Safety and productivity at the Warra silvicultural systems trial

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Abstract

The Warra silvicultural systems trial was established to develop safe and practical alternatives to the clearfell, burn and sow system of harvesting and regenerating tall wet eucalypt forest, particularly for use in oldgrowth stands. Stripfelling and patchfelling by cable, aggregated retention, dispersed retention, clearfell burn and sow with understorey islands, single tree/small group selection and group selection were trialled. An assessment of the relative safety and productivity of each system is presented here.

The system that created the most conflict and that was claimed by the harvesting contractor to be difficult and non-productive was dispersed retention as practised in the first coupe, yet this proved at the end of the trial to have been among the more productive systems. The systems that were applied in the richest stand of timber, the stripfells and patchfell, were among the less productive systems, as an unusually high proportion of the contractor's time was spent moving the cable machine to harvest relatively small areas. Single tree/small group selection was the least productive system and was also the most hazardous, to the point where the system could not be recommended for routine application.

Of the systems tested, aggregated retention holds the most promise, from both a safety and a productivity perspective, of being a practical alternative to clearfelling. The safety hazard to workers undertaking aggregated retention harvests may not be significantly greater than for clearfells if the average distance between aggregates is at least about two tree lengths or 80 m, and the system had little impact on the contractor's productivity. Monitoring of the first two years of operational application of aggregated retention harvesting (20 coupes) has confirmed the results of this trial, and shown that aggregated retention can be applied safely and without a significant impact on productivity.

Introduction

The Warra silvicultural systems trial (Hickey *et al*. 2001) was established from 1998 to 2007 to develop alternative silvicultural systems to clearfell, burn and sow (CBS) that could successfully be applied to the tall wet eucalypt forests of Tasmania, without compromising worker safety. The trial was originally established to develop alternatives for use in areas where habitat, special species or aesthetic values have additional emphasis (Hickey *et al.* 2001). The Supplementary Tasmanian Regional Forest Agreement between the Commonwealth of Australia and the State of Tasmania (Commonwealth of Australia and State of Tasmania 2005) committed Tasmania, amongst other things, to achieving non-clearfelling silviculture in a minimum of 80 per cent of the annual harvest area of couped oldgrowth forest on State forests by 2010. This increased the urgency to extend the experimental alternatives being developed at the Warra silvicultural systems trial and extend them to operational coupes throughout the State.

The silviculture of Tasmanian eucalypt forests prior to the 1950s was characterised by selective harvesting without any planned regeneration treatment (Hickey and

Photo 1

Photo 2

Photo 3

Photo 4

Photo 5

Photo 6

Photo 7

Aerial images of the WARRA LTER Silvicultural Systems Trial.

Photo 1. Clearfell, burn and sow with understorey islands at WR8B.
Photo 2. Stripfells at WR1A.
Photo 3. Patchfell at WR1A.
Photo 4. Dispersed retention at WR1B.
Photo 5. Aggregated retention at WR1E.
Photo 6. Single-tree/small-group selection at WR5D.
Photo 7. Group selection at WR8G.

Photo 8

Photo 9

Photo 10

Photo 11

Photo 12

Photo 13

Photo 14

Ground-based images of the WARRA LTER Silvicultural Systems Trial.

Photo 8. Clearfell, burn and sow with understorey islands at WR8B.
Photo 9. Stripfell at WR1A (N).
Photo 10. Patchfell at WR1A.
Photo 11. Dispersed retention at WR1B.
Photo 12. Aggregated retention at WR8I.
Photo 13. Single-tree/small-group selection at WR5D.
Photo 14. Group selection at WR8G.

Wilkinson 1999). By the 1960s, extensive research in the wet eucalypt forests resulted in the systematic application of silvicultural regimes based on clearfelling, slash burning and regeneration from seed trees or artificial sowing (CBS). This regime was extended to most eucalypt forest types throughout the 1970s, with mixed results; consequently partial-felling techniques were developed and introduced in the 1980s for multi-aged high-altitude and dry forests with sparse understoreys (McCormick and Cunningham 1989). Clearfelling currently remains the predominant regime in lowland wet eucalypt forests with a dense understorey (Forestry Tasmania 1998).

The CBS system has been widely used because it is the safest method for forest workers (compared to the previously applied selective harvesting methods), gives the highest financial return to the forest grower, and the slash burning maximises seedbed and subsequent eucalypt growth whilst removing fuel that could otherwise pose a long-term fire risk (Forestry Tasmania 1998). The system has some parallels with wildfires – natural regeneration in tall wet eucalypt forests usually only occurs following an intense disturbance such as a wildfire (Attiwill 1994) – but wildfires typically leave more structures such as standing living and dead trees (Hickey *et al.* 1999; Lindenmayer *et al.* 2000).

The CBS system has received considerable public scrutiny for a range of environmental and aesthetic reasons, including a potential reduction in late-successional species (Hickey 1994) and structures (Lindenmayer and McCarthy 2002), and a potential decline in the special-species timber resource (slow-growing non-eucalypt species prized by craftworkers), when rotations of about 90 years (Whiteley 1999) are used. A key aim in developing the alternatives being trialled at Warra has been to address these concerns. Before any alternative to clearfelling can be applied more widely, a clear understanding of the safety and productivity implications of that alternative is essential.

Safety

Harvesting forests is a potentially high-risk occupation. In the period 1989–1992, the forestry and logging industry had the highest fatality rate of all industries in Australia (Mitchell *et al*. 2001). The injury incidence rate for logging is three times the rate for all Australian industry (Foley 1994) and nearly 20% of logging injuries are severe, that is, entail more than 60 working days lost time. In 2001 and 2002, the sector had the highest lost time injury frequency rate of any industry sector in Tasmania. A considerable effort has been made to reduce risks to acceptable levels for moral, legal and economic reasons. Even so, fatalities in the Tasmanian forestry sector currently occur at 2–3 per year (Resource Planning and Development Commission 2002). There were 45 deaths related to the forest industry over 16 years from 1984 to 1999. Falling trees and limbs caused the majority of deaths (58%) (Roger Geeves, pers. comm. 2006). Clearly the most hazardous operation in forestry is felling trees.

Tall oldgrowth forests pose greater risks to harvesting personnel than do regrowth forests because of their tree size and level of decay. For example, a 50 m tall oldgrowth eucalypt tree with a diameter of 150 cm weighs about 200 tonnes, whereas a regrowth tree of the same height but with a diameter of 60 cm weighs about four tonnes (Ximenes 2006). Internal butt rot makes directional felling difficult, and rot in the canopy can cause limbs (‘widow-makers’), particularly dead limbs, to break off if brushed by adjacent felled trees. Other factors that make tree-felling hazardous include damaged trunks, irregular tree root systems, leaning trees, thick undergrowth at the tree base, buttressing, unevenly balanced crowns, interlocking limbs, dead trees, dead or burnt out limbs, and trees with burnt-out sections (Tasmanian Forest Industries Training Board 2002). Typically, these features are much more common in oldgrowth forests than in regrowth forests.

Mechanised felling using excavator-mounted chainsaws or shears is now common practice in regrowth forests with trees up to 60 cm diameter. However, manual felling with chainsaws is required for oldgrowth trees because of their size. The understorey in most tall wet eucalypt forest is a dense, closed layer of shrubs up to about 15 m tall. This restricts movement and reduces visibility. In many current operations, excavators are used to flatten much of the understorey prior to felling. This improves visibility and access and reduces a number of potential safety hazards. Excavators are also used to support leaning and hazardous trees, and to partially control the felling direction of trees.

Productivity

The wet forests at Warra are dominated by *Eucalyptus obliqua*. Wet *E. obliqua* forest is the most widespread forest type in Tasmania (Public Land Use Commission 1996), and Neyland *et al*. (2000) have demonstrated that the wet forests at Warra are representative of this forest type across Tasmania. Thus it is reasonable to expect that the findings from studies at the Warra trial are applicable in similar forest elsewhere in the State.

The fire history of the Warra block is complex. There have been known fires through the block in 1898, 1914 and 1934, and historic fires are estimated to have occurred in 1670, 1740, 1790, 1840 (perhaps) and 1873 (Alcorn *et al*. 2001). Consequently, the stands have a variable structure, comprising oldgrowth veterans, which bear the evidence of repeated fires including butt scarring and internal decay, and cohorts of regrowth following the various fires.

The timber quality of the various stands within the trial area was variable. The expected production across the Warra trial was therefore expected to vary considerably.

Methods

The range of systems tested in the Warra silvicultural systems trial, and a brief rationale for each, are given in Table 1. Photos 1 to 7 provide an aerial image of each system and Photos 8 to 14 provide a ground-based image of each system. Photos 15 and 16 show the whole silvicultural trial before and after establishment. The treatments are now being assessed against a wide range of biodiversity, silvicultural, social and economic criteria.

Safety

The safety performance of the various harvesting regimes trialled in this study was assessed by documenting all safety incidents (defined as events where evasive action was required to avoid injury) and injuries, and by regular interviews with participating contractors. Formal records of accidents and incidents are maintained by the contractor as a requirement of the Workplace Health and Safety Act 1995.

Formal risk assessments were conducted prior to the commencement of each alternative treatment. These were undertaken by a Workplace Standards Authority Officer together with the harvesting crew and the silvicultural team. A review of the safety implications of each treatment was conducted by the same people at the completion of harvesting of each experimental coupe. Site meetings were also undertaken periodically during the course of harvesting, to address specific concerns raised by the harvesting crews. All the meetings were fully documented. Where trees were deemed too hazardous to fell, contractors sought approval to have them felled using explosives. Records were maintained of all trees felled in this manner.

Productivity

For each coupe within the trial, net productivity was calculated as the tonnes of wood produced per week per person.

Photo 15. Warra Silvicultural Systems Trial area before establishment.

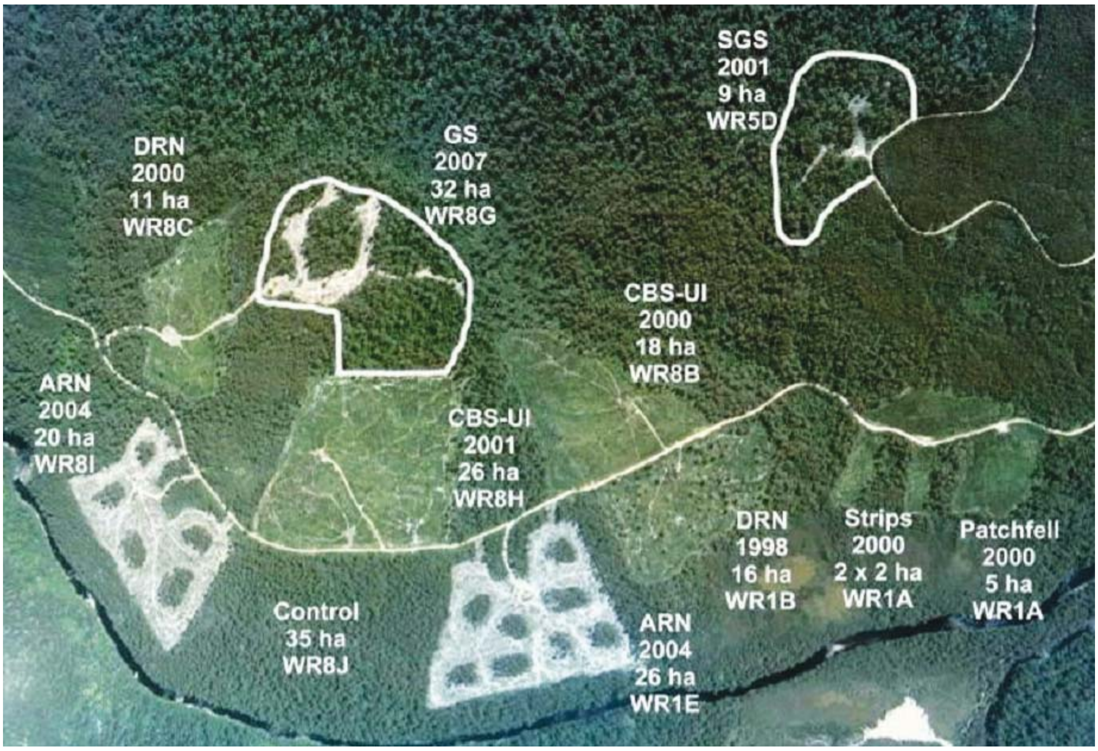

Photo 16. Warra Silvicultural Systems Trial at the completion of establishment

Table 1. Treatments at the Warra Silvicultural Systems Trial.

Treatment	Coupes (establishment dates)	Description	Objective
CBS with understorey islands (CBS-UI)	WR8B, WR8H (2000, 2001)	Up to 100-ha openings, 0% basal area retention, high-intensity burn, applied seed. Up to 5% of the coupe to be in dispersed 40 m x 20 m machinery-free areas.	Harvest eucalypt efficiently and safely, with good growth of eucalypt regeneration and enhanced local survival of understorey flora on the machinery-free areas.
Stripfell and patchfell (cable harvested)	WR1A, harvested in 3 sections (2000)	Two 250 m x 80 m strip openings and one 250 m x 250 m patch opening, low-intensity burn, natural seedfall.	Harvest eucalypt as safely as possible, with adequate growth of eucalypt regeneration and enhanced biodiversity by using strips of undisturbed forest retained for half the rotation for habitat and seed supply (all species). The patchfell was harvested to illustrate the distance limits of natural seedfall.
Dispersed retention (DRN)	WR1B, WR8C (1998, 2000)	About 10% basal area retention, low-intensity burn, natural seedfall.	Harvest eucalypt as safely as possible, with adequate growth of eucalypt regeneration and enhanced biodiversity by using individual eucalypt trees retained for a full rotation for fauna habitat and seed supply.
Aggregated retention (ARN)	WR8I, WR1E (2004, 2004)	About 30% (by area) of coupe retained in aggregates of 0.5 to 1.0 ha, with distance between aggregates at least twice tree height, low-intensity burn, natural seedfall.	Harvest eucalypt and special species as safely as possible, with adequate growth of eucalypt regeneration, enhanced biodiversity by using patches of undisturbed forest retained for a full rotation for habitat, seed supply (all species), and enhanced aesthetics.
Single-tree/ small-group selection (SGS)	WR5D (2001)	Retention of >75% forest cover, permanent snig tracks, harvest 40 m^3/ha^{-1} every 20 years, openings <1 tree height wide, heaping of slash, mechanical soil disturbance (no burning), natural seedfall.	Harvest mature trees as safely as possible, with adequate growth of eucalypt and special species regeneration and enhanced biodiversity while maintaining a continuous tall forest cover.
Group selection (GS)	WR8G (2007)	Retention of 70% forest cover, permanent snig tracks, harvest 30% of the canopy cover every 30 years using groups and strips, openings twice tree height wide, low-intensity burn, natural seedfall.	Harvest mature trees as safely as possible, with adequate growth of eucalypt and special species regeneration and enhanced biodiversity while maintaining a continuous tall forest cover.

Every timber harvesting operation is a little different. The size of the crew, the time taken to complete the coupe, the weather, the type of machinery being used, and the availability of transport all vary. Cable and ground-based operations have particular differences. In cable coupes, all the timber within the coupe is felled, then the fellers leave and a different crew moves in to drag the timber to a landing. In ground-based harvesting, the crew works to keep well ahead of the trucks, such that if harvesting ceases for some reason the trucks can continue to transport logs to the mills. At the end of harvesting, there is often a large pile of logs left at the landing, so one machine remains on-site until such time as all the logs have been removed – thus the crew commencing on another site is one machine short for a brief time. In calculating productivity figures, as many of these factors were taken into account as possible. Coupe diaries were consulted to allow a more accurate calculation of the actual number of man-hours worked. The total timber production from each coupe was extracted from Forestry Tasmania's sales system and cross-referenced against log dockets and other information gathered during the course of harvesting.

Correlation analysis was used to examine relationships between silvicultural system and net productivity, coupe area, production per hectare, and proportion of production that was sawn timber. To compare the silvicultural systems to the other variables, each system was assigned a value for the percentage of retention within that system. This was not always straightforward. In the dispersed retention coupes it was evident that 12% (WR1B) and 6% (WR8C) of the original standing forest had been retained (Neyland 2004). In the aggregated retention coupes the desired 30% retention was carefully managed for and achieved during the harvesting. In the stripfells, however, the entire strip was felled, but the productivity of the system was strongly influenced by the 50% of the potentially harvestable area that was retained as unharvested sections between the strips; it was this retention that required the harvesting contractor to invest significant resources of time and effort to redeploy the harvesting machinery into the subsequent strip. For the strips, the retention was therefore deemed to be 50%. In the single tree/small group selection coupe, only 1.6 ha of a nominal 10 ha coupe was harvested, so retention was deemed to be 84%, and similarly in the group selection coupe only 4.5 ha of a nominal 30 ha coupe was harvested so retention was deemed to be 85%. The patchfell was deemed to have retained nothing, and for each section of the clearfell burn and sow with understorey islands coupes the actual area retained within each section was determined.

Results

Safety

The only lost-time accidents in the trial occurred in the patchfell, one of the three areas to be harvested by cable, when one of the chokermen received a minor injury, resulting in three days off work, and in the stripfell, where a minor slip resulted in less than one day of lost time (Table 2). There were a number of incidents, nearly all of which involved oldgrowth trees collapsing or uprooting during the course of felling (Table 2). Typically, these heavily decayed trees fell or uprooted after the front cut had been completed but before or during the back cut. None of these incidents resulted in injury to the faller. There were insufficient coupes, incidents and accidents to allow determination of statistically significant trends from these data.

The frequency at which trees were required to be felled with explosives (blown trees) provided a basic measure of the contractor's safety concerns with a particular silvicultural system. The single tree/small group selection treatment required the highest number of blown trees per hectare (Table 2), while the lowest (nil) was in

Table 2. Lost-time accidents, incidents, blown trees and other issues during harvesting.

Coupe	Lost-time accidents	Incidents	Trees felled with explosive	Notes and recommendations
WR8B (CBS-UI)	0	1 oldgrowth tree collapsed after the front cut was completed.	4 (0.2 ha^{-1})	One of the trees felled using explosives was perched above one of the understorey islands.
WR8H (CBS-UI) (north)	0	4 oldgrowth trees uprooted during felling.	63 (5.0 ha^{-1})	One stop-work meeting about the high number of hazardous trees. Fire-damaged oldgrowth trees with unsound bases increased risk compared to regrowth.
WR8H (CBS-UI) (south)	0	None reported.	None.	
WR1A (Patchfell)	1	Worker struck by moving spar. 3 oldgrowth trees collapsed or uprooted as the back cut was commenced.	1 (0.1 ha^{-1})	
WR1A (Stripfells)	1	1 slip.	None.	Wider strips (>2 tree heights) would be safer. Strips should be flared at landings to avoid retained trees falling on guy wires.
WR1B (DRN)	0	5 trees windthrown during the course of harvesting, resulting in near misses for forest workers. 3 oldgrowth trees collapsed as the back cut was commenced.	12 (0.8 ha^{-1})	Three stop-work meetings. Flexibility in selecting retained trees reduces risk for the fellers. Regrowth trees preferred by the fellers for retention. Retention of aggregates preferable to retaining dispersed trees.
WR8C (DRN)	0	None reported.	21 (2.4 ha^{-1})	High number of cull (non-commercial) trees. Cull felling rate negotiated for felling culls.
WR8I (ARN)	0	None reported.	None.	
WR1E (ARN)	0	None reported.	2 (0.1 ha^{-1})	
WR5D (SGS)	0	None reported.	14 (8.2 ha^{-1})	Site dangerous after completion of harvesting due to broken branches caught in the canopy. Site access restricted for six months until declared safe.
WR8G (GS)	0	None reported.	None.	

the aggregated retention treatment. This occurred partly because hazardous trees, which were often ideal for retention from a wildlife perspective, could be included in retained aggregates (although not near the edges of the retained aggregates, from where they could still present a hazard), and partly because of variation in the quality of the standing forest. The second clearfell coupe with understorey islands (WR8H) had a higher than usual number of trees felled by explosives, partly because of a patch of severely fire-damaged oldgrowth trees, and partly because of the differing perceptions of forest quality by different contractors.

The contractor who completed the northern section of WR8H argued that the southern section of the coupe was too poor and too hazardous to harvest. Production data confirmed that the quality of wood in that part of the coupe was poorer than observed in other coupes (Table 3). Only 7% of the volume produced from the southern section was of sawlog quality compared to 25% in the northern section. In the northern section of the coupe (the better part) the contractor required 63 trees to be felled using explosives. This first contractor then quit the coupe and a second contractor was brought in to complete the poorer southern section of the coupe. He had no issues with the harvesting, and required no trees to be felled using explosives. Thus the two contractors, with different experience, and different expectations, had very different views of the safety implications of working in this forest.

The single tree/small group selection coupe (WR5D) was the only coupe to be declared unsafe at the completion of harvesting (May 2001). Many branches and small limbs were lodged in the canopy after the felling (by explosives) of a small number of very large eucalypts. The site was closed for about six months to allow the equinoctial gales to dislodge this material. The site was inspected in the following summer, checked for any undislodged material, and declared safe. By contrast, no safety issues were raised in the group selection coupe (WR8G). The prescribed minimum width of openings in the coupe, the equivalent of two tree heights, removed the need for felling with explosives as used in WR5D, as trees could always be felled into openings. The harvesting crew had no concerns with the system.

The first dispersed retention treatment (WR1B) caused the most safety concerns, with the crew having to work under retained trees for prolonged periods, amidst dense understoreys and heavy slash loads. Retained oldgrowth trees were of particular concern. Stop-work meetings were held to discuss productivity and safety issues at 8, 10 and 11 weeks into the 12-week harvesting period. The final stop-work meeting agreed that oldgrowth trees marked for retention, yet determined to pose an unacceptable safety risk, could be felled and substituted with an adjacent regrowth tree. This practice was also followed at the second dispersed retention coupe (WR8C).

Surprisingly, the dispersed retention coupes achieved a higher production rate (Table 3) than clearfelled coupes harvested by the same crew. This suggests that the crew was under some pressure in WR1B to achieve a high production rate and that some of the safety concerns could have been resolved by using an hourly hire arrangement rather than a piece rate (Table 3) to allow more time for developing safe systems of work. In contrast, the aggregated retention treatments (WR8I and WR1E, paid at an hourly rate) raised no significant safety issues other than to observe that the frequency of harvesting near retained forest edges required skilled directional felling. The contractors compared working around the retained aggregates to working alongside streamside reserves, or to the work required to fell trees safely when clearing roadlines. In both situations, trees must be felled directionally into clearings that are narrower than those in a clearfell.

No particular safety concerns were raised within the two coupes harvested by clearfell burn and sow with understorey islands. The contractors could elect to fell eucalypts out of the islands if that could be done without causing significant damage to the understorey, or could retain the eucalypts if they wished, and further could elect to retain eucalypts that if felled were likely to significantly damage the islands. The contractor again

Table 3. Production summary, Warra Silvicultural Systems Trial, all coupes.

Coupe	WR8B	WR8H-north	WR8H-south	WR1A-F	WR1A-N	WR1A-L	WR1B	WR8C	WR8I	WR1E	WR5D	WR8G	Mean
Silvicultural system	CBS-UI	CBS-UI	CBS-UI	Patch	Strip	Strip	DRN	DRN	ARN	ARN	SGS	GS	
Retention (%)	1.8	1.3	1.1	0	50	50	12	6	30	30	16	85	
Contractor	A	A	B	C	C	C	A	A	D	D	E	E	
Contract	Piece	Piece	Piece	Piece	Piece	Piece	Piece	Piece	Hour	Hour	Hour	Piece	
Harvesting	Ground	Ground	Ground	Cable	Cable	Cable	Ground	Ground	Ground	Ground	Ground	Ground	
Felled area (ha)	17.7	12.0	14.0	5.2	1.8	2.2	15.7	11.1	13.2	18.3	1.6	4.5	
Pulpwood (t ha^{-1})	266	283	319	282	396	353	407	210	268	267	228	328	294
Sawlog[1] (t ha^{-1})	94	94	23	241	206	187	74	62	54	69	47	174	84
Total production (t ha^{-1})	360	377	342	523	602	540	481	272	322	336	275	502	378
Total production for coupe (t)	6363	4518	4789	2719	1083	1188	7547	3015	4249	6154	440	2258	
Sawlog[1] as % of total production	26	25	7	46	34	35	15	23	17	21	17	35	25
Crew size	4	4	4	6	6	6	4	4	3	3	2	4	
Weeks for harvest	13.4	7.4	8.6	3.8	1.5	1.5	11.4	5.2	10.3	13.9	3.0	3.8	
ha $week^{-1}$	1.3	1.6	1.6	1.4	1.2	1.4	1.4	2.1	1.3	1.3	0.5	1.2	1.4
t $week^{-1}$ $person^{-1}$	119	153	139	119	120	132	166	145	138	148	73	149	127

[1] Sawlog includes all categories of sawlog and veneer log .

remarked that harvesting around the understorey islands was no different to working alongside a streamside reserve. Whilst there were no practical issues with understorey islands, their small size made them very difficult to protect during the regeneration burn, and seven out of the eight islands were burnt to varying degrees (Neyland 2005).

Productivity

Production data is shown in Table 3, and summarised in Table 4. The only moderately strong correlations amongst the productivity data were between coupe area and percentage of the coupe retained (correlation coefficient of –0.6583, P = 0.0199), and between the production per hectare and the percentage of sawlog (correlation coefficient of 0.6876, P = 0.0135). In the former case, larger coupes had only a small percentage of the coupe area retained and the smaller coupes had a large percentage of the coupe area retained. In the latter case, the coupes that produced the highest volume of wood per hectare (WR1A in three sections) also produced the highest percentage of sawlog.

The slowest production rates (Tables 3 and 4) occurred in the single tree/small group selection treatment, which was considered to be the most hazardous of the treatments due to the presence of overhanging tree crowns and restricted work areas. Production rates in the various ground-based coupes ranged from 119 tonnes per week per person in the clearfell coupes to 166 tonnes per week per person in the dispersed retention coupes. One would expect that working in retention coupes would reduce productivity due to the difficulties of working around retained trees, and that consequently production rates in such coupes would be lower, but the lower production in the clearfell coupes demonstrates that production quotas and stand quality had more impact on production rates in this trial than did the silvicultural system per se.

Table 4. Average production rates by silvicultural system.

	Production rate (t week^{-1} person^{-1})
Clearfell burn and sow, understorey islands	136
Patchfell	119
Stripfells	126
Dispersed retention	155
Aggregated retention	143
Small-group/single-tree selection	73
Group selection	149

In the group selection coupe (WR8G), only a dirt spur rather than a road was built into the coupe, which left the contractor with an unusually long snigging distance. The longest pull in the coupe was nearly 900 m compared to the other coupes in the trial where the longest pull was about 450 m. The long snigging distance could reasonably have been expected to reduce productivity in this coupe, but again this disadvantage has been outweighed by the quality of the forest, which was well above average for the trial.

Discussion

Safety

Selective logging in tall oldgrowth forests, as undertaken in the small group/single tree selection coupes, presents the greatest safety risk of the tested alternatives to clearfelling due to the size of the trees, the dense understoreys and poor visibility. Directional felling requirements and very limited machinery manoeuvrability made harvesting slow and hazardous. Group selection using gap sizes of 0.5 ha (80 m in diameter) may be appropriate if extreme care is taken. However, the commencement of harvesting of each gap requires the initial felling to be done under very restricted and difficult working conditions. Single tree/

small group selection using gap sizes less than a tree length in diameter (e.g. 40 m diameter or 0.13 ha gap area) cannot be recommended for tall oldgrowth forests in Tasmania under normal operating conditions. Studies in similar silvicultural trials in Victoria (Mitchell 1993; Bloch and Murphy 1994) noted that the occurrence of overhead hazards in small gap and dispersed retention systems was very high and that such systems could not be recommended for wider application.

Dispersed retention in tall oldgrowth forests presents a greater safety risk than aggregated retention due to the need for careful manoeuvring of machines, directional felling of trees and the amount of time required working under retained trees. Directional felling is potentially difficult, and often not possible with larger oldgrowth trees. It also leads to elevated safety hazards if the spacing of retained trees is less than one tree length. For example, a 20% dispersed retention treatment would typically require the retention of up to 15 oldgrowth (> 100 cm diameter) trees per hectare at an approximate spacing of 25–30 m between trees. If the trees are 50 m tall, then hazardous collisions between felled and retained trees are inevitable. Dispersed retention is thus not generally suitable, from a safety perspective, for tall oldgrowth forests and is better suited to shorter forests with sparse understoreys. It can also be applied in regrowth wet forests where tree sizes are much smaller and most of the harvesting is done mechanically.

Flexibility in operations seems to be important to harvesting contractors. In the dispersed retention coupes, the contractors were concerned about working beneath retained trees, but were more comfortable when given the authority to replace a tree marked for retention with another tree. In the coupes harvested by clearfell, burn and sow with understorey islands, the contractors had free choice about retention or removal of trees in and immediately around the understorey islands, and they expressed no concerns about this system. In the aggregated retention coupes, the contractors made the decision about the actual locations of aggregates based on a sketch map of the coupe showing indicative locations, and again the contractors had no issue with the system. It is clear from industry data that the most hazardous component of the business is tree felling, so giving the harvesting contractor responsibility for the decision about which trees to retain and which trees to fell provided some reassurance about their ability to deliver a safe working environment for their employees.

Productivity

As noted above, the timber quality of the different stands within the trial area was variable, mainly due to the effects of wildfires of varying intensity over the past 400 years. Previously unharvested eucalypt-dominated forests in Australia generally produce significantly more pulpwood than sawlog. In recent years sawlog volumes have been about 20% of the annual cut (Forestry Tasmania 2005), but this figure varies from coupe to coupe and from stand to stand. As this trial progressed, the acceptable minimum standard for pulpwood at the mill gate varied, which at times resulted in excessive amounts of wood being rejected at the landing. Harvesting quotas for the supply of pulpwood to the mill also varied, and at times of reduced quotas crews worked more slowly than at times when full quotas were in force. The variation in stand timber quality was of more significance in determining final production rates than was the silvicultural system. Production rates were comparable for all the systems except single tree/small group selection, in which production rates were very low due to the inherent dangers of the system.

Strip-felling by cable may have an application on steep coupes. Whilst strip-felling was possible practically, and presented no particular safety issues, the lower production rate, increased down-time required to move the cable machine from strip to strip, increased number of regeneration burns required to treat the harvested areas, and lower rate of production per kilometre of road constructed, are all issues limiting from a commercial perspective and need to be addressed before strip-felling can be more broadly applied.

Conclusions

Of the systems tested at Warra, aggregated retention appears to hold the most promise as a viable alternative to clearfelling in terms of maintaining safety and productivity at acceptable levels. Since the establishment of the Warra trial, 20 operational aggregated retention coupes have been established throughout Tasmania, and a formal safety review of these coupes has been completed (Howard 2008). Howard found that there were no particular hazards associated with aggregated retention harvesting that were peculiar to that system. Such hazards as existed were those that were always associated with timber harvesting. Howard did note that the increased perimeter to area ratio in aggregated retention coupes potentially led to an increase in risk due to the increased exposure of workers to edges. He also noted that this could best be managed by planning coupes with fewer larger aggregates, and by not locating aggregates on steep slopes such that it becomes necessary to directionally fell trees on the slope immediately above the aggregate. These recommendations also assist in designing coupes for regeneration burning, and have already been incorporated into planning of future coupes.

From the harvesting contractor's perspective, there is no difference in productivity between clearfelling and aggregated retention. From the forest grower's perspective, there is a difference because the 30% of the coupe retained as unharvested aggregates is 30% of the potential production from that coupe that is foregone.

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