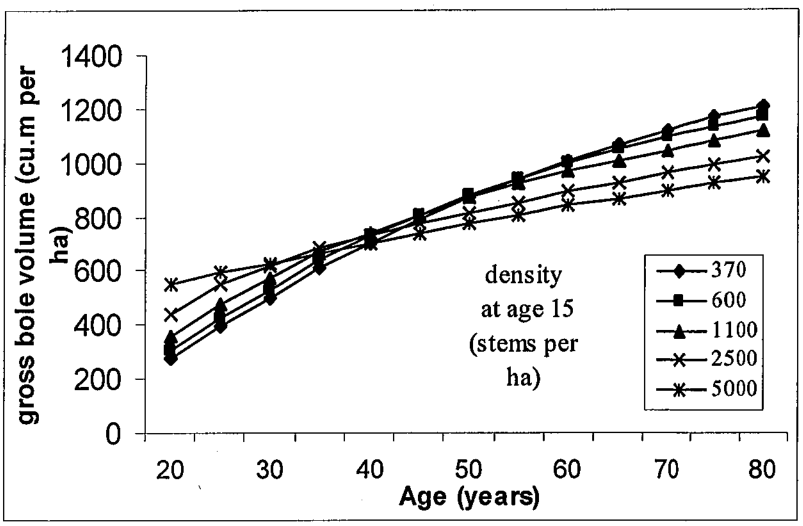
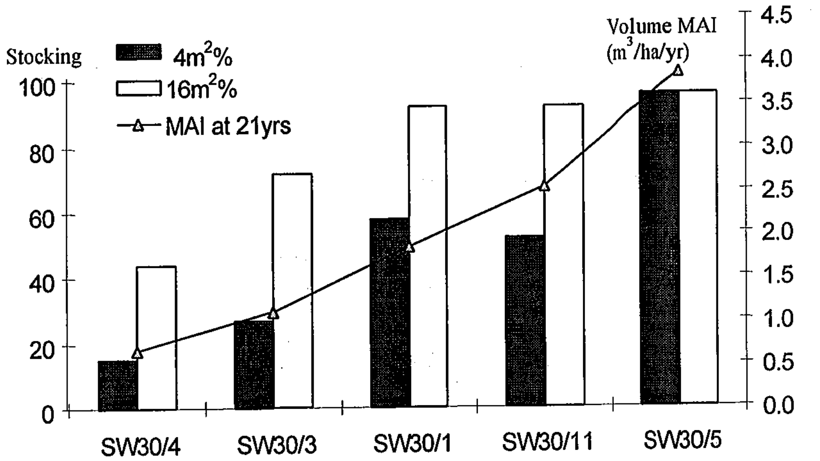


Figure 4.27The variation in gross bole volume with age as predicted by Standsim simulation from age 15 years using initial stand data from the Victoria Range Nelder trial

The mapped as stocked evaluation method which is used in Tasmania also has its derivations in the quadrat stocking of silvicultural trials, but the mapped as stocked approach was used instead of the percentage of stocked plots to avoid the question of what is the appropriate minimum standard (Mount 1961). The rules concerning the delineation of the understocked and stocked area boundaries are practical rules to identify continuous areas requiring treatment and have not been validated scientifically. Thus the standard is based on an explicit management objective, but the scientific basis is weak. The mapping rule system could be considered as a worthwhile adjunct to the stocked quadrat system for making practical decisions about retreatment, and the stocked quadrat used for expression of regeneration success because of its sounder scientific basis. In order to test the Tasmanian standard the Brockley Road trial (see section 3.3.1) was measured and analysed and the results are summarised below:

- Stocking at age 1 and age 2 was correlated with stem density and basal area up until 21 years of age. There was a better correlation between the $4m^2$ stocking and density than between the $16m^2$ stocking and density (LaSala and Dingle 2001).
- Volume MAI at age 21 increased with initial density and initial stocking (figure 4.28a).
- Potential sawlog percent did not vary consistently with density and stocking at age 21 (figure 4.28b).



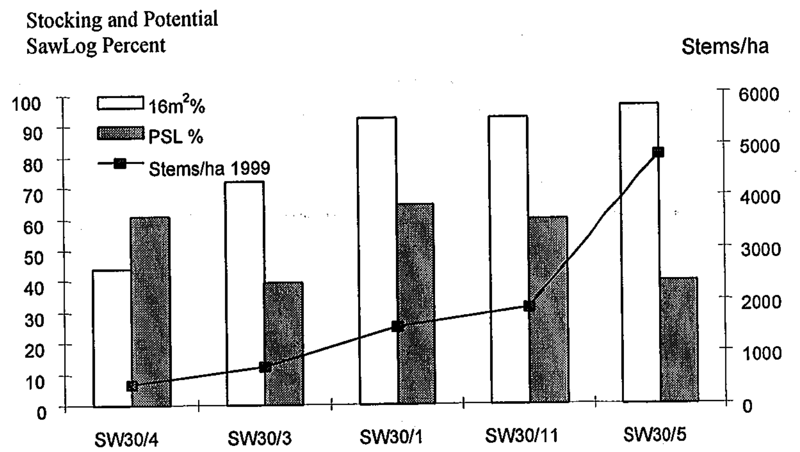


Figure 4.28The variation in (a) volume mean annual increment and (b) potential sawlog percent and density at age 21 years *with* stocking at age 2 years in the 5 x 20m x 20m plots in the 1978 replication of the Brockley Rd trial

The data to age 21 indicates that volume (total and merchantable) increases with initial seedling density up until 21 years. However Lockett and Goodwin (1998) developed a model from the data up until 16 years that indicated that volume growth was greater at lower density from approximately mid rotation. In contrast to the Standsim model, standing volume in stands with low initial density never exceeded standing volume of stands with high initial density. They conclude that without taking tree form into account, an initial 30% 4 m^2 stocking would be near ideal for growing sawlogs without thinning over a rotation of 80 years as it would achieve near maximum volume while giving larger diameters than higher stockings. Higher stockings would be required for stands destined for thinning to allow some selection for stem quality.

Considering that a stocking of 30% by $4m^2$ equates to approximately 65 to 70 % by 16 m^2 plots which is the Victorian regeneration standard and the Tasmanian mapped as stocked criterion is a lower standard than the Victorian 16 m^2 quadrat standard it is apparent that the existing standard is marginal for growing high quality sawlogs over a rotation of 80 years.

As indicated in the review the basis of the minimum seedling density standard of 500 per ha by the closest individual as used in NSW is not documented. However the density of 500 randomly distributed seedlings per ha would equate to a lower number of evenly distributed (uniformly distributed) seedlings, which could be considered marginal for timber quality. In addition, the concept of setting a minimum density standard without reference to the spatial distribution of the stand is contrary to the objective of providing a useful measure of site occupancy.

4.5.7 Summary of evaluation systems

The review and simulation study has shown the following:

- the triangular tessellation and stocking of acceptable seedling evaluation system are sensitive to changes in site occupancy
- the mapped as stocked system is relatively insensitive to changes in site occupancy
- the density by closest individual system is insensitive to changes in seedling density but sensitive to changes in site occupancy
- standards vary between existing systems in order of decreasing standard as follows: the stocking by triangular tessellation , stocking of acceptable seedlings, % mapped as stocked and density by closest individual.
- the standards of the sensitive systems could be modified to provide an equivalent standard of site occupancy
- the site occupancy standards for the major commercial forest types require further development, including consideration of management objectives and the scientific basis of the standard.

5 Measures of species composition

5.1 Introduction

The review found that measures of species composition are in an early stage of development and are a high priority for research and development. The development of this indicator of regeneration success is approached in a similar way to site occupancy. The accuracy of a number of alternative measures of species composition are compared using simulation methods. In the absence of existing evaluation systems, a number of possible evaluation systems are presented.

5.2 Spatial distributions of species mixtures

5.2.1 Introduction

As with site occupancy the variation in spatial distribution of seedlings is likely to present the greatest difficulty for measures of species composition. In this section the available information about species spatial distribution is analysed and stands were simulated to cover the range of species spatial distribution. Simulated stands provide the best method of evaluating the accuracy of species composition measures, because of the scarcity of real stand data.

5.2.2 Method

As discussed in section 2.3.4 our aim is to determine whether the species composition (ie the relative abundances of species) has changed as a result of timber harvesting. In order to test it through simulation we need to develop stands that have realistic species spatial distributions. The field of ecological studies have developed a number of measures of the affinities of coexisting species; ie how do coexisting species utilise common resources. Interspecific association is concerned with how often two species are found together in the same location and whether it is more or less than what would be expected if they were independent. Interspecific association is based solely on presence or absence, whilst interspecific covariation is based on quantitative measures of abundance; ie do species abundances together change more or less than if they were independent. The analysis of real stand data was by measures of association and covariation at various scales.

The spatial pattern of species in real stands was determined from the same stand maps used in the spatial analysis of the entire seedling population, where mixed species occurred (see 4.2.2.2). These small stands were fully enumerated, each 20m x 20m stand being subdivided into 25 x 4m x 4m ($16m^2$) plots. In addition to the stocking ($16m^2$) for each species (table 5.1) the following measures of species association were made:

- Pielou's segregation index , which is based on the nearest neighbour species association (Frohlich & Quednau 1995, Pretzsch 1997). This analysis was carried out for the most abundant species paired with each of the other species in the plot. The nearest individual to a seedling was classified as the same or different species, and the index was calculated to show whether the number of the same or different species nearest neighbours is more or less than what would be expected if they were independent. The index varied in value from -1 (total association) to +1 (total segregation).
- Ripley's K function analysis (Diggle 1983) was carried out for the interaction of the most common species and each of the minor species in the mapped stands. The function K(t), a second order neighbourhood function, describes variation in expected number of events with distance t from an arbitrary event. The cross function gives the expected number of

seedlings of species b within distance t of species a. Confidence intervals (95%) were determined by applying 20 random toroidal shifts of the pattern of the most common species and recalculating the Ripley's k cross function and selecting the highest and lowest values. This random process produces an independent association between the two species. A linearised estimator $L(t)=\sqrt{K(t)/\pi}$ enables an interpretation of the type of association as a function of distance by plotting L(t)-t against t. $L(t)-t < 0$ indicate attraction, and $L(t)-t > 0$ indicate repulsion. Visual analysis of the independence of the species was determined by examining the graphs of the cross function and associated confidence intervals.

The sparsely sampled 16 m^2 plot data from larger areas in which the stand maps were located and areas without stand maps was also used to determine species association. Species association was quantified by the following statistical analysis of the sparsely sampled RRS data pattern:

- Chi-square analysis of 2 x 2 presence/absence contingency table (Ludwig and Reynolds 1988 , Zar 1984). A 2 x 2 contingency table of the following form is prepared (where a, b, c and d are frequencies of presence or absence):

		Species 2		
		Present	Absent	Total
Species 1	Present	a	b	m=a+b
	Absent	c	d	n=c+d
	Total	r=a+c	s=b+d	N=a+b+c+d

The chi square test statistic was calculated as $\chi^2 = N(|ad-bc|-0.5n^2)^2/mnrs$ and significance of the statistic determined by comparing to the theoretical chi-square distribution. Association or segregation was determined by comparing observed "a" to expected "a" if they were independent, E(a); ie $a - E(a) = (ad-bc)/N$. If positive then there was association, if negative segregation.

The simulated stands contained a mixture of 2 species at 2 different mixture rates (90:10 and 50:50) and 3 different types of association (associated, independent and segregated). Stands were 4.0 ha (200m x 200m) in size, and contained 10000 seedlings (ie average of 2500 seedlings per ha).

Independent mixtures were produced by entirely overlapping 2 independent cluster processes with the same average number of seedlings per cluster and cluster radius.
For the 50:50 mixture Cluster number= 100;cluster radius= 13.3 m for each species
For the 90:10 mixture Cluster number= 180 for species 1, 20 for species 2; cluster radius= 13.3m for both species.

Associated mixtures were produced by randomly labelling the points produced by a cluster process (cluster number=200, cluster radius=13.3m).
For the 50:50 mixture 5000 seedlings were randomly selected and labelled as species 1, and the remainder labelled as species 2.
For the 90:10 mixture 9000 seedlings were randomly selected and labelled as species 1, and the remainder labelled as species 2.

Segregated mixtures were produced by partly overlapping independent cluster processes.
For the 50:50 mixture Cluster number= 10;cluster radius= 30 m for each species; species 1 in the western 60% of the 200m x 200m square and species 2 in the eastern 60 % of the 200 x 200m square, species distributions overlapping on 20% of the stand area.

For the 90:10 mixture Cluster number= 180 for species 1, 20 for species 2; cluster radius= 13.3m; species 1 in the western 90% of the 200m x 200m square and species 2 in the eastern 20 % of the 200 x 200m square, species distributions overlapping on 10% of the stand area.

In addition to the stocking (16 m^2) and Pielou point to nearest neighbour statistics for each species (table 5.4) the following measures of species association were made on the sparsely (40m x 20m grid) sampled 16m^2 plot data:

- Chi-square analysis of 2 x 2 presence/absence contingency table (Ludwig and Reynolds 1988 , Zar 1984).
- A distance approach was also used, that tests for independence of distances measured from the sparse set of sample points to the nearest individual of each species. Kendall's rank correlation coefficient was used to test for independence. (Diggle 1983, Zar 1984).

5.2.3 Spatial characteristics of real and simulated stands

The test of association based on the nearest neighbour (Pielou segregation index) showed that the plots in mapped stands in all forest types varied from slightly segregated to slightly associated, with most stands not being significantly different ($p<0.05$) from independently mixed (table 5.1).

The 95% confidence intervals for the k cross functions indicated that species association and segregation occurred at some distances in some stands, but there was no consistent trend. Two species mixtures that were significantly segregated by the Pielou index segregation (young ash scattered density plot 1 *E. regnans* x *E.nitens* and plot 3 *E. regnans* x *E. cypellocarpa*) also showed segregation by the second order neighbourhood function (figure 5.1). The distance over which significant segregation occurred varied with plot, being in the range 0 - 4 m for plot1 and 4 - 10 m for plot 3.

Tests of association by chi square analysis of the sparsely sampled plots at the RRSs (table 5.2) showed that species were generally associated, but the association often was not statistically significant. Thus it seems there is a tendency to association at the larger scale, that was not evident at the smaller plant to plant scale shown in the analysis of the fully enumerated stand map data.

Biologically one would not expect segregation in the forest types examined at the establishment stage. Research has indicated that there is not a difference between species in their seedbed requirements. Seed supply was clearly associated on most of the RRSs which were artificially sown with mixed seed lots. The exceptions were Students rd where there was large contributions of seed from retained seed trees on part of the coupe, but the entire coupe was oversown with a mixed seedlot. At Cabbage Tree Creek the seed tree coupes could have contained areas where seed supply from different species did not overlap, but this appears to have produced independence rather than segregation of the established species.

The rationale for inclusion of segregated stands in the simulation study was not based on the variation found in the real stands. It was based on the knowledge that there are sometimes clear division of harvested areas into different species mixes, and seed supply strategies are used to maintain this species segregation. However the entire harvested area would often be treated as a single entity in regeneration surveys.

Table 5.1 Pielou segregation index and probability of species association between the most common and each minor species at the RRS plots. The Pielou segregation index varies in value from -1 (total association) to +1 (total segregation . $p<0.05$ indicates the value of the index is significantly different from 0 and species are not independent.

			species b		species c		species d	
stand	**species association (a x b,c,d)**	**Stocking by species (4m²)**	**pielou seg index**	**p**	**pielou seg index**	**p**	**pielou seg index**	**p**
Bellbird Tk								
low density	sie x str	13,9	0.500	0.072				
Brockley Rd								
sw291	obl x oth		0.667	0.386				
sw292	obl x glo,vim,pul	36,12,12,7	-0.200	0.300	0.110	0.990	0.290	0.140
sw293	obl x glo,pul.vim	36,25,11,9	0.251	0.081	0.340	0.047	-0.084	0.910
sw297	obl x glo,pul,vim	75,2438,10	-0.065	0.420	0.009	0.979	-0.041	0.891
sw301	obl x glo,oth,vim	48,11,4,7	-0.140	0.544	-0.040	0.172	-0.090	0.941
sw303	obl x glo,oth,vim	15,11,7	0.296	0.454	-0.235	0.464		
sw304	obl x ten,oth	6,6,7	1.000	0.000	0.152	0.831		
sw305	obl x glo,oth,vim	89,29,17,50	-0.002	0.733	-0.064	0.549	-0.013	0.965
sw311	obl x glo,oth,vim	43,7,7,11	-0.089	0.960	0.116	0.881	0.051	0.986
Clarkeville Rd								
high density	fas x den	42,11	-0.054	0.854				
lo density	fas x den	33,6	-0.069	0.611				
Young ash scattered density								
plot 1	reg x nit,del	47,12,2	0.179	0.002	-0.021	0.303		
plot 2	del x reg	68,8	0.310	0.000				
plot 3	reg x del,cyp	80,50,4	0.016	1.000	0.363	0.000		
Students Rd								
high density	fas x cyp,obl	34,45,7	0.017	0.963	-0.054	0.424		
med. density	fas x cyp	26,30	0.014	0.925				
low density	fas x cyp	12,10	0.000	0.679				

Species: sie=*E. sieberi*, obl=*E. obliqua*, glo=*E.globulus*, vim=*E.viminalis*, pul=*E. pulchella*, ten=*E. tenuiramis*, fas=*E. fastigata*, den=*E. denticulata*, reg=*E. regnans*, nit=*E. nitens*, del=*E. delegatensis*, cyp=*E. cypellocarpa*, oth=more than one other species

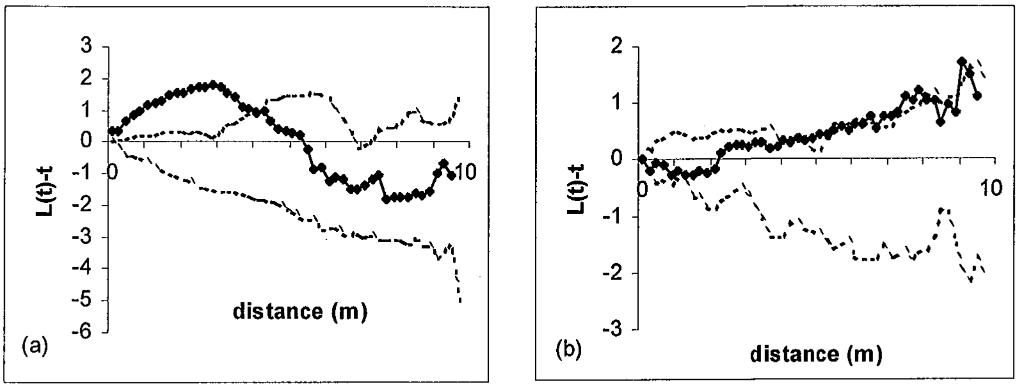


Figure 5.1 Estimates of second order neighbourhood functions (L(t)-t) and 95% confidence envelopes for Scattered ash density plots (a) *E. regnans* x *E.nitens* in plot 1 and (b) *E. regnans* x *E. cypellocarpa* in plot 3

Table 5.2 Probability and observed minus expected values for chi-square analysis of presence/absence of species association in regeneration survey plots in areas harvested by clearfall (CF), small clearfall (SCF), seedtree (ST), shelterwood (SW) and medium gap (MG) in mixed species RRSs. If a - E(a) is positive then there was association, if negative segregation.

Coupe	Harvest	No. plots	p	a-E(a)	p	a-E(a)	p	a-E(a)
Lowland forest, Vic								
SSP51056	CF	72	0.057	3.9	0.137	3.3		
SSP51102	CF	55	0.950	0.6	0.125	2.8		
SSP50919	ST	28	0.467	1.3	0.308	1.7		
SSP51051	ST	24	0.387	-1.1	0.892	0.6	0.892	-0.4
SSP51048	ST	29	0.262	-2.0			0.280	1.9
SSP51101	ST	46	0.812	0.9	0.542	1.0		
SSP50922	SCF	21	0.935	0.4	0.292	1.4		
SSP51040	SCF	30	0.928	-0.6	0.127	2.1		
SSP51105	SCF	30	0.935	-0.4	0.709	0.2		
SSP51058	SCF	30	0.913	0.6	0.342	1.3	0.687	0.8
Bellbird tk	ST	60	0.036	-4.0	0.648	0.0		
HEMS, Vic								
Students rd	LCF/ST	76	0.009	4.0	0.028	4.5		
Clarkeville rd	LCF	78	0.024	3.7			0.015	4.6
***E. pilularis*, NSW**								
Way Way	MG	24	0.552	1.1			0.384	1.2
Lower Bucca	MG	48	0.829	0.2	0.643	-1.1		
Nambucca	MG	36	0.208	2.2			0.001	5.4
***E. maculata*, NSW**								
HWD 631	Pre harvest	100	0.018	-5.3	0.264	3.2		

Simulated mixtures of species showed segregation, association and independence as intended (table 5.3). The random nature of the stand generation process was reflected in the variability of the species association. Less than 100% of stands with segregated or associated species mixtures were statistically different from independence; the percentage varied from 42 % of associated stands with 90:10 species mix to 86 % of segregated stands with 50:50 species mix. Approximately 2% of independent stands were significantly different from independence. The distance based association measure varied in a similar way; the strongest association and segregation being in the 50:50 mix.

Table 5.3 Spatial distribution by species and for all species (pielou point to nearest neighbour statistic and stocking by species) and species association indicators (percentage of stands with significant association by chi-square analysis, mean observed minus expected values for chi-square and Kendall's rank correlation coefficient)- mean and standard error of the mean of 1000 stands of 6 stand types representing 2 species mix rates (50:50 and 90:10) and 3 types of association (independent, segregated and associated)

	Species 1		Species 2		All species		Species association		
Stand type	**pielou**	**stocking**	**pielou**	**stocking**	**pielou**	**stocking**	**% p<0.05**	**a-E(a)**	**corr dist**
Indep 50:50	4.02 (0.039)	67 (0.2)	3.95 (0.036)	68 (0.19)	2.23 (0.028)	99 (0.09)	2	-0.03	-0.002
Segreg 50:50	5.86 (0.084)	38 (0.25)	5.81 (0.089)	38 (0.25)	8.36 (0.106)	68 (0.30)	49	-3.55	-0.29
Assoc 50:50	3.79 (0.037)	68 (0.19)	3.79 (0.037)	68 (0.19)	6.08 (0.071)	78 (0.18)	86	6.14	0.56
Indep 90:10	3.11 (0.034)	76 (0.19)	12.8 (0.106)	19 (0.16)	4.77 (0.057)	80 (0.18)	2	0.04	0.004
Segreg 90:10	3.75 (0.050)	72 (0.17)	5.59 (0.113)	11 (0.11)	4.98 (0.061)	80 (0.18)	64	-2.7	-0.255
Assoc 90:10	3.11 (0.036)	77 (0.19)	8.09 (0.046)	30 (0.20)	6.03 (0.072)	78 (0.19)	42	3	0.52

5.2.4 Summary of spatial distributions of species mixtures

The association of species in real stands varied with the scale of analysis. At the smallest scale, as indicated by nearest neighbour analysis, species tended to independence. At the 16 m^2 plot scale species tended to be associated.

Simulated stands included segregated, associated and independent species mixes at two rates of mixing of two species (50:50 and (90:10). The random nature of the simulation processes was reflected in the variation between stands in the degree of association.

5.3 Evaluation of accuracy of measures of species composition

5.3.1 Introduction

There are a number of possible measures of species composition (ie the relative abundances of species) which are based on general site occupancy measures. The measures are presented under the heading of the site occupancy measure and state where they are applied. Where further useful information (eg species association) could be provided without any additional data collection this is noted under the particular measure.

Triangular tessellation (WA): the species of each seedling making up the triangle is recorded then species composition is calculated as the total number of seedlings of each species as a percentage of the total number of seedlings of any species in triangles.

Closest individual (NSW): the species of each closest seedling is recorded and the species composition is calculated as the percentage of closest seedlings by species. Density of each species is estimated by multiplying the density estimate by the percentage of the species. A distance based species covariation measure could be determined using the data.

Quadrat methods (Victoria): the species are counted separately in each plot to the extent that 10 of each species are counted on each coupe. Each eucalypt species present (absent by default) on each plot is recorded, which is also a common method employed in ecological surveys. Although no further processing takes place at present, the data would enable stocking by species to be determined and a species association measure to be calculated.

Quadrat methods (other): common practices in ecological surveys include the assessment of cover class or number by species on each plot. The average cover or count for each species can be used to determine the percentage abundance or importance of each species in the community. The data could be used to calculate a interspecific covariation measure.

As for site occupancy, the accuracy of these measures can be quantified in terms of bias and precision. Inaccuracy or error can be the result of a number factors, including sampling error and human error associated with the field monitoring procedure. This section is primarily concerned with quantifying bias and precision due to sampling, through empirical and theoretical means. The stand structures to which the measures will be applied are presented in section 5.2. In addition, error due to field monitoring systems will be addressed, but on the basis of a literature review and a limited number of field observations.

5.3.2 Simulation of survey methods

As with simulation of site occupancy, the survey method based on the 40 m x 20 m systematic grid, was used for species composition estimation. However the simulation study differed slightly as 1 systematic survey was carried out on each of the 1000 stands developed by each process. Site occupancy was determined separately for each species as by the methods described for the site occupancy section (4.2.2). However quadrat size was restricted to 16 m^2. Thus the following plot measurements were taken:

- Seedling density by quadrat count (16 m^2 circular plots)
  - Count of all seedlings by species within 2.26 m radius was converted to seedling density using the formula: D (seedlings ha^{-1}) = 625 x seedling count

- Seedling density by triangular tessellation
  - Delauney triangles were created for a 10m x 10m area surrounding each plot point. The area of the triangle containing the plot point was determined and converted to an equivalent density using the formula:
    D (seedlings ha^{-1}) = 5000 / area (m^2)
    The species of the 3 seedlings making up the triangle were recorded.

- Seedling density by point to plant (distance to the closest seedling)

  - The distance (m) to and species of the closest individual was determined.

- Stocking by quadrat method (% 16 m^2 plots stocked)
  - All species present within 2.26 m were determined.

Stand level measures were calculated for each stand as follows:

- Seedling density by quadrat count and triangular tessellation by species
  - Mean and variance of plot seedling density estimates;
  - % composition by quadrat species a =
    (mean density species a) x 100/ (mean density species a + mean density species b)
  - % composition by triangulation species a =
    (No. triangle seedlings species a) x 100 / (No.triangle seedlings species a + b)

- Seedling density by point to plant (distance to the closest seedling) by species
  - The seedling density was calculated by the following formula:
    D (seedlings ha^{-1}) = 10000 / (2 x mean distance(m))^2
    A correction factor was applied for nil plots.
  - % composition by closest individual density species a =
    Dspecies a x 100/(Dspecies a + Dspecies b)
  - % composition by closest individual species a =
    No. plots closest species a x 100/ No. non-nil plots

- Stocking by quadrat by species
  - The percentage of stocked plots was calculated.
  - Species composition index 1 species a =
    stocking species a x 100 / (stocking species a + stocking species b)
  - Species composition index2 species a =
    no. plots species a only + 0.5 x no plots species a and species b/ total no.plots
    ie = ((sto%all – sto%spb) + 0.5 x (sto%spa –(sto%all – sto%spb))) x 100 / sto%all
    where sto%xxx is the overall stocking or stocking by species

5.3.3 Accuracy of estimates of percentage composition by species

Estimates of the species composition of the 50:50 species mixture were very accurate by all the measures tested (table 5.4). However the measures of species composition produced bias in estimates of percentages of the species in the following 90:10 species mixtures (table 5.4):
- Triangular tessellation: independent and segregated 90:10 species mixtures
- Closest individual: independent and segregated 90:10 species mixtures
- Closest density: all 90:10 species mixtures
- Quadrat count: independent 90:10 species mixtures;

The small 95% confidence intervals for the quadrat method produced a result that mean estimates very close to the true value were classed as biased. However the quadrat estimate was often closer to the true species mixture than the estimate by the other methods that were classed as unbiased. Thus the bias in the quadrat method is considered to have no practical importance. The bias of greatest practical importance was that produced by the triangular tessellation and closest individual methods when measuring the independent and associated 90:10 species mixtures.

Table 5.4 Estimates of species composition by triangular tessellation, closest individual, 16 m^2 quadrat count, closest density, and two indices based on stocking by species (mean and standard error of the mean of 1000 stands)

Stand type	tri tess	closest individual	quadrat	closest density	index 1	index 2
Indep 50:50	49.78 (0.2884)	49.76 (0.4112)	49.65 (0.2887)	49.61 (0.4305)	49.80 (0.1065)	
Segreg 50:50	49.8 (0.5545)	49.96 (0.4956)	50.35 (0.28)	50.17 (0.7306)	49.84 (0.2502)	49.82 (0.2709)
Assoc 50:50	50.05 (0.2718)	50.39 (0.4228)	49.99 (0.2139)	49.94 (0.3035)	50.03 (0.0689)	50.06 (0.1199)
Indep 90:10	87.15 (0.2324)	86.93 (0.2877)	90.21 (0.1738)	90.3 (0.2132)	79.70 (0.1381)	85.04 (0.1274)
Segreg 90:10	87.82 (0.1503)	87.41 (0.1626)	90.09 (0.1998)	91.43 (0.3316)	86.30 (0.1151)	87.44 (0.0950)
Assoc 90:10	89.95 (0.1637)	89.74 (0.2664)	89.99 (0.1306)	85.11 (0.1967)	71.77 (0.1313)	79.72 (0.1320)

The precision of species composition estimates was greatest for the quadrat method. On average the 95% confidence interval of the triangular tessellation method was 30% greater than by the quadrat method. The relative precision of closest individual and closest density measures varied with the species mixture process (table 5.4). On average the 95% confidence interval of the closest individual and closest density were 62 % and 70% greater respectively than the quadrat method.

The confidence interval of the estimate varied with the percentage of the species mix, the confidence interval being greater for the 50% species mixture. This is similar to the variation in stocking (see 4.3.5), the error being maximum at 50% reflecting the underlying binomial distribution.

5.3.4 Accuracy of estimates of stocking by species

True stocking was not calculated in the species mix study, because the accuracy of stocking estimates has been previously studied in the site occupancy study. The previous study found that stocking by quadrat and triangular tessellation was unbiased and that error was dependent on the number of samples and the actual value of stocking. The error was found to peak at stocking of around 50%, which was consistent with the underlying binomial distribution of proportional data. This trend was clearly shown for the simulated stand processes in the species composition study (table 5.3 & figure 5.2).

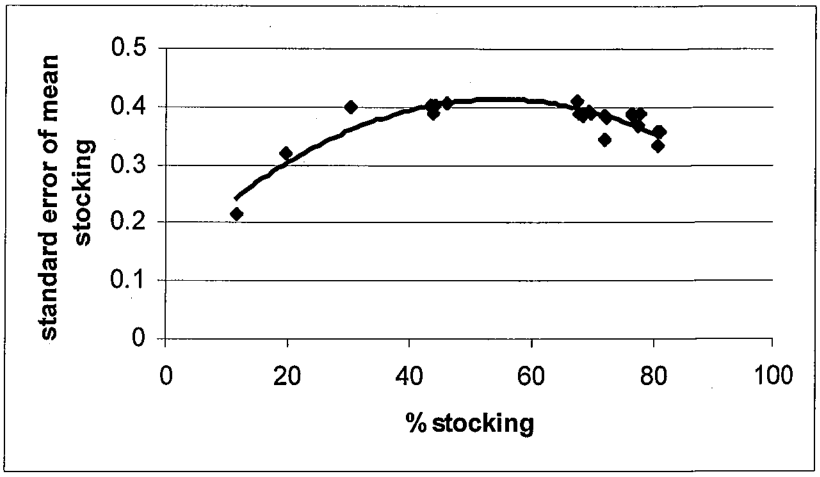


Figure 5.2 Variation in standard error of mean stocking with stocking in 5 mixed species stand types

The species composition indices based on stocking could also be assumed to be unbiased because the measures from which they are derived are unbiased. There was no consistent trend in the standard error of the species composition indices with variation in species mix (table 5.4).

5.3.5 Effect of variation in sampling intensity on the confidence interval of estimates

As for the measure of site occupancy, stocking of all seedlings, the confidence interval of species percentages and stocking by species can be predicted by binomial distribution. Figure 4.13 indicates the effect of increasing the number of samples on the standard error of the mean.

5.3.6 Inaccuracies introduced through practical application of measures

As for site occupancy there are a number of potential sources of error in addition to sampling error. In quadrat sampling these include error due to plot boundary definition and missing seedlings. In triangular tessellation they include incorrect selection of the Delauney triangle seedlings and in closest individual method include the incorrect selection of the closest seedling.

In addition to sources of error associated with incorrect selection or inclusion of seedlings, species identification is potentially a large source of error in measures of species composition. Identification of eucalypt species is most reliably made at the mature stage, often requiring the examination of many features such as bark, leaves, flower buds and capsules to distinguish between species. At the stage when regeneration surveys are carried out, the only features available for examination are the juvenile leaves. Juvenile leaves are very similar for some species, and it may only be possible to identify seedlings down to the level of species groups (eg ash eucalypts vs peppermints).

Application of the measures to mixed species RRSs sampled by sparse 16m^2 plots (table 5.5) indicated similar trends to the simulation study for the 90:10 species mixtures at some of the sites. That is, the quadrat count method gave an estimate of species composition for the major species that was greater than the other methods where seedling distribution of the major species was more clumped than the secondary species (Steep Gully, Students,Way Way, Poole, Kingston and Small Clearfall coupes at the SSP). The species mix in these stands was characterised by much higher stocking of the major species than the secondary species.

Conversely the quadrat count method gave an estimate of species composition of the major species that was smaller than the other measures where the major species was more uniformly distributed (Clarkeville Rd, Lower Bucca, Nambucca, Yalgorup and several seed tree coupes at SSP). Others had a similar distribution of the major and secondary species (the *E. maculata* stand, Kingston gap) which was consistent with the results for the simulated 50:50 mixtures. However the real stands did not have similar stocking of the two species that were being compared, with both highly dissimilar and similar stocking of the major and secondary species represented.

Table 5.5 Estimates of stocking by species for most abundant and second most abundant species, species composition by triangular tessellation, closest individual, 16 m^2 quadrat count, and two indices based on stocking by species in regeneration survey plots in areas harvested by clearfall (CF), small clearfall (SCF), seedtree (ST), shelterwood (SW) and medium gap (MG) in mixed species RRSs.

Coupe	Harvest	Stocking by species	tri tess	closest individual	quadrat	Indic. 1	Indic. 2
Lowland forest , Vic; % E.sieberi (E. obliqua at steep gully)							
SSP51056	CF	65, 28			82	70	77
SSP51102	CF	60, 34			60	63	68
SSP50919	ST	71, 29			50	71	79
SSP51051	ST	91, 46			72	67	73
SSP51048	ST	41, 41			57	50	50
SSP51101	ST	67, 39			65	63	68
SSP50922	SCF	71, 24			94	75	81
SSP51040	SCF	73, 30			91	71	76
SSP51105	SCF	60, 30			82	67	70
SSP51058	SCF	87, 40			89	68	76
Bellbird tk	ST	67, 30	77	75	64	69	71
Steep Gully	SW	97,44	92	92	94	69	77
HEMS, Victoria. % E. fastigata							
Students rd	CF/ST	49, 10	82	81	87	69	75
Clarkeville rd	LCF	68, 14	80	85	68	77	84
E. pilularis, NSW. % E. pilularis							
Way Way	MG	79, 42		100	88	66	72
Lower Bucca	MG	46, 19		79	72	79	82
Nambucca	MG	58, 36		76	62	62	69
E. maculata, Qld. % E. maculata							
HWD 631	Pre harvest	36,44	39	36	40	45	43
E. marginata, WA. % E. marginata							
Poole	SW	60,43	54	70	78	58	61
Kingston	SW	80, 63	66	53	69	56	59
	MG	83,83	50	55	49	50	50
Yalgorup	wildfire	7,57	6	15	6	11	8

5.3.7 Summary of accuracy of measures of species composition

By simulation of one systematic survey of 1000 stands per process and application of a range of species composition measures it was found that :

- Species composition by triangular tessellation, closest individual and closest density was biased for independent and segregated mixtures of two species with unequal abundance
- Species composition by quadrat generally had less bias than the other methods, and for practical purposes could be considered an unbiased estimator of species composition.
- The width of the confidence intervals of the stocking by species peaked when stocking was around 50% , reflecting the underlying binomial distribution of stocking. A similar trend would occur with estimates of species composition with confidence intervals being greatest for 50:50 species mixes.
- A minimum sample size of 50 should be used if sampling error is to be limited to 15%.

In practice seedling density and stocking estimates by the quadrat method may be less precise or biased, because of the same factors identified for site occupancy. In addition error could be introduced through incorrect identification of species.

5.4 Relationship between measures of species composition

The results of the simulation study suggest that the relationship between species composition by the least biased (ie by quadrat) and the other methods varies with relative abundance of the species in the mixture if the species are not associated. As species abundances become less equal the proportion of the less abundant species is over-estimated. In real stands the difference between the species composition by quadrat and other measures was not consistently in one direction. The different results are related to the assumption in the simulation of stands that the major species was more clumped than the secondary species. This assumption was based on the finding that clustering tends to be greater in denser stands (see section 4.2). It is apparent that when dealing with mixtures of species the degree of clustering of a given species is not as closely related to its density, as in the total seedling population.

A species composition measure based on stocking by species could be considered to be better, because such a measure should be more responsive to variation in spatial distribution. Just as site occupancy measures based on density may be misleading, the quadrat based measure of species composition may also be misleading. For example, a species with a very high abundance in a small portion of the coupe might be given a high species composition, whereas it will only occupy a small portion of the coupe. The closest individual and triangular tessellation methods partly overcome this problem by giving equal weighting to each plot. Thus the bias in the measures of species composition by triangular tessellation and closest individual in the simulated stands was a result of more dispersed arrangement of the less abundant species across the coupe.

An index based on the stocking or frequency of stocked plots by species follows the same logic as using stocking as the measure of site occupancy. A plot is stocked or species represented at each plot, provided there is at least one seedling of that species present, and additional seedlings have no effect on the species composition. The difference between the approach taken in species composition index 1 and the other approaches already considered is that each species present on each plot is given equal weighting, thus giving even more importance to less abundant species that are more dispersed. The proposed species composition index is designed so that the sum of the indices by species is 100%, providing a measure that can be compared to the other species composition measures.

An alternative approach is to give less weight to species occurrences on plots shared with other species in such a way as to achieve the same summation result (ie % species a = no. plots species a only + 0.5 x no plots species a and species b/ total no.plots). For example, if there are 100 stocked plots, 20 stocked by species a only, 30 by species b only and 50 by both species, then the % species a = (20+50/2)*100/100, % species b = (30 + 50/2) x 100/100. This is the approach taken in species composition index 2, and as expected it gives a result that is intermediate to that of applying species index 1 and the other measures of species composition.

The relationship between species composition and stocking by species depends on the degree of association and the spatial distribution of each species. Further research is required to develop these relationships. Of critical importance is whether the measures need to be converted before evaluation or whether separate evaluation systems are preferred.

This study has concentrated on the analysis of the mixture of two species, for the purpose of providing some readily interpretable results. The measures that have been used can also be applied to mixtures of more than two species. The proportion of a particular species is obtained by dividing the count of that species by the total of the counts of all the other species. The species by stocking index 1, that partly apportions counts to species if more than one species is present in the plot, can also be determined. For example, if 4 species were present on a particular plot then each species would be apportioned 0.25 counts.

5.5. Development of evaluation systems

The evaluation of species composition must be considered within the context of the system of monitoring and improving this aspect of regeneration including setting objectives, selecting measures, scales, strata and developing field monitoring systems, sustainability evaluation systems and management improvement systems.

The policy in Australian native forests is to maintain the species and genetic diversity of the forest after harvesting. This is generally achieved through using appropriate regeneration techniques and seed/ plants of local provenances. As previously described a number of states measure the output of these techniques through inclusion of species measurement during regeneration surveys. However the only state that has a clearly stated objective and evaluation standard for species composition is Victoria. In Victoria the standard used to evaluate the objective of maintaining species composition is that at there are at least 10 acceptable stems of all eucalypt species present before harvesting. This standard was proposed as an interim standard which was to be subject to research and review. It only loosely reflects the organisation's policy, to approximate the composition and spatial distribution of species present on the coupe prior to harvesting, except where past management practices have led to altered species composition.

An intuitive interpretation of the general policy might translate into either of the following specific objectives:

- To establish regeneration with seedling density by species the same as the density by species prior to harvesting
- To establish regeneration with area occupied by each species the same as the area occupied by each species prior to harvesting.

The latter objective is more consistent with the concept of site occupancy because it considers the spatial distribution as well as number of each species.

The specific objective implies that pre-harvesting assessments be carried out. A common measure applied to mature stands is basal area, a measure of the density of the stand which could be differentiated by species. This measure would also provide an estimate of the area occupied by each species as basal area and crown cover are usually correlated. The objective suggests a measure based on spatial distribution such as stocking by species. Species composition by triangular tessellation and closest individual might also be considered as useful measures, because they are sensitive to changes in spatial distribution.

The same issues that applied to site occupancy about scale and strata apply to species composition. Natural strata that are based on environmental gradients might simplify the task of monitoring species, but there are practical limitations to how small the basic units of assessment are. A practical approach is adopting the coupe as the basic unit, which would generally include only one broad forest type, but could include a number of different eucalypt species associations.

Continuing with a system specification that would be integrated with site occupancy, the field monitoring system based on systematic grid survey, as tested in the foregoing simulation study, is to be assumed. The sustainability evaluation system might include broad categories of species composition before and after harvesting and an evaluation of whether any species had changed categories. An alternative might be an evaluation of whether the percentage of a particular species had decreased or increased beyond acceptable margins.

Considering that all the potential measures have been shown to be sensitive, the sensitivity of the system to changes in species composition depends on the method of summarising the data, the decision rules applied and the standards used. The objective of establishing regeneration with area occupied by each species the same as the area occupied by each species prior to harvesting, should be considered as interim, because species dynamics might suggest that different species mixes are required after disturbance to reach a desirable species mix at maturity. Short term studies of species composition (see section 2.4) indicate that species composition of regrowth stands tend to match that of the seed supply, and that more fecund species can dominate the regrowth after disturbance. However, varying tolerance of fire and other environmental factors may alter the species composition beyond the regrowth stage. Further research on the RRS sites is required to resolve this issue. Thus in the absence of well defined models of species dynamics and lack of conviction in the specific objective a conservative approach is needed until more information becomes available. Reporting of a less processed statistic, that would enable interpretation of the results against a different standard would be desirable.

One practical difficulty that will arise with the proposed field monitoring system is that rare species may be missed by the systematic survey. In such cases a stratified systematic survey may be required to determine if the rare species has been regenerated. The pre-harvesting survey information would form the basis of the post-harvesting stratification.

In summary, the discussion of evaluation systems for species composition has shown the following:

- the triangular tessellation, closest individual, quadrat density, closest density and 2 indices of species composition based on stocking by species are sensitive to changes in species composition
- explicit objectives and standards are specified for one organisation only, but they loosely reflect the policy of that organisation.
- Interim objectives and evaluation standards need to be developed for all organisations; a natural objective that reflects current policy is to establish regeneration with area occupied by

each species the same as the area occupied by each species prior to harvesting. The standard would be based on an appropriate reference measure and include margins for error in estimating species composition.
- The measure that most closely indicates the area occupied by each species is the species composition index based on stocking; this could be used as the reference measure and other measures converted to this measure before comparison to the standard
- the species composition objectives and standards for the major commercial forest types require further validation, and possibly development, including consideration of management objectives and the ecological basis of the standard.

6. Standardised system specifications and evaluation

6.1 Introduction

As previously stated, the objective of the project is to develop cost effective standardised methods of determining regeneration success, including stocking, species composition and early seedling growth, as a basis for continuous improvement of on-ground operations and aggregation of data to regional and national levels. To this point the project has considered the current systems for monitoring site occupancy and potential systems for monitoring and evaluating species composition. The analysis has been presented within the context of the general framework of sustainability indicator development (see 2.2). The analysis has concentrated on system objectives, the measures and evaluation systems used to determine if those objectives have been met. Issues of scale and strata have been dealt with in the review and a stratification based on regeneration ecology has been suggested. The current upper and lower limits of scale, the national forest estate and coupe, are generally consistent with the objectives of the measurement system and require no further consideration at this stage. Similarly the current field monitoring systems, based on the systematic sampling of each coupe, are generally adequate. The management and operational systems required to implement the continuous improvement cycle are beyond the scope of this project.

The aim of this section of the report is to present a number of options for measuring and evaluating regeneration success that meet the objective of standardisation. The options vary from standardising the method at the coupe level to standardising the outputs from a number of different methods at the national reporting level. A useful indicator should have the following properties (DPIE 1996):

1. firmly linked to the criteria and relevant to the region and goals of forest management
2. have a sound scientific or other relevant basis
3. be understandable and clearly interpretable
4. be sensitive and be able to measure critical change with confidence
5. have costs appropriate for their benefits
6. be feasible and realistic to measure over relevant time frames and spatial scales
7. have targets for thresholds built in, or be capable of having these applied
8. contribute directly to continuous improvement in management and performance
9. taken together the indicators must also be sufficient to adequately measure ESFM.

As previously discussed, the scientific basis of current evaluation standards (property 2) needs to be addressed further before standardised evaluation systems can be developed more fully. With respect to the remaining properties, the review and analysis has shown that the options generally have these properties, but the relative merits of the options from the point of view of properties 4 and 5 are the most relevant to selection of the appropriate option. In particular the sensitivity and ability to detect critical change with confidence, is dependent on the precision of the estimates, which is likely to decrease with the inclusion of data from various sources. The information content of the measure will also influence the sensitivity, as more relevant information will increase the ability to detect critical change. Costs associated with the introduction, on-going implementation and equitability of costs may vary between systems. The issue of whether the cost of collecting additional information is equal to its benefit also needs to be determined.

6.2 Options for standardised measures and evaluation systems

A number of alternative options for standardisation of regeneration measures are presented below. The options considered are of two types: adoption of a common measure across all organisations or conversion from measures currently used by the various organisations to a common reference measure. In the conversion options simple reference measures (ie stocking and stocking by species) have been evaluated, because current measures in use by some states do not provide enough information for other reference measures such as density to be calculated.

Option 1 Triangular tessellation stocking and seedling density as the common and standard measure

Measure :
Stocking, seedling density and species composition by triangular tessellation

Evaluation method:
Plot level comparison of seedling density with an appropriate plot standard that varies with forest type.
Coupe level comparison of stocking and species composition to broad bands of regeneration success

Advantages and disadvantages:
This measure provides information on the variation in density across a coupe and is more sensitive to changes in site occupancy than stocking only. Density estimates may have poor precision, and sampling intensity may need to be increased if precise density estimates are required. Since only one organisation uses the method on a regular basis, a high cost of introduction will be incurred and operating costs would also be higher because the method is slower than the other methods that are being used. Organisations using intensive management in native forests may be able to secure a return from the extra information provided (eg facilitate scheduling of thinning operations etc), but other organisations may derive little benefit from the extra information.

Option 2 16 m^2 quadrat stocking as the common and standard measure

Measure :
Stocking and stocking by species by 16 m^2 quadrat

Evaluation method:
Coupe level comparison to broad bands of regeneration success

Advantages and disadvantages:
This measure provides a precise estimate of stocking but no information on the variation in density across a coupe and is potentially less sensitive to changes in site occupancy than triangular tessellation. Since only two organisations use the method on a regular basis, a medium cost of introduction will be incurred but operating costs would be low because the method is very quick. The benefit is reasonably high, so a medium benefit vs cost is expected.

Option 3 16 m^2 quadrat acceptable stocking as the common and standard measure

Measure :
Acceptable stocking and acceptable stocking by species by 16 m^2 quadrat

Evaluation method:
Coupe level comparison to broad bands of regeneration success

Advantages and disadvantages:

This measure provides a low precision estimate of stocking because of the poor precision of the acceptability criteria. In addition it provides no information on the variation in density across a coupe and is potentially less sensitive to changes in site occupancy than triangular tessellation. Since only one organisation uses the method on a regular basis, a high cost of introduction will be incurred but operating costs would be low because the method is very quick. The benefit is low, so a low benefit vs cost is expected.

Option 4 Various measures converted to 16 m^2 quadrat stocking as the standard measure

Measure:
Varies with organisation – includes overall stocking and stocking by species by 16 m^2 quadrat, acceptable stocking and acceptable stocking by species by 16 m^2 quadrat, stocking and species by triangular tessellation, seedling density by closest individual.

Evaluation method:
Conversion of all other measures to stocking by 16 m^2 quadrat and species composition index
Comparison of converted measures to broad bands of regeneration success

Advantages and disadvantages:
The reference measure provides a precise estimate of stocking but no information on the variation in density across a coupe and is potentially less sensitive to changes in site occupancy than triangular tessellation. Some precision will be lost in conversion to the reference measure. Although only two organisations use the reference measure on a regular basis, conversions will be readily developed and a low cost of introduction will be incurred; operating costs would be variable because the current method would continue and they vary in their cost of application. The benefit is reasonably high, so a high benefit vs cost is expected.

Option 5 Various measures converted to tri tessellation stocking as the standard measure

Measure:
Varies with organisation – includes overall stocking and stocking by species by 16 m^2 quadrat, acceptable stocking and acceptable stocking by species by 16 m^2 quadrat, stocking and species by triangular tessellation, seedling density by closest individual.

Evaluation method:
Conversion of all other measures to stocking and species composition by triangular tessellation.
Comparison of converted measures to broad bands of regeneration success.

Advantages and disadvantages:
The reference measure provides a precise estimate of stocking, but no measure of variation in density and low precision will result from conversion to the reference measure. Only one organisation uses the reference measure on a regular basis, conversions will be difficult to develop and a high cost of introduction will be incurred; operating costs would be variable because the current methods would continue and they vary in their cost of application. The benefit is low, but costs high, so a low benefit vs cost is expected.

Option 6 Various measures converted to 16 m^2 quadrat acceptable stocking as the standard

Measure:
Varies with organisation – includes overall stocking and stocking by species by 16 m^2 quadrat, acceptable stocking and acceptable stocking by species by 16 m^2 quadrat, stocking and species by triangular tessellation, seedling density by closest individual.

Evaluation method:
Conversion of all other measures to acceptable stocking by 16 m^2 quadrat and species composition index.
Comparison of converted measures to broad bands of regeneration success.

Advantages and disadvantages:
The reference measure provides an imprecise estimate of stocking and low precision will result from conversion to the reference measure. Only one organisation uses the reference measure on a regular basis, conversions will be difficult to develop and a medium cost of introduction will be incurred; operating costs would be variable because the current methods would continue and they vary in their speed of application. The benefit is low, but costs high, so a low benefit vs cost is expected.

6.3 Evaluation of options

The options have been scored against the two selection criteria in table 6.1.

Table 6.1 The performance of six options of standardisation of measures of site occupancy and species composition against sensitivity and cost criteria (the more ticks the better the performance against the criteria).

Option	Sensitivity & ability to detect critical change	Benefit vs cost
Triangular tessellation stocking and seedling density as the common and standard measure	44(4)* high precision of density estimate may require an increase in sampling intensity	4(44)* introduction and operating costs are high, but organisations using intensive management will benefit. Inequitable costs vs benefits.
16 m^2 quadrat stocking as the common and standard measure	44 high precision of stocking estimate but less information than triangular tessellation	44 Introduction cost medium, operating cost is low, but benefit is medium
16 m^2 quadrat acceptable stocking as the common and standard measure	4 low precision of acceptability criteria	4 Cost of introduction is medium, operating cost is low, but benefit is low
Various measures converted to 16 m^2 quadrat stocking as the standard measure;	44 precision medium due to conversion	444 Low cost of introduction, operating cost variable and benefit medium
Various measures converted to tri tessellation stocking as the standard measure	4 precision low due to conversion	4 Medium cost of introduction due to complex conversion, operating cost variable and benefit low
Various measures converted to 16 m^2 quadrat acceptable stocking as the standard measure	4 precision low due to conversion	4 Medium cost of introduction, operating cost variable and benefit low

* (4) indicates that performance varies – whilst the unbracketted ticks would always be achieved, the bracketted ticks would only be achieved in certain situations (see 6.2).

Two options stand out as being superior to the others. One of those options, the adoption of triangular tessellation as the standard will involve considerable cost, which might only be recouped if intensive management systems are to be applied, which is indicated by the bracketted ticks under Benefit/cost for this option. In addition, the seedling density estimate by this method may be imprecise, as indicated by the bracketted tick under sensitivity and ability to detect critical change, and the cost would be high to improve the precision by increasing the sampling rate. It is unlikely that such a system will be warranted in the short term in most Australian states. The other option, continuing with current measures in the field and converting to a standard measure for regional and national reporting, is less costly to implement. The simplest, unbiased measure (16 m^2 quadrat stocking) is chosen as the standard to reduce the imprecision associated with conversion, as assumptions about important variables such as spatial distribution are minimised. There are also options in between these approaches, such as replacing the biased closest individual measure with triangular tessellation or converting the distance data to stocking, which would increase the precision of the standardised results. These are discussed in the following section, Implementation of the Preferred Option.

6.4 Implementation of preferred options

In order to implement either of the two preferred options there are a number of issues to be addressed.

Objectives:

At present there are a few major inconsistencies in the objectives of regeneration monitoring and improvement systems. Within one state, Queensland, the monitoring of regeneration in state forests is not considered to be necessary because of the reliability of regeneration in the forest types that are being utilised for timber production. Similarly in New South Wales state forests a sample of coupes harvested each year is monitored for regeneration. The claim that regeneration is reliable could be made for many of the forest types utilised in Australia, and the monitoring effort could be reduced substantially if the Queensland or New South Wales approach was applied Australia wide. In such a system one of the current objectives, the identification of areas for remedial treatment is foregone. The regeneration of the forest is such an important process in sustainable forest management that all coupes should be monitored. The monitoring of regeneration in private forests is currently optional and also considered to be a high priority for implementation.

The difference in objectives between organisations is greatest for forests managed by selective harvesting or uneven-aged silviculture systems. Highly variable pre-harvesting stand structures may result in a large range of growth stages and gap sizes under a group/ single tree selection harvesting system. Under these conditions regeneration silviculture and measures of regeneration success become more complex than in the even–aged forest and clear management objectives are needed. The objectives may be of three broad types:

- Maintain a balanced distribution of size classes and growth stages in the growing stock by regenerating and opening large enough gaps at each harvesting event. Monitoring of all stand components is necessary to enable tree marking, harvesting and regeneration operations to be managed.
- Restore productivity to stands that have been degraded by sawmiller selection or fire by harvesting and regenerating patches as market conditions and long term supply commitments allow. Monitoring of all stand components will indicate how closely the resulting structure

approaches an ideal stand structure, but monitoring of the regeneration component is the most critical.

- Another alternative is to consider that regeneration is only important if the site becomes unoccupied. One could ignore stand components other than regeneration by only assessing gaps large enough to affect site occupancy. The current systems in use in Victoria, Tasmania and Western Australia reduce to this when evaluation systems are considered.

Scales:

The issue of whether only some coupes are monitored (identified in the objectives) is also an issue of scale; whether the coupe or the broader forest type in a district or region for is the management unit. Another issue of scale is that measurement is carried out in small plots below the coupe level and sometimes results are reported at the sub-coupe level. Regardless of these variations in scale, national reporting will be possible, because it will not be at the coupe or sub-coupe level but at the forest type level and at least to regional geographical levels. However precision will be compromised, if a standard size (or range of size) of management unit and sampling intensity is not used.

Strata:

An ecologically based stratification of forest types for monitoring and evaluation was presented in the review. The analysis of evaluation standards indicates some large variation between organisations within forest types with assumed regeneration ecology. It is proposed that differences in the evaluation standards be resolved to enable the use of the ecologically based strata.

Measures:

For the case of the conversion option a number of functions have been developed to convert between site occupancy measures. Conversion between stocking of acceptable and stocking of all seedlings is not possible at this stage. An interim approach may be to assume that acceptable stocking is equivalent to stocking of all seedlings, which will underestimate the level of stocking in Victorian coupes.

Plot level conversions will provide a much more precise estimate of combined stocking than coupe level conversions. The closest individual data could be processed to determine the percentage of plots with closest distances less than 2.26 m and the triangular tessellation output could be processed to determine the percentage of plots with density greater than 312.5.

There is also a requirement for development of conversions between species composition by various methods. In the interim the current measures could be used without conversion, with an expectation of a relatively low level of precision.

Field monitoring systems:

- Timing has been raised as a significant issue when acceptability criteria are applied. Acceptability criteria need to be developed that reflect the stage of development of seedlings.

- Uneven-aged forest is monitored differently to even- aged forest in a number of states, and the field monitoring system needs to be consistent with the objectives stated previously. Where group selection is the silvicultural system, consideration should be given to a stratified sampling approach, with the gaps within a harvesting unit being measured as a separate stratum using the same measures developed for even-aged forest with a similar sampling intensity. This could be integrated with a lower sampling intensity on areas harvested by single tree selection.

- Timing of the regeneration survey needs to be considered where a number of surveys are carried out on the one area over less than a rotation. The usual reason for more than one survey, is continuing uncertainty about the regeneration result after a harvesting / site disturbance event. For example, in the case of *E. marginata* a survey is carried out after an area is cut to shelterwood (regeneration cut) and another survey is carried out on the same area some years later before cutting a gap (shelterwood removal). In the case of shelterwood harvesting in central Victoria, the regeneration survey is only carried out once after the regeneration cut, because regeneration is known to continue developing and survive the shelterwood removal. In the case where coupes fail the regeneration survey and there is no potential of improving their status within a reasonable time frame they may be put on a program of backlog regeneration or rehabilitation. As a general principle regeneration surveys should be completed and reported within a period that is reasonable for obtaining a clear indication if regeneration has succeeded. In the case of *E. marginata* this may be 20 years after the regeneration cut at the assessment before the shelterwood removal. In most other cases it would be from 1 to 5 years after the harvesting / disturbance event that triggers the regeneration.

Sustainability evaluation systems:

The issues concerning variability in site occupancy standards for existing forest types have not been able to be resolved, but for the purpose of national reporting of site occupancy the lowest standard for a particular management objective, considered to have scientific validity, could be used. In this way a number of organisations may have higher standards than the national standard for a given management objective, but their success will appear more favourable in a national report.

It is proposed that reporting of regeneration performance should be by broad strata of regeneration success based on management objective, rather than a single pass/fail result for each harvested area. This approach would require the revision of current reporting procedures. A suggested format for the report is as follows:

	16 m^2 stocking range (and management objective)				
Forest type	0-10% (Not stocked)	10- 40% (Ecologically stocked)	40- 65% (Low wood quality)	65- 85% (Optimum wood production)	85- 100% (Maximum clear wood with thinning)
Forest type A	A1	A2	A3	A4	A5
Forest type B	B1	B2	B3	B4	B5
Forest type C	C1	C2	C3	C4	C5
Forest type D	D1	D2	D3	D4	D5

Where A1….D4 are the sum of the individual harvest areas in each category. All areas harvested in the given time period should be included in the table. If harvest areas have not been assessed, then they will be assumed to be not stocked. Some categories may not be represented in a region over a given time period.

Ecologically based species composition standards are yet to be developed. In the interim a standard based on the pre-harvesting species composition could be applied. Strata for regeneration success could be based on the shift in species composition of the regeneration strata as compared to the pre-harvesting overstorey species composition. Pre-harvesting species composition should be based on relative basal areas of species for the harvest area. In other cases the target percentages for species composition may be set by other management objectives. In either situation the performance in obtaining a desired species outcome could be summarised in the following table:

	Percentage of species with reduced relative site occupancy*			
Forest type	>50% (Minimum species diversity)	26- 50% (Medium species diversity)	1-25% (High species diversity)	0 (Maximum species diversity)
Forest type A	A2	A3	A4	A5
Forest type B	B2	B3	B4	B5
Forest type C	C2	C3	C4	C5
Forest type D	D2	D3	D4	· D5

Where A2….D5 are the sums of the harvest areas in each category. All areas harvested in the given time period should be included in the table. If harvest areas have not been assessed, then they will be assumed to have minimum species diversity. Some categories may not be represented in a region over a given time period.

* Reduced relative site occupancy is reduction of species composition by more than 20% for dominant species (eg from 60% to 39%) or more than 10% for associated species (eg from 20% to 9%).

Example 1. A harvest area with a single species pre-harvesting, has the possible outcomes:
0% of species with reduced relative site occupancy- the species is the only one in the regeneration strata
>50% of species with reduced relative site occupancy- 20% or more of other species regenerated with original species, or original species not regenerated.

Example 2. A harvest area with two species of similar basal area by species prior to harvesting, has the following possible outcomes:
0% of species with reduced relative site occupancy - both species well represented
26-50% of species with reduced relative site occupancy -one species becomes dominant in regeneration, or one species outnumbered by introduced species
>50% of species with reduced relative site occupancy -both species no longer represented or outnumbered by introduced species

6.5 Requirements for further research and development

The following issues have been raised that require further research and development action.

Growth measures:

- The attempt to include growth into the indicator of site occupancy, ie the stocking of acceptable seedlings, has resulted in poor precision of that measure. The inclusion of growth has the potential to increase the value of the indicator of regeneration success, especially if monitoring is carried out later than it currently is. Inclusion of growth measures may best be integrated with soil indicators, the stratification of soil impacts providing a sound basis for stratification of growth measurement. Thus the timing of measurement and the field monitoring systems becomes an important issue. Potential indicators are height and diameter of potential co-dominant and dominant trees. Bole quality, ie form, branching habit, potential for internal defect, could also be included.

Mapping systems:

- There is some variation between organisations in the interpretation of stocking maps and stratification of harvested areas into satisfactorily and unsatisfactorily stocked areas. Species composition information could be included and an attempt made to check whether pre-harvesting species distribution matches post-harvesting species distribution. The inclusion of growth measures and integration with soil indicators suggests that overlaying of maps of soil impacts and regeneration may be a useful analytical approach. Thus there is scope for revising and improving methods of stratifying and mapping stocking status at the coupe level.

Uneven-aged systems:

- measures of site occupancy for components of multi-aged and uneven-aged stands need to be further evaluated.

Sustainability evaluation systems:

- The development of evaluation methods and standards requires a thorough understanding of stand dynamics from seedling through to maturity in order for measures to be indicative of long term ecosystem productivity.
- There is considerable variation between evaluation standards between states, even for forest types which have similar regeneration ecology that need to be resolved.

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