Silvicultural monitoring in uneven-aged highland dry *Eucalyptus delegatensis* forests in Tasmania

M.G. Neyland[1,2] and J.K. Cunningham[3]

[1]Forestry Tasmania, GPO Box 207, Hobart, Tasmania 7001, Australia
[2]Email: mark.neyland@forestrytas.com.au
[3]258 Redwood Road, Kingston, Tasmania 7050, Australia

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Summary

Poor early establishment and growth of regeneration following clearfelling of highland dry *Eucalptus delegatensis* forests in Tasmania in the 1970s led to the development of alternative practices. Shelterwood retention, shelterwood removal, potential sawlog retention and advance growth retention systems were developed and implemented by forest owners as preferable alternatives to clearfelling in most instances.

Less than optimal outcomes following partial harvesting led to the development of formal monitoring procedures. These procedures assess the pre-harvesting forest structure, guide development of the harvesting prescription, follow the course of harvesting, return information on progress to the harvesting contractor, and allow for continuous improvement of operations. Together they ultimately provide improved outcomes for the forest grower.

The paper discusses the development of uneven-aged management and describes the processes used to develop and monitor the outcomes.

Keywords: natural regeneration; silviculture; monitoring; *Eucalyptus delegatensis*; Tasmania

Introduction

Eucalyptus delegatensis forests in Tasmania can be divided into two broad types. Tall (> 41 m) wet *E. delegatensis* forests range from 400 to 800 m a.s.l. in areas where the rainfall exceeds 1000 mm y^{-1}. These forests typically have a closed understorey of rainforest or wet forest shrub species 10–30 m tall (Ellis 1985). Highland dry *E. delegatensis* forests (27–41 m tall) range from 600 m to 1000 m a.s.l. and typically have an open understorey of grasses, herbs, bracken and shrubs, often < 1 m tall (Ellis 1985).

Clearfelling is the predominant silvicultural system used in tall wet *E. delegatensis* forests at lower altitudes, where abundant slash arising from logging and disturbance of the understorey requires high-intensity fire to prepare a receptive seedbed (Forestry Tasmania 2001). Clearfelling was also used in the past in highland dry *E. delegatensis* forests, but on frost-prone sites this sometimes resulted in poor establishment and growth of regeneration due to growth check (Keenan and Candy 1983). Subsequently, a better understanding of the needs of the regeneration and an appreciation of the value of existing advance growth (McCormick and Cunningham 1989) led to the widespread adoption of uneven-aged management techniques in the higher, frost-prone forests (Forestry Tasmania 2001). It is these forests and the management systems applied in them that are the focus of this paper.

The Tasmanian subspecies of *E. delegatensis* (*E. delegatensis* subsp. *tasmaniensis*) is physiologically and morphologically different from the mainland form (*E. delegatensis* subsp. *delegatensis*) (Brooker and Kleinig 1999). The mainland form has fibrous bark covering only the lower half of the trunk, poor vegetative recovery following damage and is fire sensitive. In contrast the Tasmanian form has fibrous bark which often extends up to the base of the branches in the crown of a mature tree, can coppice from stumps, is more fire resistant as an adult, and can persist as a suppressed seedling in the understorey for up to 30 y, yet still retain the ability to respond to release from overstorey competition (Bowman 1984; Ellis and Lockett 1991). These differences give the Tasmanian sub-species much greater silvicultural flexibility than mainland forms.

Tasmania's *E. delegatensis* forests are a very significant resource. There are about 290 000 ha of dry *E. delegatensis* forests in Tasmania of which about one-third is conserved in reserves, one-third is privately owned and one-third is in State forest (RPDC 2002). About one-tenth of Tasmania's production forest estate is dominated by *E. delegatensis* (RPDC 2002).

History of harvesting

Dry *E. delegatensis* forests have a long history of extensive management and have provided sawn timber, fence posts, firewood and rough grazing for over 150 y. Historically, most harvesting was by sawmiller selection, often with little formal guidance (Kostoglou 2000). This left extensive areas of forest dominated by trees of relatively poor quality. Fortuitously, periodic fires lit to promote forage growth often resulted in abundant regeneration. In some areas the standing forest was ringbarked to improve the quality of grazing, resulting in local patches of good quality regrowth stems. By the 1970s these forests had experienced a diverse management history resulting in widely varying structures, often including a component of advance growth (Ellis *et al.* 1987).

Ellis *et al.* (1987) indicated that the sawlog yield in these forests could be significantly increased by careful uneven-aged management.

They found that total volume production of sawlogs over a rotation of 80 y could be increased from < 1 m^3 ha^{-1} y^{-1} to 2.3 m^3 ha^{-1} y^{-1} through uneven-aged stand management. By applying a regime of repeated cutting on an approximate 25-y cycle, production could be increased even further, they suggested. Ellis *et al.* (1987) conducted their research during a known drought period (Bureau of Meteorology 2001). In good seasons, even higher volume production could reasonably be expected.

Conservation management in wood production forests

Conservation management of dry *E. delegatensis* forests is fairly straightforward as few threatened species are found only in this forest type (Bryant and Jackson 1999; Forest Practices Board 2002). Known threatened plants, such as *Discaria pubescens,* have localised distributions that can be protected. Known threatened animals, such as the endangered native fish *Galaxias fontanus* (swan galaxiid), also have localised distributions, and forest management within these catchments can be modified to conserve them (Crook and Sanger 1997). As long as there is a diversity of age classes within a catchment, areas of vigorously growing regeneration need not prejudice water yield (Stoneman 1992) and this should assist the long-term survival of the fish within these forests.

In addition to formal reserves, the production forests occur within a matrix of informal landscape reserves, wildlife habitat strips (Forest Practices Board 2000) and streamside reserves, which form an interlocking network. Furthermore, in partially harvested coupes, habitat clumps, which are undisturbed patches of about 30 m diameter, are now retained at a spacing of one clump every 5 ha, but not within 200 m of other retained areas. These clumps should contain at least two habitat trees (Forest Practices Board 2000). The habitat clumps, wildlife habitat strips and streamside reserves provide undisturbed understorey as well as retaining old-growth stems. The mix of production areas and reserved areas is considered to provide a good balance between wood production and conservation requirements.

Clearfelling: a silvicultural problem in dry forests

The silvicultural system of clearfelling followed by high-intensity burning and aerial sowing was originally developed for use in wet eucalypt forests (Gilbert 1959; Cunningham 1960). Where forests have a tall dense understorey, clearfelling followed by high-intensity burning is necessary to create the mineral earth seedbed required for successful eucalypt regeneration. The development of a eucalypt pulpwood market in the 1970s resulted in an expansion of the forest industry in Tasmania, with clearfelling becoming the normal practice in a wide range of forest types. By the late 1970s, however, it was apparent that regeneration in dry *E. delegatensis* forest did not always establish successfully (Keenan and Candy 1983; Webb *et al.* 1983). The regeneration often developed a condition referred to as 'growth check', particularly on the highest altitude sites, and on flat and hence frost-prone sites where grass was a significant component of the understorey. There was also a recognition that clearfelling resulted in a significant loss of advance growth and potential sawlogs which, if retained and grown on, could develop into sawlogs more quickly than could new regeneration.

Growth check and competition

Growth check is an extreme form of growth impediment with no known single cause. However, frost and severe competition from dense *Poa* grass have been implicated as major factors (Orme 1971; Webb *et al.* 1983; Ellis *et al.* 1985; Bowman and Kirkpatrick 1986c; Nunez and Bowman 1986; Fensham and Kirkpatrick 1992). Growth check is not an 'on–off' condition, nor a diagnosable disease. It is the growth response to adverse conditions which, in any one year, may be caused by the independent or interactive effects of many factors including frost, browsing, grass competition, soil nutrition and insect attack (Keenan and Candy 1983).

Trees with growth check tend to have bushy, rounded crowns with no apparent apical dominance and smaller, thicker and more leathery leaves than vigorously growing individuals. They may have heavy infestations of insects and fungi. Trees may be growing slowly and exhibit all or none of these attributes. Growth check as a condition may persist for periods from a few to more than 15 y (Orme 1971). Under favourable conditions, trees have eventually recovered from growth check and resumed reasonable growth rates (Keenan and Candy 1983).

To prevent seedlings becoming checked it is necessary to retain a partial canopy. However, retained overstoreys with basal areas of > 12 m^2 ha^{-1} have a pronounced suppressive effect on the growth of regeneration (Battaglia and Wilson 1990). Bowman and Kirkpatrick (1986b) concluded that the principal cause of the growth difference between seedlings growing in the open, and seedlings growing beneath a retained canopy, is competition for moisture by mature trees. On a test site at Waddamana in the Central Highlands they found that under a shelterwood treatment (with 50% basal area retained) soil moisture levels were below those necessary for growth for 12 weeks of summer, compared with only 4 weeks in a matched clearfell treatment. In a trial across four different sites ranging from high- to low-rainfall areas, Battaglia and Wilson (1990) showed that the height increment of regeneration at the wettest site was least affected by retained basal area and, conversely, was most affected at the driest site. The relationship between the site rainfall and the rate of reduction in height increment was found to be very strong, further supporting the hypothesis that moisture deficit is the main factor limiting growth. Experience in other forest types (Dunlap and Helms 1983; Wellington 1984; Flint and Childs 1987) also supports the general principle that competition for soil moisture by retained trees is important in the suppression of regeneration.

There has been no conclusive evidence that retained trees act in any other manner to suppress regeneration of *E. delegatensis*. Competition for light is not limiting, nor is intraspecific allelopathy a significant factor in the growth of regeneration (Bowman and Kirkpatrick 1986a,b). Bowman and Kirkpatrick (1986c) also investigated intraspecific competition for nutrients and concluded that while applying NPK fertiliser increased growth, nutrition did not appear to be the factor limiting seedling growth where the seedlings were in competition with mature trees.

Partial harvesting

There are two conflicting requirements in partial harvesting operations. Where new regeneration is required it is essential to maintain some canopy until such time as the regeneration is well established, usually for the first decade or so after harvesting. However, it is also important that the retained canopy be sufficiently open to allow the regeneration to compete successfully for moisture. From the work of Battaglia and Wilson (1990), target retention levels were established at 9–12 m^2 ha^{-1}. Prior to harvesting, basal areas in highland *E. delegatensis* forests are generally in the range of 27–40 m^2 ha^{-1} (Forestry Tasmania 2001).

Partial harvesting of *E. delegatensis* forests: benefits and problems

Partial harvesting provides many advantages compared to clearfelling. The dramatic visual impact of clearfelling is a major reason for the current controversy surrounding this technique. In partially harvested stands, retained trees and the often patchy nature of the stand mean that the visual impact of harvesting can be small. As the coupe is not totally exposed and high-intensity burning is not used, soil impacts are reduced (Rab 1999).

Where fire must be used to reduce heavy loads of slash fuel, low-intensity burns are essential to ensure that the retained trees are not severely damaged. With partial harvests in dry forests, the fuel load is often relatively light. This increases the range of options, and burning is not always required. Where the fuel load is small, burning of waste heaps at landings may be sufficient. Where required, low-intensity burns can take place later in the autumn than high-intensity burns. This increases the window of opportunity for burning, reduces the risk of fire escape and spreads the workload across the burning season.

With partial harvesting, there is reduced reliance on new seedling regeneration as significant amounts of advance growth are retained. The use of on-site seed from the retained trees and from the heads of felled trees means that sowing costs are lower or avoided completely. The retention of intact vegetation provides alternative food sources for browsing animals, resulting in lower browsing pressure on the seedling regeneration and lower costs of browsing control.

In the 1980s and the 1990s there was a general acceptance of the use of partial harvesting systems. These took the form of shelterwood, potential sawlog retention and advance growth retention systems. Specifications were developed for these systems to give the best outcomes (Forestry Commission 1994), although outcomes were rarely actually measured.

The widespread adoption of clearfelling in the late 1960s and throughout the 1970s conditioned Tasmanian foresters to a low level of supervision. Hence the shift to partial harvesting in the 1980s and 1990s was not accompanied by the levels of supervision necessary for successful uneven-aged management. It was hoped that broad prescriptions would be interpreted and implemented by supervisors and contractors without the need for a formal monitoring procedure. In some cases, a combination of experienced supervisors and motivated contractors achieved excellent results, but the results were often sub-optimal. Inexperienced staff and contractors had great difficulty in developing and implementing prescriptions for partial harvesting in the absence of quantitative parameters and formal monitoring, and several problems were encountered. These are described below.

Cull retention. Predominantly cull-quality trees have sometimes been retained in shelterwood retention operations. The economic imperative encouraged the retention of culls (sometimes biased towards non-ash species); these will always be unsaleable and suppress regeneration. Where the shelterwood comprises predominantly cull-quality trees, it may be economically impossible to have the shelterwood removed.

Shelterwoods not removed. Shelterwoods are best removed when regeneration has an average dominant height above 1.5 m, but not much taller. However, the small commercial volume available per hectare and the mistaken belief that the regrowth will benefit from a longer period of shelterwood protection have meant that shelterwoods have often not been removed. Retaining shelterwoods beyond their useful life leads to long-term reduction in stand productivity.

Advance growth destroyed. The contractor may fail to appreciate the future value of clumps of advance growth (<20 cm diameter at breast height (dbh)) which have often been damaged or destroyed during harvesting. Supervisors have had no objective basis to complain about this in the absence of pre-logging data on the amount of advance growth and its potential contribution to the stand.

Potential sawlogs harvested as pulpwood. Well-formed poles from 20–60 cm dbh have not always been retained to grow on into sawlogs. Again, supervisors have had no basis for complaint in the absence of clear objectives, prescriptions or data on the role of this stand component.

Uniform suppression by cutting to a basal area limit. Some managers have responded to the complexity of uneven-aged management by issuing contractors with basal area gauges that enabled them to cut to a 12 m^2 ha^{-1} basal area limit, regardless of the initial stand structure. This is the minimum basal area required to satisfy current Forestry Tasmania stocking standards (Forestry Tasmania 2003), and theoretically no regeneration treatment (burning or scarification) is needed. In the absence of treatment the grassy stratum often strengthened and, depending on stand structure, any regeneration which did establish was often impeded as it developed.

Excessive retention levels. In the absence of quantitative prescriptions and monitoring, inexperienced supervisors sometimes required excessive retention of mature trees. This was occasionally valid to meet landscape or community objectives, but commonly was not related to specific objectives, and merely resulted in foregone revenue and reduced site productivity.

Against this background, there was clearly a need for a formal monitoring procedure.

The uneven-aged treatment procedure

The monitoring technique designed to deliver a consistently better standard of uneven-aged management in dry *E. delegatensis* forests is known in Tasmania as the uneven-aged treatment procedure (UAT). The UAT provides quantitative parameters for each of the silvicultural systems through a pre-logging assessment of stand components. Harvesting prescriptions are based on this assessment and the outcomes are measured against the prescription by progressive harvesting assessment.

The procedure links the main silvicultural systems that were introduced in Tasmanian dry *E. delegatensis* forests in the 1980s (McCormick and Cunningham 1989). These systems include 'shelterwood retention', 'shelterwood removal', 'advance growth retention' and 'potential sawlog retention' (Forestry Commission 1994; Forestry Tasmania 2001).

The silvicultural systems used in UAT, the conditions under which each is applied and the retention targets are summarised in Table 1. There are many instances, of course, where the forest consists of a mosaic of cohorts of varying ages arising from previous disturbances, and more than one system may be applied during the one harvest. For example, where advance growth is present only as discrete clumps within canopy gaps, the clumps would be released by removing all surrounding stems while maintaining the clumps intact (i.e. advance growth retention), while in areas lacking advance growth a shelterwood would be retained (i.e. shelterwood retention).

Pre-logging assessment

A pre-logging assessment (PLA) procedure is used to collect detailed information about the diameter class distribution, mean dominant height and quality (sawlog, pulpwood or cull) of the trees in a stand. This information is then used to develop a harvesting prescription specifying the appropriate silvicultural system and the diameter class, quality and quantity of stock to be retained. This can be compared subsequently with the post-harvest stand data. In Tasmania, at present, the minimum small-end diameter for a commercial log is 10 cm, which for regrowth poles roughly equates to a diameter at breast height overbark (dbhob) of 20 cm. A category 1 sawlog has a minimum small-end diameter of 30 cm which roughly equates to a dbhob of 60 cm. Thus the diameter classes currently used in the PLA are 0–20 cm dbhob (advance growth), 20–60 cm dbhob (potential sawlog and pulpwood trees) and ≥60 cm dbhob (commercial sawlog and pulpwood trees).

The PLA procedure uses a combination of strip-line and plot-point assessment methods. A grid, 200 m by 100 m, is overlaid on a map of the coupe. At each plot point (i.e. at each intersection on the grid) a basal area sweep (factor 2 wedge) is done, and each tree included in the sweep (an 'in' tree) is assessed for diameter class, timber quality (sawlog, pulp only or cull) and species. The height and dbhob of two 'in' stems, 20–60 cm dbhob, where present, are measured. The height of one 'in' stem, >60 cm dbhob, where present, is measured. Based on the recommended sampling intensity of one plot per two hectares with two basal area sweeps per plot, there is a 95% probability for a typical 60-ha coupe that the average merchantable volume per hectare for a 100% sample would be in the range of ± 10% of the actual sample estimate (S. Candy, *pers. comm.*). Because the system relies on the use of a basal area wedge, good visibility is essential. The understorey in dry *E. delegatensis* forest in Tasmania typically comprises a layer of 'short pricklies' up to about 1.5 m high, and visibility is generally very good (Fig. 1).

The seed crop at the plot point is assessed as described in Forestry Commission (1991). The slope and aspect at the plot point are measured. Whilst moving from plot point to plot point along the strip-line, the operator records and measures presence and stocking of advance growth every 20 m on circular plots 16 m^2 in area. Any noteworthy feature of the landscape is diagrammatically recorded on the field sheet. Typically, features such as rocky outcrops, streams, swamps, changes in the species composition of the forest, roads, tracks and old landings are recorded. An assessment team of two people travelling one hour each way from office to coupe and return, can complete 12–20 plots per day which is equivalent to about 25–40 ha of forest. In most instances, once the coupe has been systematically surveyed by the pre-logging

Table 1. Performance indicators and retention targets for uneven-aged treatment operations

Treatment type	Forest structure pre-harvest	Performance indicator	Retention target	Tolerable variance
Shelterwood retention	Forest of various size classes, lacking advance growth or potential sawlogs	• Retained BA • Percentage of retained BA with sawlog potential • Damage	• 9–12 m^2 ha^{-1} • >50% BA in sawlog potential trees • Zero	± 10% ± 10% 0–10%
Shelterwood removal	Two-age (minimum) forest, adequately stocked with advance growth >1.5 m average height	• Retained undamaged stems per hectare	• >1000 potentially merchantable stems per hectare	• 1000 stems minimum acceptable stocking
Advance growth retention	Multi-aged from multiple disturbances	• Retained undamaged stems per hectare	• >500 potentially merchantable stems per hectare	• 500 stems minimum acceptable stocking
Potential sawlog retention	Two or three age classes. Basal area of potential sawlogs between 5 and 16 m^2 ha^{-1}	• BA or • SPH • Damage • Percentage of retained BA with sawlog potential	• As per FPP prescription • As per FPP prescription • Zero • >80% sawlog potential stems	± 10% ± 15% 0–10% ± 10%

BA= Basal area; SPH = Stems per hectare; FPP = Forest Practices Plan

Figure 1. Uneven-aged high-altitude *Eucalyptus delegatensis* forest in north-eastern Tasmania: a complex mixture of over-mature, mature and regrowth trees with a layer of suppressed seedlings

assessment, only a brief additional coupe visit is required to confirm road and landing locations to complete the Forest Practices Plan.

A spreadsheet template has been developed which automatically generates coupe-level data from the field data. The spreadsheet calculates volumes (m^3 ha^{-1}) and basal areas (m^2 ha^{-1}) by diameter and product class, mean dominant height (m) of the trees >60 cm dbhob and 20–60 cm dbhob, and the species mix on the coupe (as percentages). The density and distribution of any advance growth present can be mapped and the advance growth stocking for the coupe determined. The seedcrop across the coupe can be assessed and mapped.

Preparation of harvesting prescriptions

Once there is a clear understanding of the structure of the forest and the land and vegetation features of the coupe, preparation of the harvesting prescription is generally straightforward. Forests which are dominated by stems >60 cm dbhob and which lack a significant component of advance growth are harvested to a 'shelterwood retention' prescription. The retained basal area should be 9–12 m^2 ha^{-1} (tolerances are defined in Table 1); at least half the retained basal area should where possible be in sawlog-quality stems, damage to retained stems should be minimal (<10%), and cull trees should either be incorporated in habitat clumps or felled. Insisting that at least half the retained basal area is in sawlog-quality stems helps to ensure that there is a commercial harvest in the retained shelterwood: that is, there is a commercial incentive to recover that volume at the appropriate time in the future.

Forests with a low stocking of stems >60 cm dbhob over well-established advance growth are harvested to a 'shelterwood removal' prescription. The critical outcome of a shelterwood removal operation is that at least 1000 well-spaced undamaged stems of advance growth be retained per hectare. 'Advance growth retention' is similar to shelterwood removal except that the advance growth is usually older and has arisen opportunistically rather than from a deliberate shelterwood retention harvest. Hence, the stocking of advance growth may be lower, and the average piece size larger, so the critical outcome is that at least 500 well-spaced undamaged stems of advance growth be retained per hectare.

Table 2. Potential sawlog retention spacings (assuming that the retained basal area is within the range 5–16 m^2 ha^{-1})

Mean dbhob (cm)	Total stems per hectare	Average spacing (m)
20	200–400	6–8
25	100–325	6–10
30	70–225	7–12
35	50–175	8–14
40	40–125	9–16
45	30–100	10–18
50	25–80	11–20
55	21–70	12–22
60	18–60	13–24

Forests with more than 5 m^2 ha^{-1} basal area (and up to 16 m^2) of potential sawlog trees (defined as stems 20–60 cm dbhob and with a length of at least 2.5 m of sawlog-quality wood) are harvested to a 'potential sawlog retention' prescription. (Forests with a retained basal area of regrowth stems of more than 16 m^2 are typically even-aged regrowth and in these forests commercial thinning may be applied.) The actual spacing for retained sawlogs is determined from Table 2, based on the mean dbhob of the potential sawlog trees which is calculated by the spreadsheet from the PLA data. For example, where the mean dbhob of the potential sawlog trees is 40 cm the prescription states that 80 stems ha^{-1} will be retained at a mean spacing of 12 m. The wide range in acceptable retained basal area (5–16 m^2) accommodates the wide range of diameter classes (20–60 cm dbh) to which potential sawlog retention may be applied. Generally, the retained basal area should be in the middle of the range but this will sometimes be impossible for the smallest diameter classes: for example 100 stems ha^{-1} with mean dbhob of 25 cm equates to a basal area of 5 m^2 ha^{-1}.

Progressive assessment during harvesting

When harvesting has been underway for about three or four weeks (allowing time for establishment of landings and major snig tracks and for an assessable area of forest to have been harvested), progressive harvesting assessment is commenced.

Sampling intensity for progressive harvesting assessment (PHA) is 1 plot per 2 ha on a rectangular grid layout (100 m x 200 m). This is the same spacing as used for the PLA, but no attempt is made to align the two surveys. Each plot is 100 m long by 10 m wide. Plots are continuous along strip lines 200 m apart (i.e. each plot follows on immediately after the previous plot). A minimum of 50% of the coupe must be sampled, at a rate of 1 plot per 2 ha.

On each plot a count of advance growth stems in a circular plot, 16 m^2, is undertaken every 20 m along the centreline. A basal area sweep (factor 2 wedge) is done at 0 m and 50 m. Each 'in' tree is visually assigned to a diameter class (0–20, 20–60, or >60 cm dbhob) and graded as either sawlog, pulpwood or cull. Every tree within 5 m of the centreline is visually assigned to a diameter class, graded as either sawlog or pulp only (culls are assessed only in the basal area sweep) and assessed for damage. The type of damage and its location on the tree is recorded. Each plot must be assigned to one of the four silvicultural systems: shelterwood retention, shelterwood removal, potential sawlog retention or advance growth retention. This allows the silvicultural systems to be identified by plot on the coupe map if required. Comparisons can then be made with pre-harvesting information. For example, where half the coupe is identified as shelterwood retention and half as advance growth retention, the average retained basal areas for the coupe should be 4.5 to 6 m^2 ha^{-1} and there should also be at least 250 stems ha^{-1} of advance growth.

It is suggested that the sampling be carried out once a fortnight, based on the following assumptions: that there is an average of at least 100 m^3 ha^{-1} of wood available for harvest, that the average daily harvest rate is 120–150 m^3, and that the contractor would therefore cover about 15 ha in a fortnight. In practice, the logging supervisor often conducts the sampling during weekly visits to the coupe, in which case areas that have been completed since the previous visit are sampled.

As for the PLA procedure, PHA is supported by a spreadsheet template which generates results from the field data. Results can be derived for both the day's sample and for the coupe as a whole. The spreadsheet calculates advance growth stocking (where present), basal areas (m^2 ha^{-1}) by diameter and product class, and damage to retained trees (as a percentage and also broken down into wound type to allow identification of the cause of the damage). The results of the assessment can then be compared with the harvesting prescription to assess the contractor's performance against the stated targets. Difficulties can be identified and addressed, importantly whilst the harvesting is still in progress.

Depending on the nature of the harvest, not all components of the PHA are required in all instances. For example, following complete shelterwood removal, there is only advance growth to count.

Economic appraisal

Two economic models of the UAT procedure have been developed (Stevens and Neyland 2000, unpublished), one for a shelterwood retention/shelterwood removal system and one for a potential sawlog retention system. Both models compare the costs and benefits of UAT monitoring with informal monitoring where the retained trees are largely of cull or pulpwood quality. Both models show that there is a small cost involved in UAT, in addition to the sampling and monitoring cost, which primarily derives from the UAT requirement that a proportion of the sawlog be retained on site. The discounted return from the future sale of that sawlog is less than the value of selling that sawlog now, so the returns under UAT are lower than under current procedures. No model was developed comparing partial harvesting with clearfelling followed by regeneration failure — clearly in such a case the partial harvesting would be superior.

Field experience suggests that the UAT procedure more than pays for itself because in most cases too much basal area had previously been retained. Identification and removal of trees that are surplus to requirements for retained basal area has been shown to more than cover the costs of the assessment in a number of recent coupes (M. Neyland and J. Cunningham unpublished data). With experience of the UAT procedure, some contractors deliver excellent results and in these cases the sampling intensity can be reduced, leading to a further reduction in costs. As supervisors have always visited each coupe on a regular basis, the PHA procedure is simply a method for formalising an inspection of the harvest area and recording the results of their monitoring. The cost of this monitoring has always existed, but the results are now documented.

An unexpected outcome of the introduction of this procedure has been the increased pride taken in the quality of the harvest by the harvesting crew. With measured results being graphically available at the time of sampling or shortly thereafter, the crews become very interested in the results. This feedback between the grower and the harvester is an essential part of the procedure and contributes to improved outcomes for the grower. The results from the PHA are stored on a coupe file and are reported annually by the Districts as part of Forestry Tasmania's quality standards process. This also allows the grower to look for continuous improvement in the quality of harvesting and regeneration operations over time.

Conclusions

Bauhus (2000) identified five criteria for good silvicultural practice in uneven-aged forests. The capacity of the UAT procedure to address these criteria is described below.

Use of natural processes for the regeneration and tending of stands. The seedbed in partially harvested coupes is prepared either through mechanical disturbance during harvesting or, where fuels are excessive and there is no advance growth to protect, by low-intensity fire. Regeneration arises from seed shed from the retained trees or from the heads of felled trees, and from pre-existing advance growth. The understorey is light enough to be of little impediment to regeneration. In partial harvests, browsing pressure is generally light and there is often no need for browsing control to be undertaken.

Protection of advance growth and growing stock during harvesting operations. In dry *E. delegatensis* forests advance growth can represent up to 30 y of growth — it is therefore very much in the forest grower's interest to ensure that this stock is protected. Whilst removal of mature stems will always involve damage to some of the advance growth present, the UAT procedure allows for monitoring and control of damage levels, ensuring that the stand is adequately stocked with undamaged stems at the completion of harvesting.

Maintaining the growth potential of cohorts across the range of diameter classes. Potential sawlogs, when present, are spaced appropriately to ensure maximum growth, and there are procedures for initiating and protecting seedling regeneration. Advance growth is protected wherever possible. The requirement that at least 80% of the retained stems in potential sawlog retention operations (50% in shelterwood retention) are of sawlog quality, wherever possible, ensures that the retained trees are growing into sawlogs, not only pulpwood. Maintaining the basal area of retained shelterwoods in the prescribed range balances the conflicting requirements of protection and growth of the establishing regeneration. Removing the shelterwood at the appropriate time ensures that growth of the regeneration is not significantly reduced through competition for moisture between the regeneration and the shelterwood.

Optimum allocation of growing space to the different cohorts. For all of the defined silvicultural systems, the prescribed basal areas or stocking targets are based on research which has established suitable targets for maximising growth whilst ensuring protection. Cull trees outside habitat clumps are removed to release competing stems. Sawlog-quality stems are retained as a priority to ensure the commercial viability of future harvests.

Maintenance of structural diversity. Partial harvests take place in a landscape which is a complex mosaic of reserved and production forests. Formal reserves, wildlife habitat strips and streamside reserves ensure that structural diversity is maintained at the landscape level. At the coupe level, cull and/or habitat trees are reserved within habitat clumps, and landscape features such as rocky outcrops and swamps are reserved from harvesting. Mapping of these features during the pre-logging assessment means that the grower and the harvester are aware of these values, and can protect them during the harvesting operation.

The UAT procedure is delivering good silviculture for a modest cost that is often met by productivity improvements. The procedure is readily adaptable to other forest types and product classes, subject only to there being sufficient visibility within the forest to allow the use of a basal area wedge. The interest shown in the quality of the harvesting by the forest grower results in the harvester being very aware of the grower’s desire for the best possible outcomes. Moreover, the harvesters develop great pride in their work as the results are clearly and easily demonstrable. With repeated assessments, continuous improvement in the quality of the harvesting is often apparent as the harvesting team learns exactly what is expected.

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