Rationale and design for the Warra silvicultural systems trial in wet *Eucalyptus obliqua* forests in Tasmania

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Abstract

Clearfell, burn and sow (CBS) is the prescribed silvicultural technique for wood production from lowland wet eucalypt forests. Its widespread adoption raises concerns, particularly due to initial aesthetics, a reduction in late successional species and structures, and a decline in the special species timbers resource when rotations of about 90 years are used. Cases for and against the CBS technique are presented. The Warra silvicultural systems trial is being established in the period 1998–2002 to compare CBS with five alternative treatments that were selected after a review of silvicultural systems applied in wet forests elsewhere. The alternatives include CBS with understorey islands, stripfell/patchfell, 10% dispersed retention, 30% aggregated retention and single tree/small group selection. Prescriptions for the six treatments and indicators for monitoring their initial performance are described, along with expectations and limitations of the Warra trial.

Introduction

Wet eucalypt forest includes both wet sclerophyll forest and mixed forest (Kirkpatrick *et al.* 1988), with the former having a broad-leaved shrub understorey and the latter having a rainforest understorey. Clearfelling, high intensity burning and aerial sowing has been the standard silvicultural system for lowland wet eucalypt forests with dense understoreys in Tasmania since the 1960s (Hickey and Wilkinson 1999a). Prior to this, selective logging of the best trees was common but regeneration in cut-over wet eucalypt forests was usually inadequate, except where it resulted from subsequent wildfires. The clearfell, burn and sow (CBS) technique is based largely on the research of Gilbert (1958) and Cunningham (1960a) in wet eucalypt forests and was extended to most eucalypt forest types throughout the 1970s with mixed results. Partial-harvesting techniques were developed and introduced in the 1980s for drier and high altitude forests with sparse understoreys to encourage retention of useful advance growth and to overcome 'growth check' on high altitude sites subject to cold-air ponding. These forests are frequently multi-aged due to previous selective logging or wildfires. Despite the increased application of partial-harvesting techniques where appropriate and feasible, clearfelling with high intensity burning and aerial sowing remains the prescribed silvicultural system for lowland wet eucalypt forests (Forestry Tasmania 1998a). Table 1 summarises silvicultural systems used for major commercial forest types in Tasmania.

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Partial cutting of wet eucalypt forest with dense understoreys is generally considered inappropriate because the dense slash impedes regeneration, most stands lack advance growth of eucalypts, there are significant safety concerns for harvesters and an increased risk of wildfire in cut-over forest. Trials in wet eucalypt forests in Tasmania have included partial cutting (Neyland *et al.* 1999; Bassett *et al.* 2000) and, while not conclusive, have indicated that alternative silvicultural systems to clearfelling are suboptimal in terms of wood production. These studies have not reported effects on other values such as biodiversity, soils or aesthetics, nor have they incorporated wider scientific and community involvement. Both nationally (e.g. Lindenmayer and Franklin 1997) and locally (e.g. Southern Forests Community Group 1996), ongoing cases have been made for alternative silvicultural systems to be applied to wet eucalypt forests. The Tasmanian Regional Forest Agreement (Commonwealth of Australia and State of Tasmania 1997) noted a priority for research on 'commercial viability of new and alternative techniques especially for harvesting and regenerating wet eucalypt forests and maximising special species timbers production and rainforest regeneration where appropriate'. The term 'special species timbers' refers to timber from non-eucalypt tree species, with the most common being blackwood (*Acacia melanoxylon*), myrtle (*Nothofagus cunninghamii*), leatherwood (*Eucryphia lucida*), celery-top pine (*Phyllocladus aspleniifolius*) and sassafras (*Atherosperma moschatum*).

Consequently, a silvicultural systems trial is being established in wet *Eucalyptus obliqua* forest at Warra, in southern Tasmania, to compare feasible alternative systems with the routine clearfell, burn and sow system, and to develop silvicultural alternatives for areas where habitat, special species timbers or aesthetic values have additional emphasis. Wet *E. obliqua* forest is the most widespread forest type in Tasmania (Public Land Use Commission 1996a) and Neyland *et al.* (2000a) have demonstrated that the wet forests at Warra are representative of this forest type in Tasmania.

This paper provides:

- A review of the cases for and against clearfelling wet eucalypt forests;
- A summary of research on alternatives to clearfelling;
- A rationale for the selection of silvicultural treatments at Warra;
- Prescriptions for the selected treatments; and
- Indicators for monitoring their early performance.

It also includes a brief discussion of the expectations and limitations of the Warra silvicultural systems trial.

The case for and against clearfelling wet eucalypt forests

Clearfelling removes all trees on a coupe in one operation. Fischer (1980) cited in Bradshaw (1992) describes a gap of four to six times mature tree height as the lower size limit for clearfelling. Where native forest regeneration is required, clearfelling is followed by a high intensity slash-burn to remove the dense understorey vegetation and logging debris, and to create a seedbed receptive to sown eucalypt seed.

The case for clearfelling followed by burning

- Clearfelling fulfills the biological requirements for eucalypt regeneration in wet forests (Cunningham 1960a; Gilbert 1959; King *et al.* 1993a). The system creates a relatively uniform seedbed of heat-sterilised mineral soil over a larger proportion of the harvested area compared with alternative systems.
- Wet eucalypt forests, especially *E. regnans* forests, are often even-aged (Gilbert 1959). Hence there is often no requirement to retain advance growth.

Table 1. Silvicultural systems used for major commercial forest types in Tasmania.

Forest type	Silvicultural systems
Lowland wet eucalypt forest	Clearfell, burn and sow
Lowland dry eucalypt forest	Advance growth retention Potential sawlog retention Seed tree Clearfell, burn and sow
High altitude *E. delegatensis* forests	Shelterwood Advance growth retention Potential sawlog retention Clearfell, burn and sow
Rainforests	Selective sawlogging Overstorey retention
Blackwood	Clearfell and fence Overstorey retention and fence

- It has been demonstrated in some forest types that clearfelling is the safest harvesting system for harvesting contractors, forest workers and machinery (Mitchell 1993).
- Clearfelling requires less knowledge, experience and supervision to implement than most alternatives (Burgess 1997a; Kimmins 1997).
- When followed by slash-burning, it creates a more productive regrowth forest in terms of early establishment and growth of eucalypts (King *et al.* 1993b; Lockett and Candy 1984). This is related to enhanced nutrition of the seedbed (Attiwill and Leeper 1987; Ellis *et al.* 1982) and to higher light intensities on the forest floor (Ashton and Turner 1979).
- Slash-burning reduces fuel loads and therefore the risk of wildfire (Forestry Commission 1993). It also allows more ready access for future forest operations.
- It is the most cost-effective method of harvesting and regenerating wet eucalypt forests (Dignan 1993).
- Removal of the entire forest canopy ensures free growth of the regeneration (Bassett and White 2001).

The current use of clearfelling in publicly owned native forests in Australia is briefly summarised in Table 2.

The case against clearfelling followed by burning

Community attitudes toward clearfelling and burning are generally negative (Public Land Use Commission 1996b) and it is commonly considered detrimental to the environment (Ferguson 1985; Kimmins 1997). The perceived disadvantages of clearfelling and burning include:

- Creation of an extreme initial visual impact, reducing landscape values (Forestry Commission 1990b) and impinging on social amenity (Burgess *et al.* 1997).
- Effects on biodiversity, including at least short-term changes in vascular plant species composition (e.g. Dickinson and Kirkpatrick 1987; Ough and Ross 1992; Peacock 1994), only sparse regeneration of the rainforest component in mixed forests (Hickey 1994), and loss, or a significant reduction of oldgrowth structures and the frequency of those species dependent on older forest (e.g. Lindenmayer *et al.* 1990; Taylor and Haseler 1995; Chesterfield 1996; Meggs 1996; Ough and Murphy 1996; Michaels and Bornemissza 1999).

under retained overwood of 12 m^2/ha. The density of dominant and co-dominant seedlings under a 100% overwood was only 17% of that under negligible overwood.

Campbell (1997) summarises current knowledge on alternative silvicultural systems in Victorian mountain ash forests and implications for forest ecosystems, management systems, and social and economic systems. He reported considerable potential to improve existing practices for clearfelling and seed-tree systems. Improvements include detailed design, layout and implementation of harvesting and seedbed preparation to conserve soil, maintain flora (e.g. by retention of root stocks, standing plants, tree ferns and soil-stored seed) and fauna (e.g. by retention of tree clumps, understorey vegetation and debris). For a given level of wood production, he reported that the multiple disturbance of a coupe in a single rotation, and the increase in gross area disturbed in a single year, placed shelterwood and selection systems at a severe ecological disadvantage. The high hazard to people associated with tree felling also placed partial-cutting systems at a management disadvantage. These findings have contributed to guidelines for retention of potential hollow-bearing trees and trialling of understorey islands and retained overwood systems (e.g. 10% retention for wide application and 30% retention for buffering reserves) (Lutze *et al.* 1999).

Wet forests in North America

Clearfelling has been the dominant harvesting system in the tall wet coniferous forests of the Pacific North-West region of the United States of America and Canada. Replicated experiments have recently been implemented at several locations in the United States and Canada. Perhaps the largest is the Demonstration of Ecosystem Management Options (DEMO) (http://www.fs.fed.us/pnw/demo/design.htm) which involves six treatments, including a control, replicated at eight locations in western Oregon and Washington.
The treatments are designed to explore the relative operational, economic and ecological trade-offs between various levels of dispersed and aggregated retention. They include: 15% retention in a dispersed pattern; 15% retention in an aggregated pattern; 40% retention in a dispersed pattern; 40% retention in an aggregated pattern; 75% retention with harvest in small groups; and 100% retention as a control.

Response variables include small mammal, bird and fungal populations, vascular plants and ground-layer cryptogams, regeneration and growth of trees, and growth and mortality of retainers.

Another important replicated silvicultural systems trial in oldgrowth wet forest in North America is the Montane Alternative Silvicultural Systems (MASS) project on Vancouver Island, British Columbia, Canada. The MASS study (Arnott and Beese 1997) includes four treatments:

- Green tree retention where 25 trees/ha are permanently retained in a dispersed pattern. Natural regeneration is prescribed and supplemented by planting as required.
- Uniform shelterwood where 30% of the basal area is retained. Regeneration is by advance growth and natural seed supplemented by planting to achieve a target density of 1200 stems/ha.
- Small patchfells designed with alternating retained strips so that all the patch is within two tree lengths of an edge. The retained patches will be felled when the regeneration reaches 10 m in height. Regeneration will be achieved primarily by natural regeneration supplemented by planting as required.
- Large clearfell (one replicate only), being a 69 ha area where the regeneration objective is to establish a mixed stand of conifers through natural regeneration from advance growth and natural seed supplemented by planting.

The DEMO and MASS projects are long-term multi-disciplinary trials and only limited results are currently available.

Rationale for the selection of silvicultural treatments at the Warra trial

Silvicultural systems are generally named after the harvesting or regeneration method because this is usually the most significant intervention which shapes the stand structure in the long term (Bauhus 1999). Campbell (1997) notes that these systems generally lie on one of two continuums related to the size of the opening, or the density of the retained trees. There are a very large number of possible variations to the major recognised systems that could be tested in a silvicultural systems trial. However, the number of possibilities can be significantly reduced given the following operational constraints:

- The wet forests of southern Tasmania have dense understoreys (Forestry Tasmania 1998a). Harvesting in these forests produces large quantities of fire-hazardous fuel. Site preparation treatments must be capable of reducing this fuel hazard.
- Systems must be biologically suited to the successful regeneration and adequate growth of eucalypts.
- Systems must be operationally feasible in terms of occupational health and safety, harvesting productivity and economic viability.

It was also decided that low cost regeneration methods based on artificial sowing or natural seedfall would be used rather than planting. Eucalypt regeneration from seed requires the establishment of seedbeds by either burning or mechanical disturbance.

The following silvicultural systems and sub-systems were considered for testing at the Warra trial. Each system is discussed according to its advantages and disadvantages.

A. CLEARFELL SYSTEMS

Clearfell, burn and sow (CBS)

This system is the standard for lowland wet eucalypt forest and hence must be included in the trial for comparison with alternatives. Its advantages and disadvantages have been discussed earlier in this paper. Two variations of the clearfell, burn and sow system include reducing the fire intensity or replacing burning altogether with mechanical disturbance.

Clearfell, low intensity burning and sow

The burning intensity is kept low to increase the survival of understorey plants and soil invertebrates.

(a) Advantages

The following advantages are relative to the clearfell, hot slash-burn and sow option.

- Maintenance of organic matter and a possible reduction in the long-term loss of nutrients from the site. Low intensity burns are suited to soils with low nutrient status due to the maintenance of peat soil horizons where applicable (Grant *et al.* 1995).
- Greater survival of understorey species throughout the coupe after burning (Jordan *et al.* 1992).
- Lower likelihood of fires escaping during the burning operation.
- May be more socially acceptable given the current community attitude and controversy surrounding high intensity burning (Kimmins 1997).

(b) Disadvantages

- Broadcast low intensity burns are difficult to achieve in clearfelled wet eucalypt forest. They either burn intensely or, when lit under humid conditions, burn patchily and often only scorch the elevated fuels.
- The majority of logging slash, dense undergrowth and surface litter (duff)

layers will not be removed, so that harvested coupes may fail to regenerate adequately due to the lack of suitably receptive seedbed.

- The remaining slash will pose a major fire management risk for some years. The use of high intensity burning is often justified on this basis alone (Forestry Commission 1993; Shea *et al.* 1981).
- If seedlings do establish, growth may not be optimal due to the lack of adequate ash-bed effect (King *et al.* 1993a).

Clearfell, mechanical disturbance, and sow

Mechanical disturbance is occasionally carried out on clearfelled coupes as an alternative to burning.

(a) Advantages

- Creates suitably receptive seedbed for eucalypts (Fagg 1981; Strachan and King 1992).
- Can be used where slash and vegetation are difficult to burn; for example, on damp aspects or on coupes harvested over more than one season where fine fuels have rotted and live vegetation predominates (NRE 1998).
- Minimises the loss of nutrients, particularly on infertile sites.
- Produces no smoke nuisance.

(b) Disadvantages

- Expensive and operationally impractical to apply over large areas (Forestry Commission 1992; Sharp 1993).
- Can reduce the frequency of understorey vegetative regenerators (Ough and Murphy 1996).

Clearfell, burn and sow (CBS) with understorey islands

Understorey islands are small designated areas in a coupe within which mechanical disturbance, particularly disturbance to the soil, is minimised (Ough and Murphy 1998). Their purpose is to enhance the survival of flora species dependent on resprouting for recovery after disturbance and to maintain the presence of oldgrowth structures, such as large manfern (*Dicksonia antartica*) and musk (*Olearia argophylla*) stems, and the epiphytic species that rely on these structures for a substrate. Heavy machinery is excluded but overstorey trees can be felled and extracted. There is no specific requirement to protect the islands from slash-burning other than to ensure that logging slash is clear of the island.

(a) Advantages

- Flora species dependent on vegetative regeneration are better represented after harvesting (Ough and Murphy 1998) than in completely felled areas. Due to the lack of machine disturbance in these areas, individuals survive, thus maintaining a higher level of age and structural diversity in the harvested area. This benefits epiphytic species that rely on trunk and branch habitats for their growth substrate.
- Islands are likely to be a source of propagules (i.e. seeds, spores) for species that would otherwise be poorly represented in silvicultural regeneration.
- Retaining small islands of vegetation may reduce visual impacts of clearfelling.

(b) Disadvantages

- The system will require closer supervision of harvesting contractors prior to and during the harvesting operation to ensure the most appropriate islands are selected and protected during harvesting.
- Islands affected by slash-burning may harbour smouldering embers and peat layers which may become points of later re-ignition into adjacent forest.
- Some islands may be almost entirely consumed by the regeneration burn (which will reduce, but may not negate, their function).
- Productive area available for eucalypt regrowth is decreased compared to the standard clearfell system.

B. Seed-tree systems

Seed trees with high intensity burn (and rapid seed-tree removal)

This method is sometimes used for wet eucalypt forests in temperate Australia (Florence 1996). The high intensity burns used to expose a suitable seedbed frequently kill, or severely damage, the seed trees. About 3–5 large-crowned veterans per hectare can be sufficient in tall oldgrowth *E. regnans* forest (Korven-Korpinen and White 1972) whereas about 40 seed trees/ha might be needed in 65-year-old *E. regnans* regrowth (Cunningham 1960b). The seed trees should be removed by the spring following the autumn regeneration burn to avoid excessive damage to seedlings.

(a) Advantages

- This system is similar to clearfelling in terms of harvesting, relatively high regrowth productivity, safety and fuel management.
- On-site seed is utilised, having benefits for gene conservation, site matching with seed source (Forestry Commission 1991; Wilkinson 1995), and lower regeneration costs per hectare (King 1991).

(b) Disadvantages

- This system relies on the presence of an adequate on-site seed supply. Seed-crops in wet forest eucalypts are very variable and often difficult to forecast (Cunningham 1960a; Ashton 1975).
- There is a need for increased skill, experience and supervision to manage seed crops for seed-tree system application.
- Assessing and marking seed trees is time-consuming in dense forests.
- Loss of timber volume within retained seed trees, particularly if seed trees are not harvested following successful regeneration. This second harvest is frequently unfeasible due to fire damage and operational constraints.

Seed-tree retention with low intensity burns

The system is sometimes applied to drier eucalypt forests where 7–15 trees are commonly retained (Forestry Commission 1994). Here, the lower slash levels result in less intense burns which allow survival of the seed trees. An ongoing seed source on climatically harsh sites is desirable and it is recommended that seed trees are retained for up to seven years on harsh sites (Forestry Commission 1994), although they are often retained for much longer.

(a) Advantages

- An ongoing seed source for up to seven years.
- Slash-seed can be used as a secondary source of seed.

(b) Disadvantages

- Some loss of regrowth productivity is expected due to the suppressive effects of retained overwood (Incoll 1979; Rotheram 1983; Bauhus *et al.* 2000; Bassett and White 2001). This effect will be long term if seed trees are not removed.

C. Stripfell and patchfell systems

Stripfells can be used to provide seed and shelter for regenerating adjacent cleared areas (Smith *et al.* 1997). They are used in Europe to encourage the regeneration of shade-tolerant species and to protect regeneration from wind (Florence 1996). They have been suggested for eucalypt forests on steep terrain where soils are likely to be eroded or where it is important to minimise the visual effect of harvesting. Florence (1996) has suggested a minimum strip width of 35–75 m for eucalypt forests. In Tasmania, the system has been used in rainforest trials (Hickey and Wilkinson 1999b) and operationally in dry eucalypt forest (Neyland 2000). Although the system has many variations, one approach is to establish alternate cut and retained strips so that all felled areas are within one tree length of an edge. The remaining 50% of the stand may be harvested at mid rotation or earlier, particularly if artificial regeneration is used to regenerate the second stripfellings. If regeneration can reliably be expected at distances more than a tree length from an edge, then the cut blocks can be broadened (e.g. Arnott and Beese 1997) and the system is referred to as patchfelling.

(a) Advantages

- Regeneration is obtained by seedfall from trees retained along the edge of strips and patches. This is cheaper than artificial collection and application (Sharp 1993) and the seed is genetically adapted to the site, with positive implications for survival, tree form and growth.
- Stripfells have been demonstrated to achieve adequate regeneration of eucalypts (Strachan and King 1992; Neyland 2000) and rainforest species (Hickey and Wilkinson 1999b); hence, the treatment is potentially suited to regeneration of mixed forests.
- Reduces the short-term degree of ecological change at the coupe level by spreading harvesting over a longer time period.
- Reduces the effect on aesthetic values at the coupe level (Arnott and Beese 1997; Kimmins 1997) although visual effects at the landscape level can be bizarre, particularly on hillsides.

(b) Disadvantages

- Stripfells increase the spatial and temporal disturbance required within a region for a given level of wood production. This may increase the scale of impact on soil and water (Burgess *et al.* 1997).
- There is an increased requirement for access roading to achieve the same level of regional wood production.
- The number of individual regeneration burns will be greatly increased to achieve the same regional level of wood production. This would be operationally difficult, costly and increase the risk of fire escapes.
- High intensity burning will be difficult to achieve due to the shading effect of edges and the management objective to minimise fire damage to retained belts.
- Damage to retained stems in adjacent forest with *Nothofagus cunninghamii* may increase the incidence of myrtle wilt (Packham 1991).
- Seedfall will be protracted over a period of time after site preparation. This may result in a lack of regeneration since seedbed loses receptivity over time. This system also relies on the presence of adequate seed crops that are often variable in space and time. Good knowledge of seed crops is therefore required.
- Eucalypts of wet forests are shade intolerant (Ashton and Turner 1979). The forested edge-effect of adjoining felled strips may cause significant reductions in height growth and vigour of eucalypt regeneration.

D. VARIABLE RETENTION HARVEST SYSTEMS

Variable retention harvest systems retain structural elements of the harvested stand for at least the next rotation in order to achieve specific management objectives (Franklin *et al.* 1997). Variable retention is extremely flexible in application and is well suited to the maintenance or rapid restoration of environmental values associated with structurally complex forests. The retention may be either as dispersed trees or as aggregates of trees with intact understoreys. Decisions on the actual level of retention are complex and there are few quantitative data for most groups of organisms on how species diversity and population levels respond to levels of retention (Franklin *et al.* 1997).

Dispersed retention (overwood retention)

The objective is to leave trees on a dispersed pattern, throughout an otherwise clearfelled area, to enhance structural diversity and aesthetics. This system can be similar to a seed-tree system with low intensity burning except the retained trees are kept (if possible) for a full rotation of the regeneration. The system is not practised deliberately in Tasmania although the commercial value of the seed trees, particularly in dry eucalypt forests, is sometimes too low to justify their salvage harvesting and the system occurs by default. The level of retention can be varied but proposed levels are usually fairly low; for example, about 10% of mean basal area or 10 trees/ha in wet eucalypt forests (Burgess *et al.* 1997) or up to 25 trees/ha (Arnott and Beese 1997) in coniferous forests.

(a) Advantages

- Natural seed source with benefits for gene conservation and regeneration costs.
- Provides an even distribution of mature habitat trees for conservation of hollow-dependent birds, mammals and invertebrates across the coupe.
- Provides an ongoing source of large logs and other coarse woody debris, which is important for ecosystem functioning (Harmon *et al.* 1986), and particularly for invertebrate conservation.
- Modest increase in aesthetics compared to clearfells.

(b) Disadvantages

- Safety risks to harvesting personnel due to the presence of overhanging limbs and the risk of collisions between falling and retained trees.
- Regeneration burning is very difficult, particularly in wet forests with very high fuel loads because the burn must be intense enough to create seedbed but not so intense that it kills the retained trees.
- Retained trees reduce growth of shade-intolerant eucalypt regeneration (e.g. Bauhus *et al.* 2000).
- Loss of timber in retained trees unless they are harvested at the end of the rotation.
- Exposed trees can blow over.

Aggregated retention

Aggregated retention, as currently applied in north-western North America, retains aggregates of 0.1–1.0 ha in size (Franklin *et al.* 1997). Retention levels vary widely from about 15% to more than 40% of coupe area. The felled area is primarily regenerated by planting either with or without slash-burning.

Aggregated retention is not regularly practised in Tasmania although clump retention (Neyland 2000) has been used as an alternative to seed-tree retention in dry forests. It is uncertain if aggregated retention can be adapted to wet eucalypt forests with a dense understorey. Regeneration from natural seedfall or artificial sowing will require at least low intensity burning or mechanical disturbance to create seedbed.

(a) Advantages

- Retains biodiversity including multiple vegetation layers and structurally intact forest habitat (Franklin *et al.* 1997).
- Retains aesthetic values, particularly if more than 15% of the coupe is retained (J. Franklin, pers. comm. 2000).
- The hazard to harvesting personnel is not greatly increased over clearfelling.
- Potential for natural seeding with benefits for gene conservation and regeneration costs.

(b) Disadvantages

- The net harvestable area is significantly reduced; either more coupes will need to be harvested to achieve the same level of harvest or the sustainable yield is decreased.
- Regeneration burning will be very difficult, particularly in wet forests with very high fuel loads because the burn must be intense enough to create seedbed but not so intense that it substantially burns the aggregates.
- The seedbed created by low intensity burns may be insufficient for adequate stocking levels to be achieved.

- Seed supply from natural sources will be variable and will require monitoring or supplementary sowing or planting.
- Aggregates may provide in-coupe refuges for browsing animals that will threaten seedling survival in felled areas.

E. SHELTERWOOD SYSTEMS

Shelterwood systems allow the development of more or less even-aged regrowth under the shelter of an overstorey which is removed progressively, or entirely, over the first part of a rotation. The method is appropriate for species that require protection from climatic extremes (e.g. low temperatures, high levels of insolation, strong winds) at the regeneration phase. In Tasmania, the shelterwood system is commonly used for high altitude *Eucalyptus delegatensis* forests. Trees are retained at a rate of 9–14 m^2/ha of basal area at the first harvest and then removed about 5–15 years later when the regeneration is at least 1.5 m tall (Forestry Commission 1990a). A similar system is used in dry eucalypt forest at low elevation in Victoria (Kellas and Hateley 1991). It has also been applied experimentally in wet eucalypt forests (Bassett *et al.* 2000) and rainforests (Hickey and Wilkinson 1999b) in Tasmania.

(a) Advantages

- This system is suited for sites where regeneration is susceptible to exposure (Keenan 1986).
- Reduced visual effect of harvesting, particularly where the shelterwood is retained for at least 10 years (Burgess *et al.* 1997).
- The system encourages the regeneration of rainforest species (Bassett *et al.* 2000; Hickey and Wilkinson 1999b), particularly if rainforest trees are retained and mechanical disturbance, rather than burning, is used for site preparation.
- Natural seeding with benefits for gene conservation and regeneration costs.

(b) Disadvantages

- Shelterwoods suppress the growth of eucalypt regeneration (Ellis *et al.* 1987; Battaglia and Wilson 1990; Dignan *et al.* 1998). This effect is hard to justify in forest types that do not require shelterwoods for reliable regeneration establishment.
- Further loss of productivity occurs due to damage to regeneration caused by the shelterwood removal harvest (Savenah and Dignan 1997).
- Damage to the boles of retained trees during harvesting may lead to reduced wood quality (Neumann *et al.* 1997)
- A reduction in harvesting productivity, due to the need for careful manoeuvring of machines and directional falling of trees (Dignan 1993).
- The hazard posed to harvesting personnel, particularly where an evenly distributed, high level of canopy retention is required (Mitchell 1993).
- Once the shelterwood is removed, the system confers little advantage for biodiversity retention compared to clearfelling.

F. SELECTION SYSTEMS

Selection systems involve the removal at any one harvest of only part of the existing growing stock and are suited to forests with a range of tree sizes and ages (Florence 1996). There is wide variation in the proportion of the growing stock removed at any one harvest. At one end of the continuum is the classical single tree and small group selection system as described, for example, by Schabel and Palmer (1999), which represents the way the method was developed in European silviculture for shade-tolerant species. At the other end is heavy selection cutting where some trees are retained through a range of size and age classes but the size of groups removed is much larger.

The classical selection system implies there will be a balanced distribution of size classes, near full stocking at all times, good growth of trees through all size classes, and enough space to develop after each harvest (Florence 1996). It is not generally considered by foresters to be appropriate for wet eucalypt forests. However, selection systems based on removal of large groups or retention of specific stand components are commonly applied in multi-aged dry eucalypt forests in Australia (Bauhus 2000) including the high altitude and dry eucalypt forests of Tasmania (Forestry Commission 1994). A basic form of single tree/small group selection, but with very long return cycles, is practised in special species timbers coupes with *Nothofagus* rainforest in Tasmania (Forestry Tasmania 1998b).

Single tree/small group selection

The single tree/small group selection method does have some appeal to the general public and has been advocated by some community groups (e.g. Southern Forests Community Group 1996) for the management of oldgrowth mixed forest in Tasmania.

(a) Advantages

- Aesthetic values are maintained at the coupe level because most of the forest cover is maintained.
- Structural diversity is maintained (Florence 1996) if sufficient habitat trees are kept.
- Allows regeneration and growth of rainforest tree species (Hickey and Wilkinson 1999b).
- Natural seeding with benefits for gene conservation and regeneration costs.

(b) Disadvantages

- Very hazardous for harvesting personnel due to the presence of overhanging tree crowns and the need to fall trees into standing forest (Mitchell 1993; Viner 1992).
- Damage to some retained trees during harvesting and consequent lowering of wood quality through decay.
- Major reduction in harvest productivity; hence harvest costs per cubic metre of wood produced are high.
- Uncertain regeneration and growth of eucalypts, particularly in gaps less than 30 m wide (Ashton and Chinner 1999).
- Creation of large accumulations of slash that impede regeneration and pose a subsequent fire hazard.
- Destruction of initial regrowth when adjoining groups are subsequently harvested (Bradshaw 1999).
- High planning and supervision costs due to multiple cut and spatial distribution of groups and coupes (Burgess 1997a).
- Increased roading requirement to maintain multiple fellings throughout the rotation (Burgess 1997b).

Group selection

A more feasible way of managing uneven-aged stands is the group selection system where, if the regeneration openings are made large enough, it is possible to accommodate the ecological requirements of almost any tree species (Smith *et al.* 1997). The maximum width of the groups, or gaps, is approximately twice the height of the mature trees. This system was adopted for much of the wet eucalypt forests of coastal New South Wales in the 1950s (Florence 1996). It has not been used routinely in Tasmanian wet eucalypt forests but examples exist at the Forestier and Arve silvicultural trials.

(a) Advantages

- Retains some aesthetic values.
- Openings are large enough to allow piling and burning of slash.
- Openings are large enough to encourage the regeneration and growth of shade intolerant eucalypts.
- Trees develop in even-aged aggregations which encourage good form.
- Natural seeding with benefits for gene conservation and regeneration costs.

(b) Disadvantages

- Safety risk to harvesting personnel as trees to be felled are very close to retained edges.
- Large accumulations of slash which require piling or burning to reveal seedbed.
- Burning of slash is difficult and costly; fires are difficult to extinguish in wet forest.
- Damage to retained trees on edges from harvesting and slash-burning.
- Low yields due to suppressive effects of forest edges.
- High harvesting costs due to limited manoeuvrability of machines.
- Multiple entries to coupe require a large roading network to be maintained.
- Openings are too large to be acceptable to some community groups.

Treatments chosen for the Warra SST

The treatments that could potentially be included in the Warra trial were too many to be fully investigated within the resource constraints available to the project. Operational inputs from planners, harvesting contractors and fire management crews would limit treatment implementation to about two experimental coupes per year. Hence it was necessary to select a subset of treatments that either (a) had potential broad application, addressed key issues such as aesthetics, habitat requirements, regeneration of late successional species and structures (mixed forest regeneration); or (b) provided a continuing supply of special species timbers. Table 4 summarises the treatments considered for Warra, their potential application and their inclusion/exclusion at the Warra trial. A single tree/small group selection treatment was included because of its appeal to some groups (e.g. Southern Forest Community Group 1996) although it was recognised that it may not meet slash management, eucalypt regeneration and harvest productivity outcomes. It was included on the provision that harvesting would only occur if health and safety issues were addressed.

Study site and treatment prescriptions

The trial is located in southern Tasmania at latitude 43°04'S, longitude 146°41'E and lies within the 15 900 ha Warra Long-Term Ecological Research (LTER) Site (Warra Policy Committee 1999). It covers 200 ha at an elevation of 80–240 m on a southerly aspect, uniform slope and on soils mostly derived from Jurassic dolerite. Average annual rainfall is 1080 mm. The wet *Eucalyptus obliqua* forest has a height of 40–65 m and is multi-aged due to fires that occurred before 1800, in 1898 and in 1934 (Hickey *et al.* 1999). Eucalypt diameters vary widely from less than 20 cm to more than 2 m dbh. Understoreys range from dense *Gahnia grandis* and *Melaleuca squarrosa* on soils with impeded drainage to *Pomaderris apetala* and *Nematolepis squamea** on well-drained soils (Neyland 2001). Long unburnt patches have callidendrous or thamnic rainforest (*sensu* Jarman *et al.* 1994) understoreys.

Prescriptions for selected treatments

Clearfell ± understorey islands

The CBS and CBS with understorey islands treatments will be implemented in two coupes each of about 20 ha. All vegetation, except in understorey islands, will be completely felled. Four islands of 40 m x 20 m are to be marked for retention in each coupe while four similar 'phantom' islands are to be assessed for their floristics before routine clearfelling. Islands are to be at least 60 m (more than a tree height) from the coupe boundary and from each other. About 3% of the coupe will be designated

* Formerly known as *Phebalium squameum* (see Wilson 1998).

Table 4. Possible treatments at the Warra silvicultural systems trial.

Treatment	Potential application in lowland wet eucalypt forests	Inclusion at Warra
Clearfell, burn and sow (CBS)	Current standard	Yes
Clearfell, disturb and sow	Small areas where burning is difficult or unacceptable	No
CBS with understorey islands	Broad application	Yes
Seed tree (with seed tree removal)	Areas where collected seed stocks are low	No
Stripfell	Mixed forest regeneration	Yes
Dispersed retention	Priority areas for arboreal fauna	Yes
Aggregated retention	Broad application	Yes
Shelterwoods	Small areas that are exposed sites	No
Single tree/small group selection	Mixed forest regeneration	Yes
Group selection	Mixed forest regeneration	No
Unharvested control (natural system)	Reserve management	Yes

as understorey or phantom islands. Islands are to be included in a high-intensity burn. Regeneration of eucalypts will be achieved by aerial seeding. The planned rotation length is 90 years although this could be shortened to 65 years if thinning is adopted (Brown 1997), or substantially lengthened, perhaps doubled to 180 years, if the objective was to increase the component of late successional species and structures.

Stripfell/patchfell

Two 80 m wide strips (about twice average tree height) and one 200 m wide patch (about five times average tree height) will be completely felled. The stripfells (2 ha) and the patchfell (5 ha) are to be separated by two retained belts also of 80 m width. Low intensity burns are required to reduce fuel hazards and create some seedbed. Regeneration will be achieved from natural seedfall. The planned rotation length is 200 years, with alternate strips cut every 100 years. This implies that future strips will be seeded from 100-year-old forest, which would be the minimum time needed to get a significant seed supply from rainforest species.

Dispersed retention

Retain eucalypt trees equivalent to about 10% of pre-harvest standing basal area. A mix of oldgrowth and regrowth trees will be marked on an approximate spacing of 30 m x 30 m. Defective oldgrowth trees with hollows will supply initial habitat while retained regrowth trees of good form and free from defect can potentially provide habitat over subsequent decades or even centuries. A low intensity burn will be undertaken to reduce fuel hazards, induce eucalypt seedfall and create some receptive seedbed. Regeneration will be achieved from natural seedfall and monitored using randomly located seed traps. The planned rotation is 90 years when further trees will be marked for retention. These may include some original retained trees if they are still standing. If they are not available, the oldest trees at subsequent harvests will be 180 years.

Aggregated retention

Primary snig tracks will be established as if the coupe were to be clearfelled. However, felling is to be confined to 40 m (one tree length) either side of the snig tracks to create 'fairways'. At this stage, patches of 0.5–1.0 ha, amounting to 30% of the coupe area, will be retained. All portions of the coupe should be within one tree height of an aggregate or stand edge. The aggregates should be broadly representative of the vegetation and stand conditions in the

Table 5. Prescriptions and summary of potential advantages/disadvantages of treatments at the Warra SST.

Treatment	Coupes	Key potential advantages	Key potential disadvantages
1. **Clearfell, burn and sow (CBS)**	2 (part)	• seedbed for eucalypts • safe harvesting • low supervision cost • low fuel loads • fast eucalypt growth • high return to grower	• visual impact • few oldgrowth species • low structural diversity • few special timbers • smoke pollution • nutrient loss
2. **CBS with understorey islands** (40 m x 20 m machinery-free areas)	2 (part)	• survival of oldgrowth flora • source of propagules	• harbour embers • establishment cost
3a. **Stripfell (cable harvested)** (250 m x 80 m strips; low intensity burn, natural seedfall)	2	• mixed forest regeneration • natural seed • reduced visual impact • special timbers supply	• more cuts in the landscape • more roading & burns • losses in retained strips
3b. **Patchfell (cable harvested)** (250 m x 200 m patch; low intensity burn, natural seedfall)	1	• will show maximum colonisation distance	
4. **Dispersed retention** (10% basal area retention, low intensity burn, natural seedfall)	2	• natural seed • hollows for fauna • large log habitat • reduced visual impact	• safety risk to loggers • difficult fire management • reduced eucalypt seedbed • variable seed supply • suppressed eucalypt growth
5. **Aggregated retention** (30% area retention, log one tree length either side of snig tracks, retain aggregates of 0.5–1.0 ha, low intensity burn, natural seedfall)	2	• biodiversity retention • structural diversity • improved aesthetics • natural seed • low safety risk • special timbers supply	• more cuts in the landscape • difficult fire management • reduced eucalypt seedbed • variable seed supply
6. **Single tree/small group selection logging** (retain > 75% forest cover, permanent snig tracks, harvest 40 m^3/ha every 20 years, mechanical disturbance (no burning), natural seedfall)	1 (many small gaps)	• biodiversity retention • structural diversity • improved aesthetics • natural seed • special timbers supply • smoke-free	• high safety risk to loggers • high harvest cost • multiple entries; roading cost • low eucalypt growth • fire hazard from slash • damage at subsequent harvests

coupe and not disproportionately located on sites of lower timber volume or productivity. Unmarked areas will be completely felled and burnt at low intensity. Regeneration will be achieved from natural seedfall. The aggregates will be retained for the planned rotation length of 90 years after which they could be retained for a second rotation or logged and new aggregates retained. In the latter case the oldest aggregates at subsequent harvests would be 180 years.

Single tree/small group selection (SGS)

Retain at least 75% of the forest canopy at all times. Primary snig tracks will be heavily corded and used for subsequent harvests. Oldgrowth trees identified as dangerous, due to unsound bases, excessive leans or unstable crowns, will be felled first to reduce hazards. Trees damaged by this felling are also to be felled. Any tree with the potential to grow additional useful wood is to be retained while all other marketable trees are to be removed (i.e. leave the best trees standing and remove the poorest trees first). Gaps created by harvesting and removal are to be mechanically disturbed to expose seedbed. Slash will be either incorporated as matting into primary snig tracks or pushed into piles in gaps to maximise the area of exposed seedbed. About 40 m^3/ha are planned for harvest every 20 years. This yield is based on an estimated mean annual increment of merchantable volume of 2 m^3/ha. Regeneration will be achieved from natural seedfall. There is no set rotation length but the stump return time for eucalypts might be 100 years and up to 400 years for celery-top pine (*Phyllocladus aspleniifolius*) which has the slowest growth rate of the special species timbers.

Table 5 summarises the prescriptions and key potential advantages/disadvantages for treatments included at the Warra trial. No supplementary or remedial treatments are prescribed in the event that particular treatments fail to meet stocking standards (Forestry Tasmania 1996). This will allow the long-term implications of inadequate seedbed or seed supply on stocking and growth to be documented.

Allocation of treatments to coupes

The treatments and coupes are shown in Figure 1. While the site is uniformly dominated by wet *E. obliqua* forest, there is considerable variation in understorey types between the coupes (Neyland 2001). Rainforest understoreys were common in coupes WR001A and WR005D and also occurred in WR008B and WR008H but were virtually absent from WR001E, WR008C, WR008I and WR008J. Hence, the stripfell and SGS treatments, which were primarily concerned with regeneration of mixed forest, were allocated to WR001A and WR005D. Understorey islands were allocated to each of rainforest and wet sclerophyll understoreys in WR008B and WR008H. Large internal controls were designated in the middle of the trial (WR008J and WR008K), with further control sites established in retained forest around most of the treatments to ensure inclusion of all forest types. Dispersed and aggregated retention treatments were allocated in pairs so that they were well matched to forest type. All treatments are scheduled for ground-based harvesting except for the stripfell/patchfell treatment, which is located on a steeper site, where a cable harvester is prescribed to minimise soil damage and to achieve sharply defined strips.

Five of the six treatments have been established to date. Appendix 1 lists coupe sizes and dates (where applicable) for harvest completion, burning and sowing. Appendix 2 includes photos of the treatments soon after their establishment. Coupe sizes are generally in the range of 10–20 ha although some treatments, for example stripfells and SGS, require much smaller openings in a particular harvest cycle.

Performance indicators for initial evaluation of treatments

The treatments at Warra are being established in the period 1998–2002 and will be followed by a major evaluation, based on performance of all coupes over their first three years, in 2005 (Neyland *et al.* 2000b). The indicators for assessing performance over the first three years are shown in Table 6. Pre-harvest inventories have also been made for birds and mammals (T. Wardlaw, pers. comm.) but a comparison of species and abundances after three years

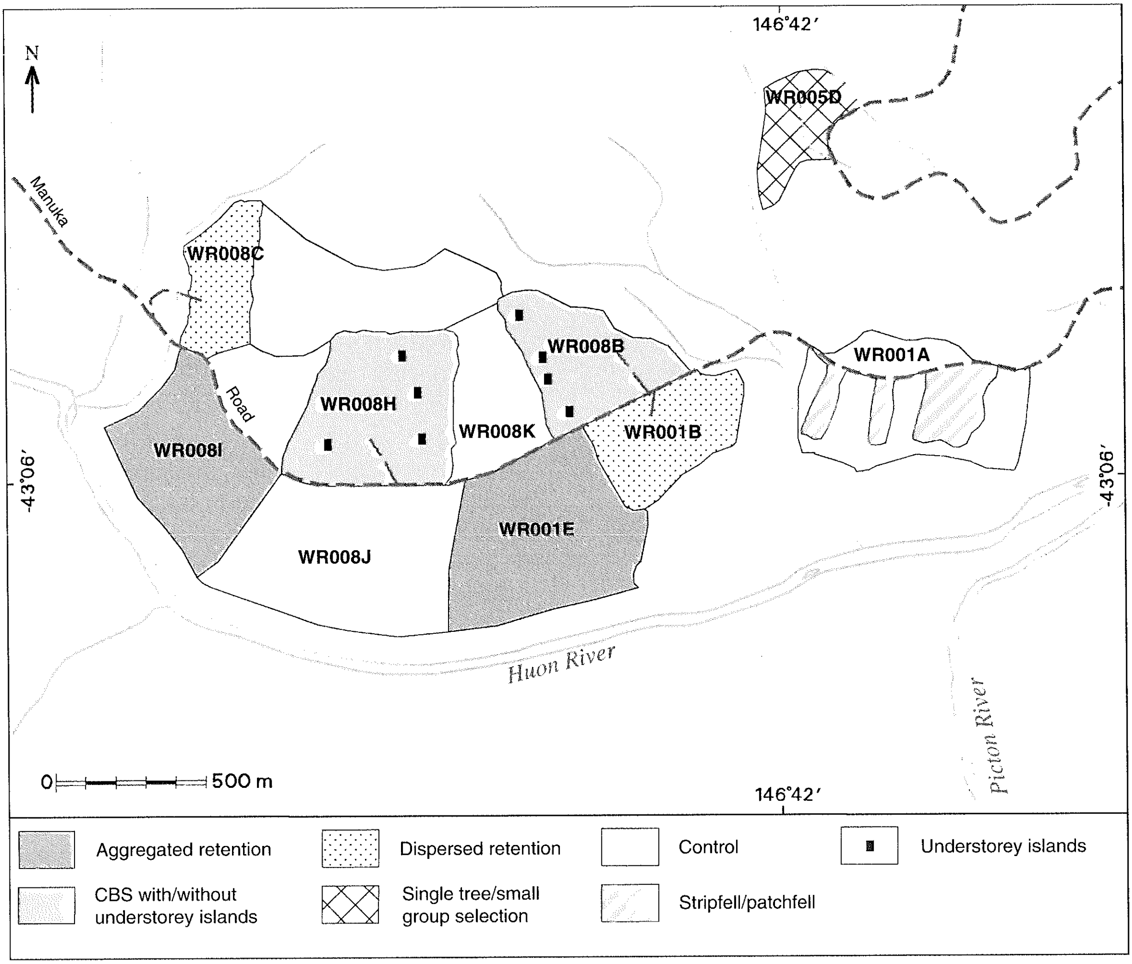

Figure 1. Map of treatments at the Warra silvicultural systems trial.

is not likely to be very informative, particularly for wide-ranging species. A further comparative evaluation of treatments should be made in 2015 based on the performance of treatments over ten years. Subsequent evaluations should be made periodically over the rotation length of the treatments. In addition, the treatments will be available for exploration of particular research questions at any time as needs and resources become available.

It was recognised that a comprehensive evaluation of treatments would include comparisons with the natural system, which includes regeneration after stand-replacing wildfire. Some comparisons with wildfire effects can be made from monitoring of plots in understorey islands within the CBS treatments. The option of burning a block of standing forest under extreme conditions within the Warra trial was considered but the risk of damage to surrounding assets was considered too great. Instead, wildfire reference sites have been identified (e.g. Hickey 1993; Edwards 1999; Baker 2000) from previous wildfires in the vicinity in the 1960s and 1970s and more will be documented if sites become available.

Expectations and limitations of the Warra silvicultural systems trial

The Warra silvicultural systems trial includes a broad range of treatments that

Table 6. Indicators for initial evaluation of treatments at the Warra silvicultural systems trial.

Criterion	Indicator	Treatments
ECOLOGICAL		
Biodiversity	Species richness and abundance of vascular plants	All treatments
	Species richness and abundance of non-vascular plants	CBS ± understorey islands, dispersed and aggregated retention
	Species richness and abundance of invertebrates	CBS ± understorey islands, dispersed and aggregated retention
Productivity	Proportion of suitable seedbed according to burn/disturbance classes	All treatments
	Site occupancy and early growth of eucalypts and competing vegetation	All treatments
	Site occupancy and early growth of special species timbers	CBS ± understorey islands, stripfells and SGS
	Growth of retainers	SGS treatment
	Windthrow and crown health of retainers	Stripfells (belts), dispersed retention, aggregated retention and SGS
	Effect of browsing on eucalypt regeneration	All treatments
Soil	Changes in soil physical and chemical properties following logging and high intensity burning (CBS) or low intensity burning	CBS and dispersed retention (one replicate each)
	Proportion of coupe area in snig tracks and landings	All treatments
SOCIAL		
Worker safety	Summary of incidents, contractor views and Workplace Standard Authority inspections	All treatments
Social assessment	Measurement of public perceptions	All treatments
ECONOMIC		
Timber production rates	Timber produced per day	All treatments
Costs to the forest grower	Marking, regeneration and contractor subsidy costs	All treatments
Financial evaluation of treatments	Assessment of timber values and discounted costs and revenues over multiple rotations	All treatments
Fire management	Proportion of fuel reduced, resources required, burn intensity matched to prescription	CBS ± understorey islands (one replicate), stripfells and dispersed retention

have potential, or have been proposed, as alternatives to clearfelling in wet eucalypt forests. These alternatives may better meet objectives for biodiversity, aesthetics and special species timber production than the standard clearfell, burn and sow system. The trial does not include a full continuum of gap sizes and retained overwood, replicated over two years, as explored by the Victorian silvicultural systems trial (Campbell 1997) in regrowth *E. regnans* in Victoria.

The Warra trial is replicated to the extent that treatments have been repeated twice at the one location. Replication is highly problematic in silvicultural trials, particularly where a mosaic of burning intensities is required. Prescribed burn intensities are very difficult to replicate. Coupes scheduled for high intensity burns must be large to enable hot burns but coupe size needs to be small to minimise the topographic and vegetation variations that occur as the trial area becomes large. Ideally, coupes planned for high intensity burns are scheduled before adjoining treatments planned for low intensity burns to minimise the risk of reburning partially burnt coupes. This creates its own problem in that coupes are then established over more than one year which raises the issue of replication in time as well as space. The treatments at Warra are being established over a period of five years.

The allocation of treatments to coupes at Warra was not random; instead it took into account vegetation attributes to test particular treatments. Hence, stripfell and SGS treatments were allocated to coupes with rainforest understoreys as they were primarily designed to test mixed forest regeneration. This subgrouping of the treatments will probably lead to some future studies choosing subsets of treatments for comparison. The allocation of treatments to coupes was also hampered by the realities of boundary definition in forests with very dense understoreys. Two coupes, WR008B and WR008C, were substantially reduced from their prescribed size after the discovery of unmapped streams on the east and west boundaries respectively.

These practical problems can be resolved but require a very large initial allocation of resources, for example as in the Victorian Silvicultural Systems Trial (Powers 1999), and/or the replication of single sets of treatments over multiple locations, for example, as in the DEMO project. Neither of these options was available at the time of Warra trial establishment. Despite these limitations, the Warra trial has a greater scope than previous silvicultural trials in wet forests in Tasmania, represents a major investment in long-term, multi-disciplinary forest research and will enable the demonstration and testing of several alternatives to clearfelling at a single site. No single trial or study site can provide answers to all the complex ecological, economic and social questions asked of forest managers. The results gained at Warra can be networked with similar long-term silvicultural sites established elsewhere to develop sustainable forest management outcomes which are broadly applicable to wet forests.

Acknowledgements

The trial design evolved after helpful discussion with numerous colleagues. Humphrey Elliott, Evan Rolley and Mick Brown expanded the scope of the trial by urging the inclusion of treatments that were locally considered infeasible. Rob Campbell and Jerry Franklin willingly shared insights gained from their experience with silvicultural systems trials elsewhere. Leigh Edwards and staff from Huon District provided practical insights on trial implementation. Joanne Dingle provided GIS and GPS skills and produced Figure 1. Leigh Edwards provided the photos for Appendix 2. Peter Fagg and Simon Grove made helpful comments on an earlier draft.

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Appendix 1. Coupe sizes and establishment dates. (Aggregated retention coupes are not yet established; na = not applicable.)

Treatment	Coupes	Size (ha)	Harvest end	Burnt	Sown
CBS ± understorey islands	WR008B	17.7	03/12/98	26/03/00	01/04/01
	WR008H	26.0	15/03/01	07/04/01	16/04/01
Stripfell/patchfell	WR001AF	5.8	11/06/99	26/03/00	na
	WR001AN	1.5	11/06/99	27/03/00	na
	WR001AL	1.9	11/06/99	07/04/00	na
10% Dispersed retention	WR001B	15.7	06/03/98	29/04/98	na
	WR008C	11.1	02/11/99	09/04/00	na
30% Aggregated retention	WR001E	*c. 20*	*Feb 02*	*May 02*	*na*
	WR008I	*c. 20*	*Feb 02*	*May 02*	*na*
SGS	WR005D	9.1	21/5/01	na	na

Appendix 2. Treatments soon after their establishment (Photos 1–4), and planned treatments (Figure 2).

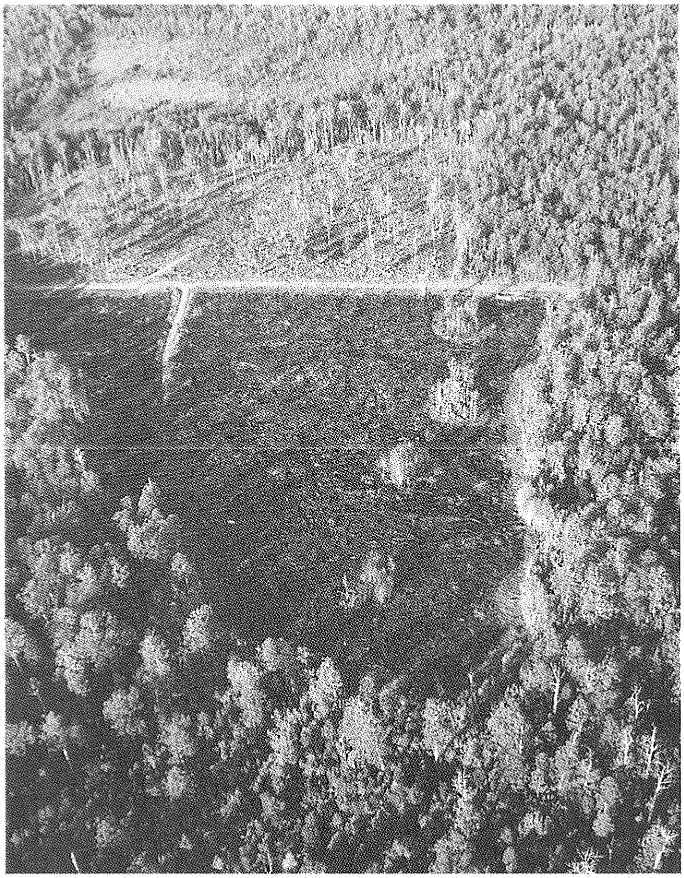


Photo 1. Clearfell, burn and sow with/without understorey islands at WR008B (foreground) and 10% dispersed retention at WR001B (background).

Photo 2. Stripfells/patchfell at WR001A. (The area above the road was a small patch that was clearfelled, burnt and sown but not as a formal part of the trial).

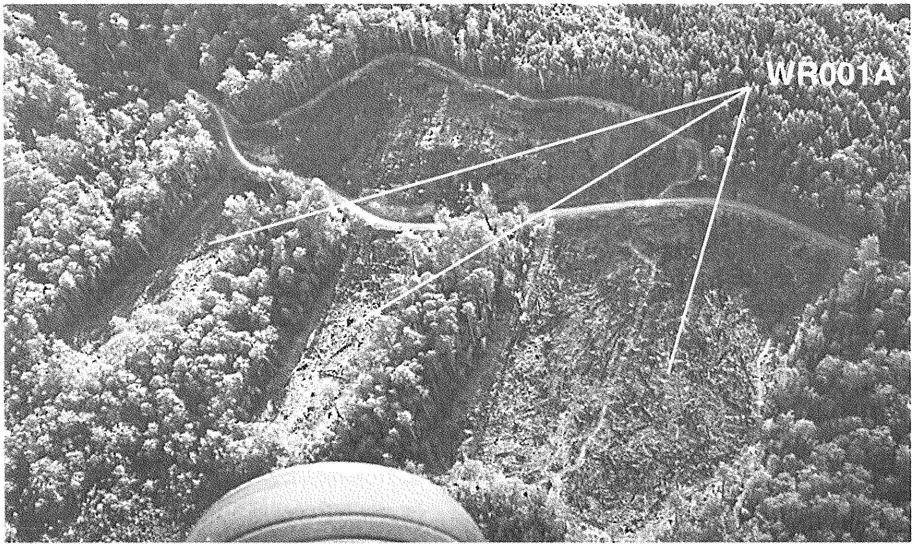
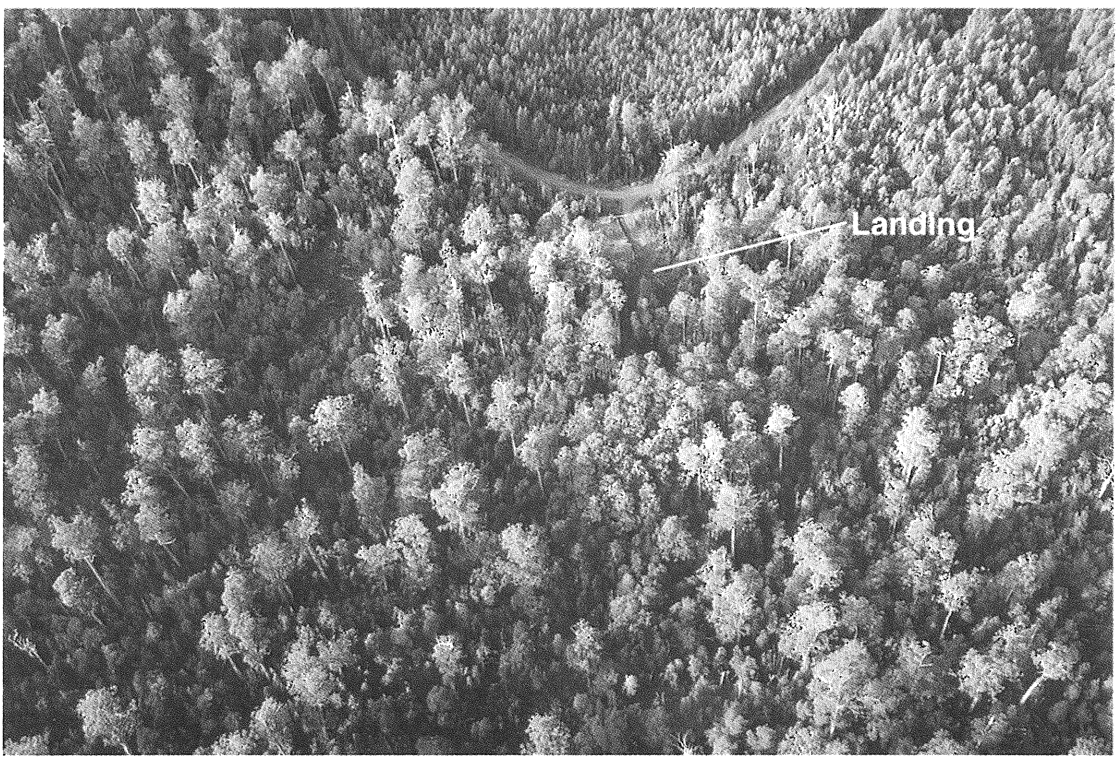


Photo 3. Dispersed retention at WR001B.

Photo 4. Single tree/small group selection treatment at WR005D.



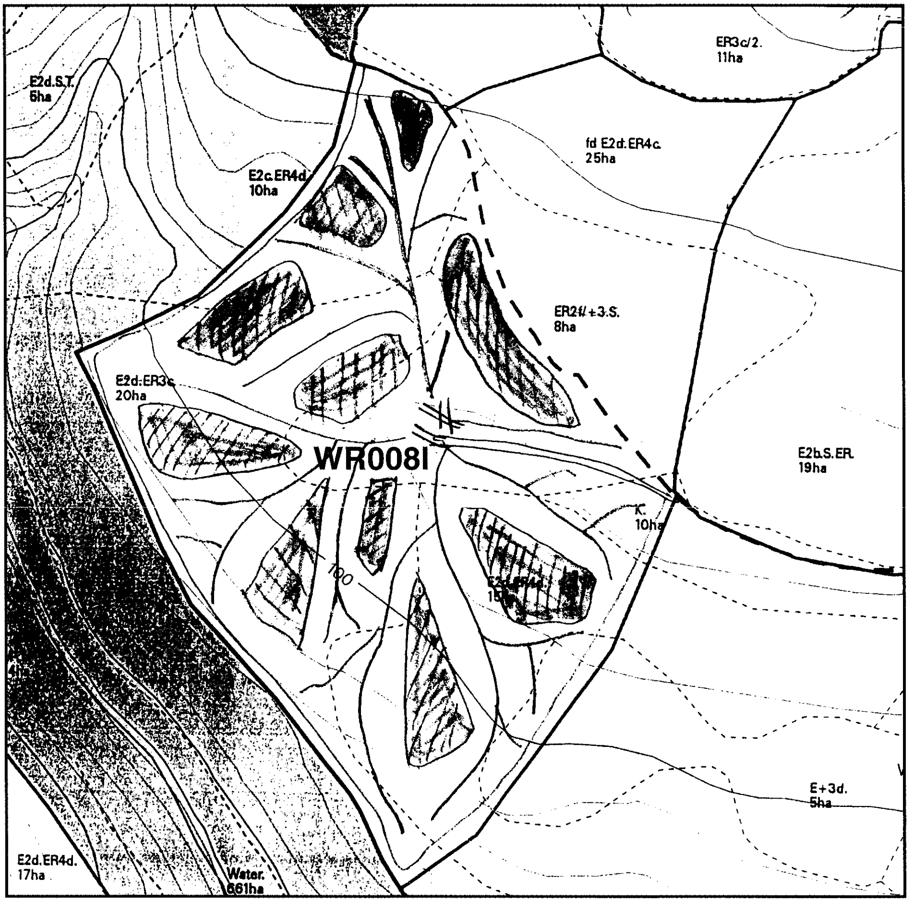


Figure 2. Planned aggregated retention treatment at WR008I.