Effect of silvicultural system on vascular flora in a wet sclerophyll forest in south-eastern Tasmania

M. Wapstra[1,2], F. Duncan[1], K. Williams[3,4] and D. Walsh[3]

[1]Forest Practices Board, 30 Patrick Street, Hobart, Tasmania 7000, Australia
[2]Email mark.wapstra@fpb.tas.gov.au
[3]Forestry Tasmania (formerly Forestry Commission)
[4]Current address: Environmental Protection Agency, 160 Ann Street, Brisbane, Queensland 4002, Australia

Revised manuscript received 28 January 2003

Summary

Floristic composition in wet sclerophyll forest in south-eastern Tasmania was examined prior to logging and 6 y after logging under a range of native forest silvicultural systems (clearfell with and without regeneration burning, group selection with and without regeneration burning, partial logging). For all silvicultural treatments, the floristic composition of logged sites differed significantly from that of unlogged sites. There was an overall increase in richness of vascular species following harvesting, regardless of silvicultural treatment. However, different life form groups varied considerably in their response. Richness of epiphytic ferns and abundance of trunked ferns (*Dicksonia antarctica*) decreased following harvesting, while the richness of herbaceous species, low shrub species and graminoids increased. Native pioneer species were abundant following harvesting and account for most of the difference in composition between logged and unlogged areas. We suggest that most native vascular species in lowland wet sclerophyll forests will either survive typical native forest silvicultural practices or recolonise harvested areas if suitable sources of propagules are available. Groups requiring particular microenvironments, such as the moisture-sensitive epiphytic ferns, may be most vulnerable to disturbance from timber harvesting and may benefit from modified silvicultural practices that retain patches of forest with suitable substrates.

Keywords: flora; botanical composition; plant ecology; forest management; silvicultural systems; clear felling; logging effects; sclerophyllous forests; Tasmania

Introduction

Extensive areas of lowland Tasmania support wet sclerophyll forests dominated by eucalypts (mainly *Eucalyptus regnans* and *E. obliqua*) with an understorey of broad-leaved shrubs. Within areas designated as production forests, this forest type is a focus for intensive logging (mainly clearfelling) due to the large volumes of timber and the suitability of the sites for successful regeneration of native species or establishment of plantations.

Hickey and Wilkinson (1999) note that silvicultural practices in Tasmanian native forests have been refined through substantial research but that much remains to be learnt about the long-term effects of these practices on productivity and biodiversity. Neyland *et al*. (1999) addressed the effects of different silvicultural systems on productivity in a wet sclerophyll forest in south-eastern Tasmania. The present paper describes the effects of these systems on floristic composition at the same site.

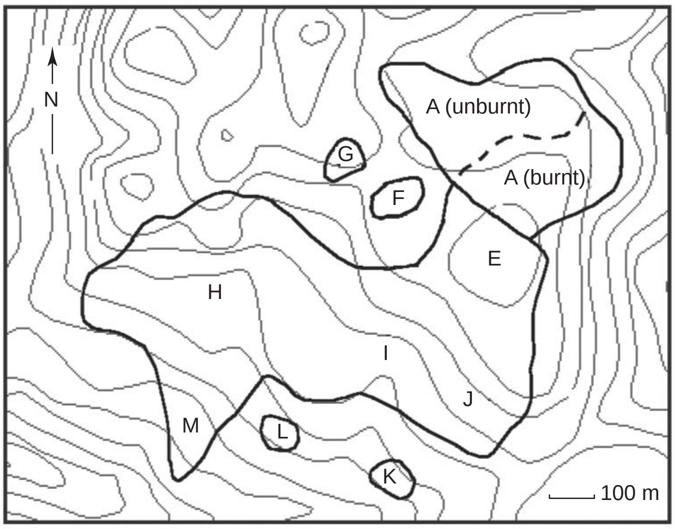
The effect of silvicultural systems on vascular flora has been studied in Tasmania and elsewhere in Australia in both dry forest types (e.g. Loyn *et al*. 1983; Dickinson and Kirkpatrick 1987; Kellas *et al*. 1988; Stewart 1996; Burrows *et al*. 2002) and wetter forest types including mixed forest or rainforest (e.g. King and Chapman 1983; Hickey 1994; Chesterfield 1996) and wet sclerophyll forest (e.g. Cremer and Mount 1965; Murphy and Ough 1997; Ough 2001). In wetter forests, there is a clear pattern of change as the forest ages, with initial rapid colonisation by opportunistic bryophytes and herbs being followed by dense growth of ferns, herbs, graminoids and woody soft-leaved shrubs within a few years. Most studies of wet forest floristic changes following logging have focused on only one silvicultural system (mostly clearfelling) or have used spatially separated sites to examine the effects of different silvicultural systems on similar forest types. The present study aimed to examine the broad effects of concurrent silvicultural systems on the vascular flora in contiguous areas of forest.

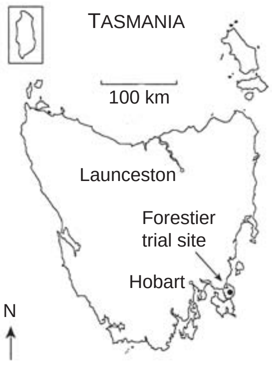
Methods

Study site

The study site (Fig. 1) was located on State forest on the Forestier Peninsula, south-eastern Tasmania (1:25 000 Tasmap 5624 'Murdunna' about 573500E 5244500N). Most of the site comprised a gentle slope with a south-easterly to south-westerly aspect, but part of the area was flatter with a more northerly aspect. The rock type is Jurassic dolerite. Altitude is 150–260 m asl. Rainfall of the area is about 900 mm y^{-1} and the site lies within the humid warm/moist subhumid warm climatic zones (Gentilli 1972). Further details of the site are provided in Neyland *et al.* (1999).

Prior to logging, the vegetation comprised mainly even-aged forest dominated by 60–80-y-old *E. regnans* with *E. obliqua* co-dominant





	Number of plots per treatment		
	Pre	Post	Control
Clearfell			
A	14	11 (5 burnt 6 unburnt)	5
Group selection			
F (burnt)	5	4	2
G (unburnt	5	5	4
K (burnt)	9	5	3
L (unburnt)	7	4	4
Partial logging			
E (25–50%)	7	6	0
H (25–50%)	13	10	3
I (25–50%)	8	9	0
J (25–50%)	20	5	11
M (50%)	17	8	4

Figure 1. Location of the Forestier study site in south-eastern Tasmania, and the layout of the site showing silvicultural treatments. The table shows the number of pre- and post-logging (and 'control') plots recorded in each silvicultural treatment area.

or subdominant. *Eucalyptus globulus* and *E. viminalis* were locally dominant or present as minor species. The forest was 27–44 m tall and its potential height at maturity (41–55 m) indicated high site quality (Neyland *et al*. 1999). The dense understorey was dominated by small trees and broad-leaved shrubs including *Acacia melanoxylon*, *Pomaderris apetala*, *Olearia argophylla*, *Beyeria viscosa* and *Bedfordia salicina*. Trunked and ground ferns such as *Dicksonia antarctica*, *Hypolepis rugosula* and *Polystichum proliferum* were abundant. The rainforest tree *Atherosperma moschatum* and associated hygrophilous ferns were present within sheltered gullies throughout the study area. Drier sites adjacent to the study area were characterised by a hard-leaved dry sclerophyll understorey.

Forest in the study area prior to logging could be ascribed to these communities (based on Kirkpatrick *et al*. 1988): *E. regnans*/*E. obliqua – Pomaderris apetala – O. argophylla* wet sclerophyll forest (widespread over most of the study area); *E. regnans – A. moschatum – Acacia dealbata – O. argophylla* wet sclerophyll/mixed forest (largely restricted to sheltered gullies and slopes); *E. obliqua – A. dealbata – O. argophylla* wet sclerophyll forest (less widespread throughout the study area); and *E. globulus – B. salicina – B. viscosa* wet sclerophyll forest (localised occurrences within the study area).

The area had been selectively logged early in the 1900s for sawlogs, and wildfires occurred between 1900 and 1920 (Neyland *et al*. 1999). Recent harvesting commenced in December 1987 using ground-based machinery and was completed in January 1989. Silvicultural systems ranged from clearfelling to partial logging. Silvicultural and regeneration techniques are described in Neyland *et al*. (1999), and are summarised below. Locations of treatment areas are shown in Figure 1.

Clearfell (Area A)

The standard clearfell technique applied to wet forests in Tasmania was used. About half the treatment area was burnt with a high-intensity regeneration burn in March–April 1989. The burnt and unburnt areas were sown in late April 1989 with eucalypt seed mixtures (at 0.6 kg ha^{-1}).

Group selection (Areas F, G, L and K)

Complete felling was used to create gaps, 100 m in diameter, within each of the paired areas (F/G and L/K). One of each pair (F and K) was burnt in March–April 1989. All areas were sown in late April 1989 with eucalypt seed mixtures.

Partial logging (Areas E, H, I, J and M)

About 50% of stems were retained in treatments E, J and H, and about 25% in treatments M and I. Harvesting was followed by top disposal burning and sowing. Neyland *et al*. (1999) analysed area M separately, considering it to be significantly drier than the rest of the area treated by partial logging. However, we have combined all areas treated by partial logging as there was significant local variation within all treatments, and we consider that parts of treatment H were also relatively dry.

Neyland *et al*. (1999) reported that eucalypts successfully regenerated only in areas that were clearfelled, burnt and sown. Stocking was adequate in the partially-logged areas shortly after sowing, but subsequently declined and the result was poor by age 5 y. They considered that intense browsing by native animals was responsible for failure of the regeneration in areas not subject to a clearfell, burn and sow treatment.

Sampling strategy

Floristic surveys were conducted prior to logging in 1987, and after logging in 1995/1996. Temporary plots were located in each treatment area prior to logging using a stratified random approach. Post-logging plots (referred to as 'logged' plots) were placed in the same general area as the pre-treatment plots (referred to as 'unlogged' plots), avoiding severely disturbed sites such as landings and roadside banks. At the time of the post-logging sampling, a number of plots were also placed in seemingly undisturbed forest close to each treatment area to act as 'controls' for future monitoring that might occur at the site. These 'control' plots were not used in the analyses. The number of plots in each treatment area is shown in Figure 1. Plots for the clearfell treatment

(Area A) were 5 m x 5 m. Plots for all other treatments were 20 m x 20 m. This difference in plot size between some treatment areas is because of differences in the initial sampling strategy for the study. In both pre-logging and post-logging sampling, all vascular species within the plot were recorded and their projected canopy cover was scored using a Braun–Blanquet scale (Mueller-Dombois and Ellenberg 1974). Species nomenclature follows that of Buchanan (1999).

Analysis

Patterns of change in species composition following the different silvicultural treatments were examined using semi-strong hybrid multidimensional scaling and flexible unpaired group mean averaging (flexible UPGMA) classification techniques in the pattern analysis software package PATN (Belbin 1995). Some species were grouped or excluded for analysis. Orchids were excluded as their occurrence is strongly dependent on season. All grasses (represented by species of *Deyeuxia*, *Ehrharta* and *Agrostis*) were grouped into a super-category called 'grass species' in the analyses as identification to species or genus level was not consistent because of the absence of diagnostic features over some of the sampling period. Abundance scores were transformed to presence–absence data because several different recorders were involved in the sampling. Other studies in Tasmania (e.g. Duncan and Brown 1995) have concluded that analyses based on presence–absence data reveal trends similar to those found using abundance scores.

Three sub-sets of data were chosen for analysis: (1) large clearfell treatment (A); (2) group selection treatments (F, G, K, L); and (3) partially logged treatments (E, H, I, J, M). For each analysis, samples were ordinated and classified using the default values in the SSH and FUSE routines, respectively, in PATN. Similarity matrices were computed using the Bray–Curtis (Czekanowski) coefficient. Within each sub-set of data, plots were assigned to *a priori* groups (logged or unlogged) to examine differences in the floristic patterns using the ANOSIM algorithm in PATN.

Species richness before and after logging within each treatment was compared using *t*-tests. Each species was also assigned to a life-form group: tree, tall shrub (typically more than 2 m in height in the study area), low shrub (typically less than 2 m in height in the study area), herb (including non-sclerophyllous graminoids), graminoid (sclerophyllous graminoids), grass, climber, ground fern, trunked fern (represented by *Dicksonia antarctica*) and epiphytic fern. For each treatment, *t*-tests were used to compare the mean number of species within life-form groups before and after harvesting. No *t*-test was performed on three groups with very low species richness (grass, climber and trunked ferns).

The response of individual species was assessed by comparing the frequency of occurrence of the species before and after logging. Frequency of occurrence comprised the proportion of plots containing the species within each treatment area.

Results

Floristic patterns

The ordination for the large clearfelled treatment (Fig. 2) shows some separation of logged and unlogged plots, especially in the plot of axes 2 and 3. There is a slight separation of burnt and unburnt logged plots within the ordination space for the treatment. The ANOSIM test shows that the differences in floristic composition between logged and unlogged plots is highly significant ($P < 0.001$). The dendrogram of the clustering of plots (Fig. 3) also indicates a clear separation of logged and unlogged plots. In both the ordination and the dendrogram, one logged plot is clearly grouped with the unlogged plots. Although located within the clearfelled area, this plot was closer to the coupe boundary than most other plots, and it was the only logged plot in which *Dicksonia antarctica* was recorded.

Logged and unlogged plots from the group selection treatment separate within the ordination space quite clearly (Fig. 4). Plots from Areas F and G and from Areas L and K group together within

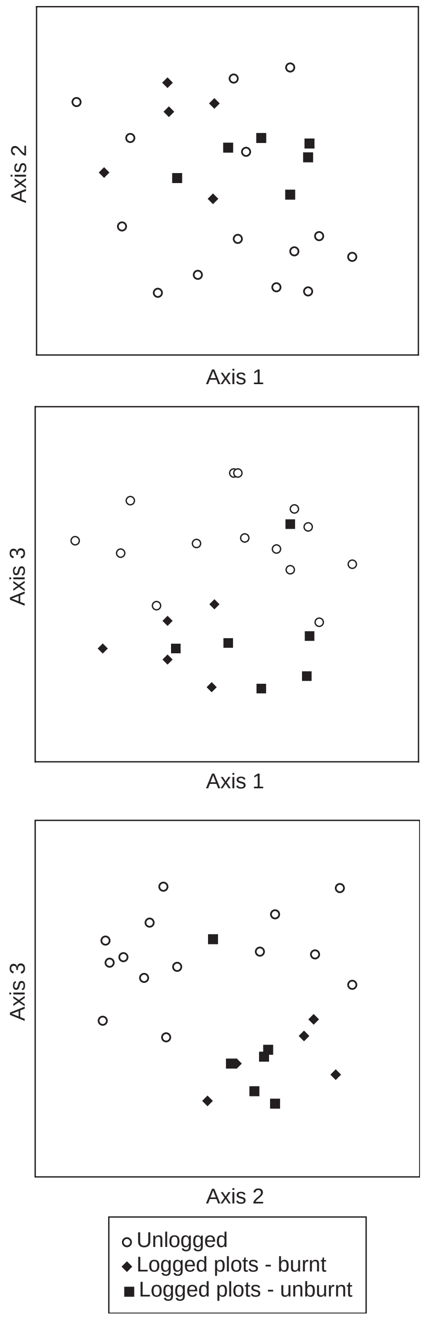


Figure 2. Ordination of plots for clearfell treatment (stress = 0.148)

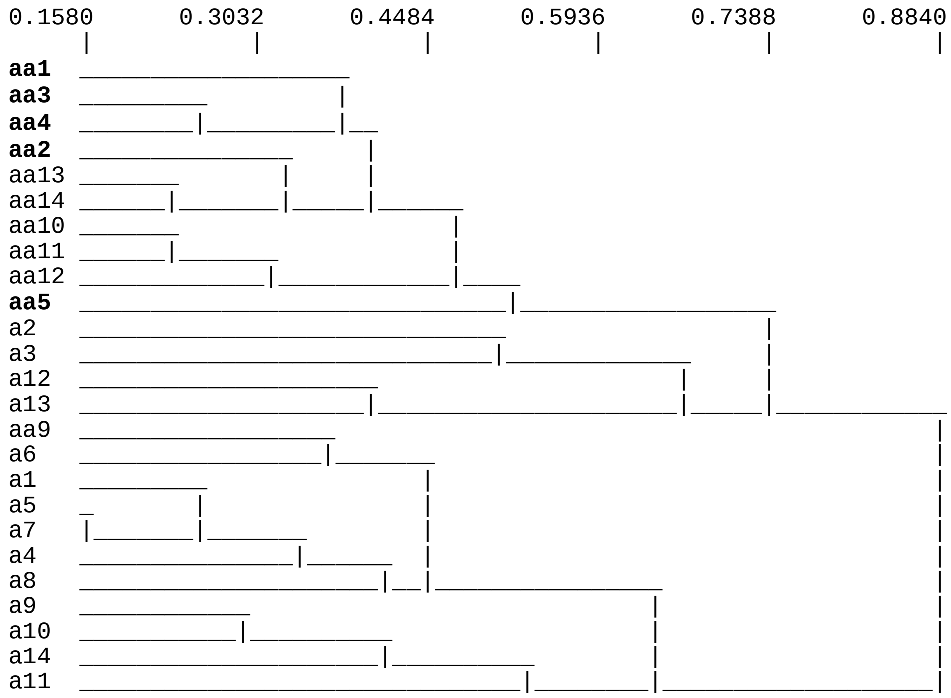


Figure 3. Dendrogram of the UPGMA clustering of plots from the clearfell treatment. Plot numbers are shown down the left-hand side (single letter = unlogged plot; double letter = logged plot; bold type = burnt plot) and the dissimilarity is displayed on the top edge of the dendrogram.

the ordination space. Areas F and G were located close to each other but about 500 m from Areas L and K, which were also located close to each other. Logged plots from Areas F (burnt) and G (unburnt) separate slightly (but not distinctly) in the ordination space. A similar pattern is displayed by post-logging plots from Areas K (burnt) and L (unburnt). The ANOSIM test shows that the differences in floristic composition between logged and unlogged plots is highly significant ($P < 0.001$). The classification using UPGMA shows a very similar separation of logged and unlogged plots, and of plots within individual treatment areas (Fig. 5).

Logged and unlogged plots from the partially logged treatment separate in the ordination space (Fig. 6). The ANOSIM test shows that the differences in floristic composition between logged and unlogged plots is highly significant ($P < 0.001$). The classification using UPGMA shows a very similar separation of logged and unlogged plots (Fig. 7). It should be noted that the dendrogram shows plots from different treatments within the broad partial logging treatment area, and that there is some separation of treatment areas both within the main logged and unlogged grouping. While the individual treatment areas were contiguous (see Fig. 1), there were clearly some site differences that are shown in the dendrogram. Areas H and M were more exposed and supported drier forest than the more sheltered aspects of the other treatments.

Species richness

There was a general trend for species richness to increase in logged areas (Fig. 8). Species richness increased significantly after logging in all treatments. Within the group selection treatment, species richness increased by about 36% (*t*-test: $t = 4.464$, df = 42, $P < 0.0001$), and within the partially logged treatment by about 52% (*t*-test: $t = 9.815$, df = 101, $P < 0.0001$) and within the clearfell treatment by about 33% (*t*-test: $t = 2.316$, df = 23, $P < 0.05$). There was no significant difference (*t*-test: $t = -1.925$, df = 9, $P > 0.05$) in species richness between burnt and unburnt areas of the clearfell treatment (Area A).

Logging resulted in changes in species richness within selected life-form categories (Fig. 9). There was a significant decrease in epiphytic fern richness following all logging treatments. Ground fern species richness changed significantly only within the partial logging treatment, with an increase in richness following logging. Species richness of the low shrub layer increased significantly for all treatments. Species richness decreased significantly only in the partial logging treatment. Herbaceous and graminoid species increased significantly in the group selection and partial logging treatments but not in the clearfell treatment. This may be due in part to the smaller plot size in the Area A clearfelled treatment compared to the plot size in the group selection and partial logging treatments, i.e. there was less chance of infrequent species being recorded in the smaller sample area.

Individual species

Individual species responded differently to silvicultural treatments. Table 1 lists species which either appeared or disappeared or showed a marked increase or decrease (greater than 10% change) in frequency of occurrence in plots. In this table, the two main eucalypt species (*E. regnans* and *E. obliqua*) that comprised 95%

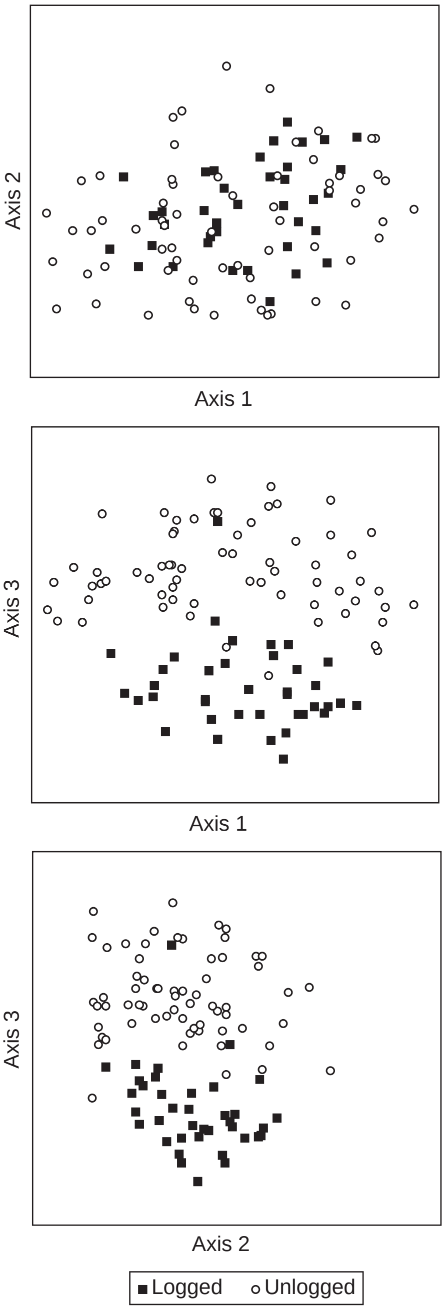


Figure 4. Ordination of plots for group selection treatment (stress = 0.152)

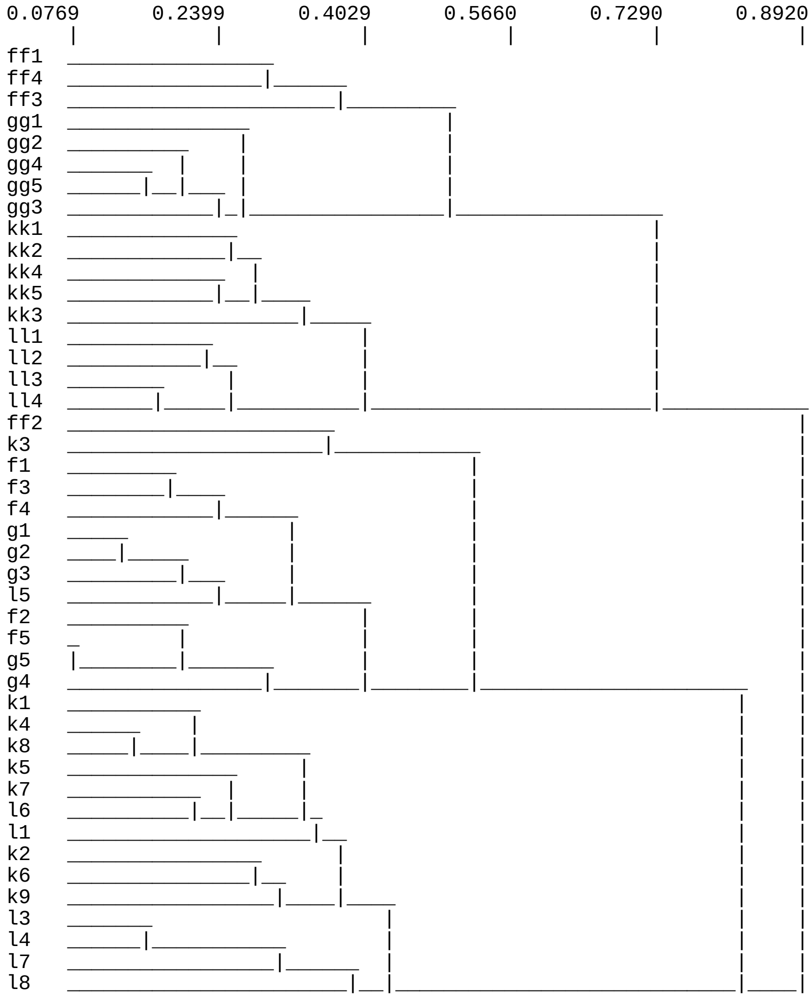


Figure 5. Dendrogram of the UPGMA clustering of plots from the group selection treatment. Plot numbers are shown down the left-hand side (single letter = unlogged plot; double letter = logged plot) and the dissimilarity is displayed on the top edge of the dendrogram.

of the seed mixture sown on the site have not been considered because the sowing treatment effectively negates any conclusions about the effects of the logging treatment on these species. Neyland *et al*. (1999) noted that there was a very poor seed crop over most of the harvest area and hence the entire trial area was aerially sown. The same comment does not apply to other eucalypt species, as post-logging regeneration (or lack of it) is almost entirely due to regeneration of on-site seed.

All species of epiphytic fern decreased in frequency of occurrence after logging in all treatments. Trunked ferns, represented only by *Dicksonia antarctica*, decreased in all treatments, being reduced to no occurrences in group selection treatments. Because of the role of this species in the ecology of wet forests, results for *Dicksonia antarctica* are presented in Table 2.

Several other species from different life form groups showed substantial decreases in frequency of occurrence after logging (discussed below). In the case of species that were recorded infrequently prior to logging (e.g. *Pittosporum bicolor*, *Exocarpos cupressiformis*), the apparent decrease may be an artefact of sampling because of the non-coincidence of logged and unlogged plots. However, the decrease in abundance of species recorded more frequently in unlogged plots (e.g. epiphytic ferns and *Dicksonia antarctica*) is more likely to be the result of the logging treatment. Species of epiphytic ferns could fall into this latter category because of their requirement for substrates associated with older forests, and their sensitivity to changes in microclimate.

Opportunistic shrubs with wind-dispersed seed, such as *Cassinia aculeata* and *Olearia lirata*, either 'appeared' after logging or showed a very large increase in frequency of occurrence. Several

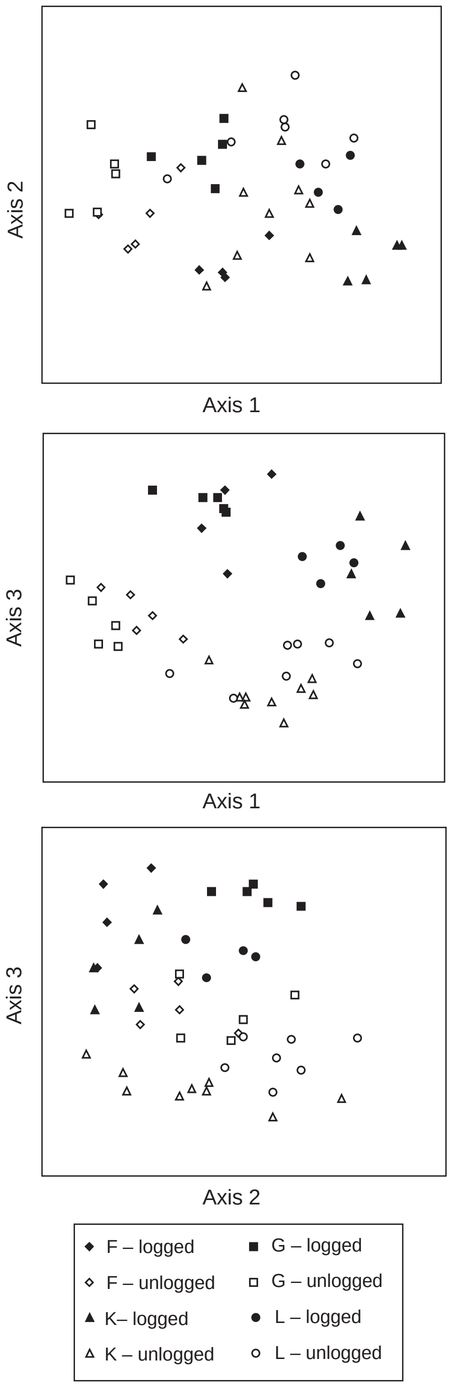


Figure 6. Ordination of plots for partial logging treatment (stress = 0.182)

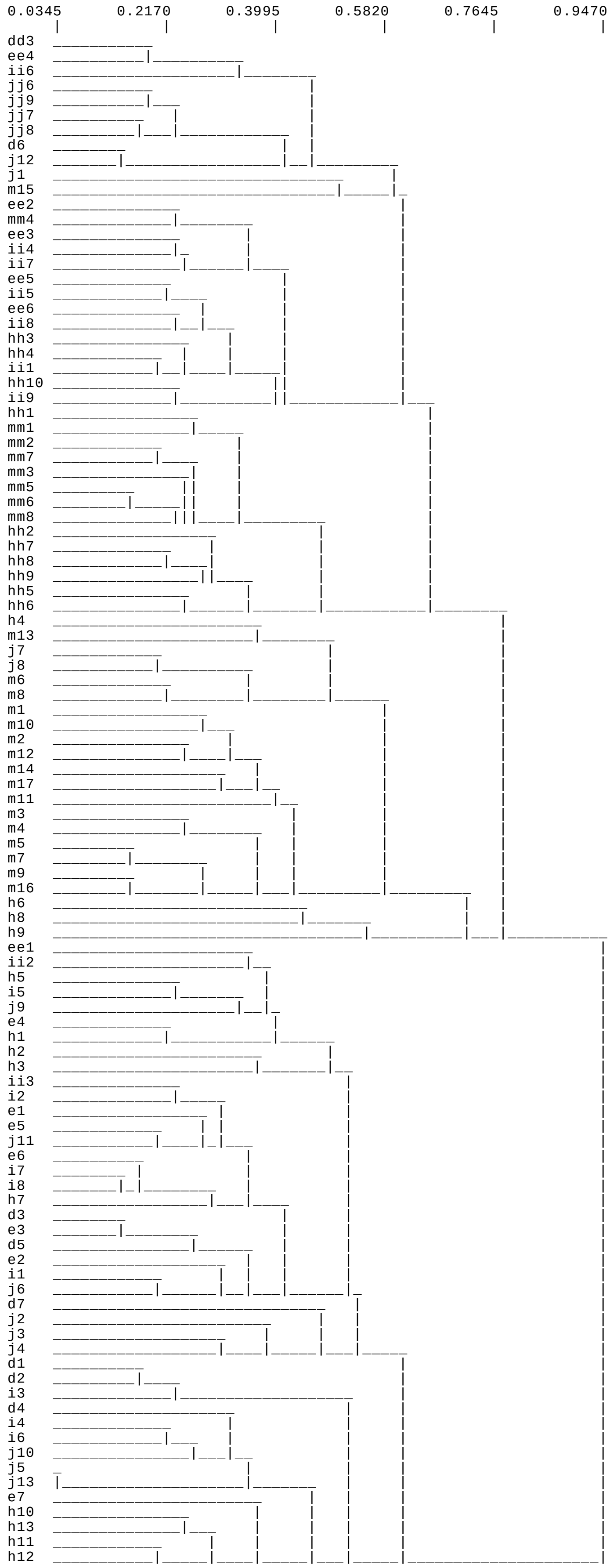


Figure 7. Dendrogram of the UPGMA clustering of plots from the partial logging treatment. Plot numbers are shown down the left-hand side (single letter = unlogged plot; double letter = logged plot) and the dissimilarity is displayed on the top edge of the dendrogram.

Table 1. Relative changes in proportions of selected species following logging

Relative change in abundance	Treatment	Life form:	Species
Complete 'loss' of species following logging (if present in >10% of pre-logging plots)	Clearfell	Tall shrubs:	*Monotoca glauca*
		Herbs:	*Galium australe*
		Epiphytic ferns:	*Hymenophyllum australe*, *Grammitis billardierei*
	Group selection	Trees:	*Eucalyptus globulus*
		Tall shrubs:	*Pittosporum bicolor*
		Epiphytic ferns:	*Hymenophyllum australe*
		Trunked ferns:	*Dicksonia antarctica*
	Partial logging	Epiphytic ferns:	*Hymenophyllum australe*
Substantial (>10%) decrease in frequency of occurrence following logging	Clearfell	Trees:	*Acacia melanoxylon*
		Tall shrubs:	*Olearia argophylla*
		Herbs:	*Drymophila cyanocarpa*
		Ground ferns:	*Polystichum proliferum*
		Trunked ferns:	*Dicksonia antarctica*
		Climbers:	*Clematis aristata*
		Graminoids:	*Lepidosperma elatius*
	Group selection	Tall shrubs:	*Exocarpos cupressiformis*, *Olearia argophylla*
		Herbs:	*Drymophila cyanocarpa*
		Epiphytic ferns:	*Grammitis billardierei*, *Hymenophyllum cupressiforme*, *Rumohra adiantiformis*
	Partial logging	Trees:	*Eucalyptus globulus*
		Tall shrubs:	*Notelaea ligustrina*
		Epiphytic ferns:	*Ctenopteris heterophylla*, *Grammitis billardierei*, *Hymenophyllum cupressiforme*, *Rumohra adiantiformis*
'Appearance' of species following logging (if present in >10% of post-logging plots)	Clearfell	Low shrubs:	*Cassinia aculeata*, *Goodenia ovata*, *Leptospermum scoparium*
		Herbs:	*Euchiton collinus*, *Gonocarpus teucrioides*
		Climbers:	*Billardiera longiflora*
		Graminoids:	*Gahnia grandis*, *Juncus* spp.
	Group selection	Low shrubs:	*Ozothamnus ferrugineus*
		Herbs:	*Acaena novae-zelandiae*, *Geranium solanderi*, *Euchiton collinus*, *Gonocarpus teucrioides*, *Hydrocotyle hirta*, *Hypochoeris radicata*, *Senecio* spp., *Uncinia* spp., *Urtica incisa*, *Viola hederacea*
		Climbers:	*Billardiera longiflora*
		Grasses:	Grass spp.
		Graminoids:	*Juncus* spp.
	Partial logging	Trees:	*Eucalyptus amygdalina*, *E. pulchella*, *E. tenuiramis*
		Low shrubs:	*Cassinia aculeata*
		Herbs:	*Senecio* spp.
		Climbers:	*Billardiera longiflora*
		Graminoids:	*Juncus* spp.
Substantial (>10%) increase in frequency of occurrence following logging	Clearfell	Tall shrubs:	*Acacia verticillata*, *Beyeria viscosa*
		Low shrubs:	*Olearia lirata*, *Ozothamnus ferrugineus*
		Herbs:	*Geranium solanderi*, *Viola hederacea*
		Ground ferns:	*Pteridium esculentum*
		Grasses:	Grass spp.
	Group selection	Trees:	*Acacia melanoxylon*
		Tall shrubs:	*Acacia verticillata*, *Prostanthera lasianthos*
		Lower shrubs:	*Goodenia ovata*, *Olearia lirata*, *Zieria arborescens*
		Ground ferns:	*Histiopteris incisa*, *Polystichum proliferum*
		Graminoids:	*Gahnia grandis*
	Partial logging	Trees:	*Acacia melanoxylon*
`		Tall shrubs:	*Acacia verticillata*, *Bedfordia salicina*, *Pittosporum bicolor*, *Pomaderris apetala*
		Low shrubs:	*Coprosma quadrifida*, *Cyathodes glauca*, *Cyathodes juniperina*, *Goodenia ovata*, *Lomatia tinctoria*, *Olearia lirata*, *Ozothamnus ferrugineus*, *Pimelea nivea*, *Pultenaea daphnoides*, *Zieria arborescens*
		Herbs:	*Acaena novae-zelandiae*, *Geranium solanderi*, *Gonocarpus teucrioides*, *Hydrocotyle hirta*, *Hypochoeris radicata*, *Viola hederacea*
		Ground ferns:	*Histiopteris incisa*, *Pteridium esculentum*
		Climbers:	*Clematis aristata*
		Grasses:	Grass spp.
		Graminoids:	*Gahnia grandis*, *Lepidosperma elatius*

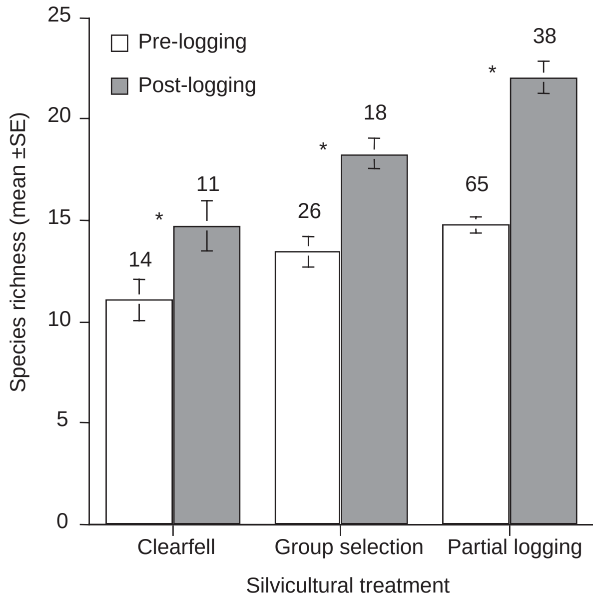


Figure 8. Comparison of species richness before and after logging for each silvicultural treatment. Values are mean richness ± SE. Asterisks above each pair of bars indicate that differences between the values in each pair are significant at $P < 0.05$. Numbers above bars indicate sample sizes.

herbs, including *Acaena novae-zelandiae*, *Gonocarpus teucrioides*, *Geranium solanderi* and *Hydrocotyle hirta* were also first recorded after logging or increased significantly in occurrence. The ground ferns *Histiopteris incisa* and *Pteridium esculentum* were more abundant following logging in all treatments. Other species of ground ferns showed variable patterns of change. Grass species (represented by the grouped species) and most graminoids, including *Gahnia grandis* and species of *Juncus*, were more abundant and frequent after logging in all treatments.

Discussion

In the present study, the increase in diversity of vascular species in the early post-logging period following logging of wet eucalypt forest is largely because of the increase in abundance and frequency of species tolerant of open, disturbed conditions. Species least likely to recolonise regenerating forests are epiphytic ferns associated with moist, shaded environments and specific substrates, found in late-successional stage forests. Not surprisingly, the presence of such species is inversely proportional to the degree of disturbance: partially logged areas had more epiphytic ferns (and substrates favoured for colonisation by epiphytes) than clearfelled areas.

Pioneer shrubs such as *Olearia lirata*, *Cassinia aculeata* and *Ozothamnus ferrugineus* increased in all silvicultural treatments following logging. Other shrubs that increased significantly following logging included *Acacia verticillata* and *Zieria arborescens*. In a study of regeneration in wet eucalypt forests in the Florentine Valley in Tasmania, Cremer and Mount (1965) observed similar patterns of colonisation by *Acacia* species and *Z. arborescens* (regenerating from long-lived, soil-stored seed) and *Olearia* species (regenerating from wind-borne, off-site seed).

Table 2. Change in frequency of occurrence of *Dicksonia antarctica*

Treatment	Frequency (%)	
	Unlogged plots	Logged plots
Clearfell	28.6	9.1
Group selection	34.6	0.0
Partial logging	24.6	15.8

Cunningham and Cremer (1965) suggested that the relative unpalatability of *Z. arborescens* may give it a competitive advantage over other woody shrubs such as *P. apetala*. In the present study, *P. apetala* was present in almost every plot in all treatments, before and after logging. Murphy and Ough (1997) noted that in clearfelled wet forest coupes in Victoria, most species regenerated by seed, and that the most frequent and numerous species recorded in logged plots was *Pomaderris aspera*.

All silvicultural treatments resulted in a substantial reduction in frequency of epiphytic ferns. Both Baxter and Norton (1989) and Hickey (1994) report that the abundance of species of *Hymenophyllum* decreases substantially after logging. Previous studies (Peacock and Duncan 1994) have shown that vascular epiphytes associated with late-successional stage forests may take 50 y to recolonise logged substrates. Hickey (1994) suggests that epiphytic ferns may recolonise clearfelled and regenerated forests provided that there is adequate spore dispersal and that suitable microsites are available. In our study, however, epiphytic ferns were observed in clearfelled areas outside the surveyed plots, indicating that at least some suitable microsites are still present. Epiphytic ferns are likely to recolonise partially logged areas more rapidly than clearfelled areas.

The decrease in frequency of occurrence of epiphytic ferns in logged areas may be explained in part by the decrease in suitable substrates. In the present study, *D. antarctica* declined least in the partially logged silvicultural treatment and most in the clearfell and group selection treatments, being reduced from a frequency of occurrence in pre-logging plots of about 35% to no recorded specimens in logged plots in the latter treatment. Other authors (e.g. Ough and Murphy 1996) have also recorded a substantial decline in the abundance of trunked ferns following clearfelling, and point to the importance of *D. antarctica* and some shrub species (e.g. *O. argophylla*) as substrates for epiphytes. Ough and Murphy (1998) recorded substantially greater survival of *D. antarctica* in retained 'understorey islands' than in the general harvest area, highlighting the importance of retaining undisturbed patches of forest for maintaining species diversity within logged areas. A study of 120 tagged *Dicksonia* (trunked plants) in an *E. regnans* mixed forest coupe in the Florentine Valley showed that 70% of ferns survived intensive logging (clearfelling and cable yarding) but following regeneration burning survival had dropped to 35% of the tagged plants (Peacock and Duncan 1994). Most of the survivors had severely burnt and damaged trunks which, together with the open conditions created by logging and burning, meant that conditions were unfavourable for recolonisation by hygrophilous species.

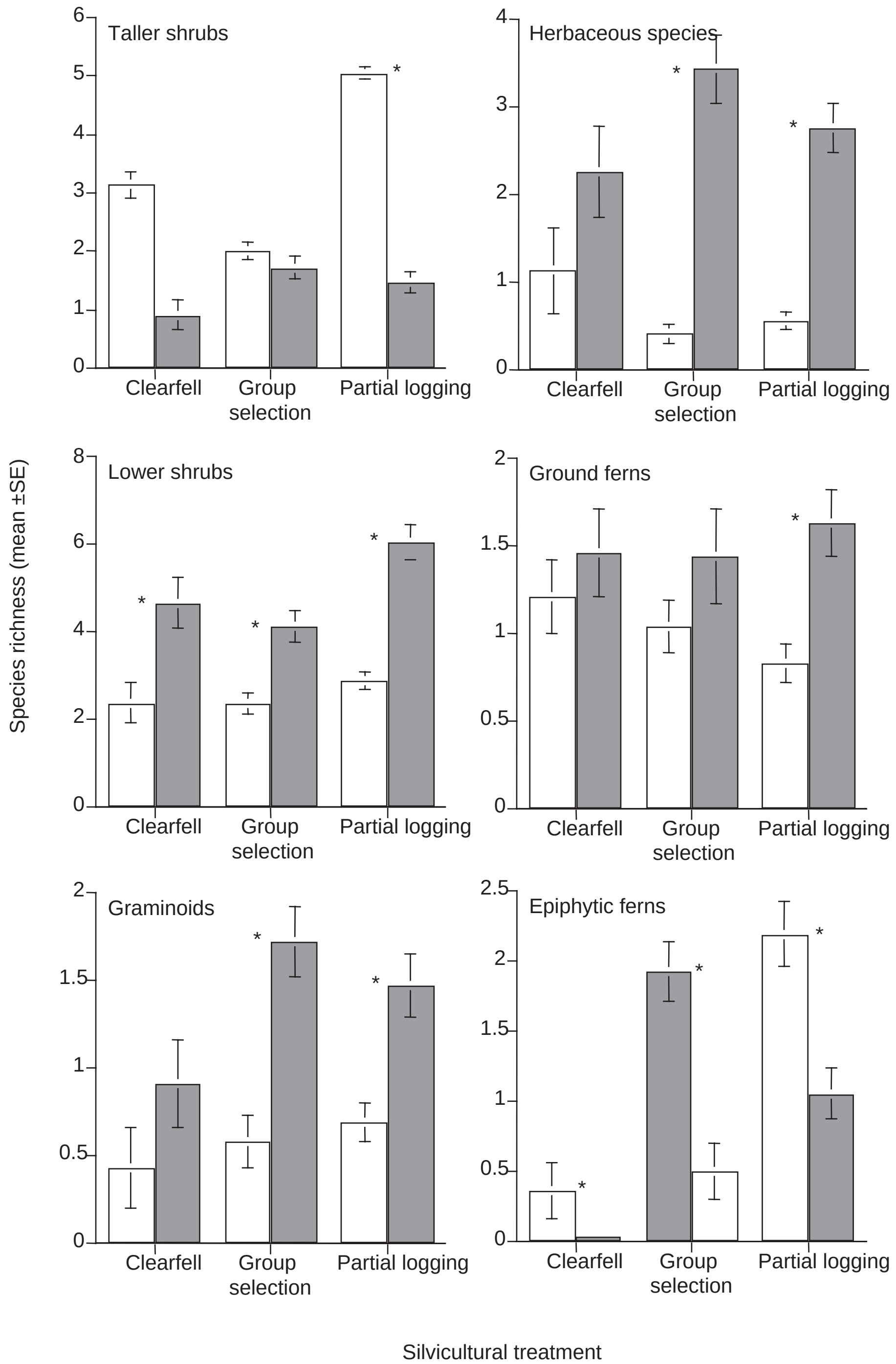


Figure 9. Comparison of species richness within life form groups before and after logging for each silvicultural treatment. Values are mean richness ± SE. Asterisks above each pair of bars indicate that differences between the values in each pair are significant at $P < 0.05$.

The type of silvicultural system had some influence on the species richness of ground ferns. Partial logging increased species richness, while no substantial difference was discerned in clearfelled or group selection treatments. Partial logging provides habitat for rhizomatous ferns of the family Dennstaedtiaceae (notably *Pteridium esculentum*, *Histiopteris incisa* and *Hypolepis* spp.) which commonly form dense patches in openings in wetter forests. At the same time, partial logging maintains habitat for species (e.g. *Polystichum proliferum*) that tolerate shading. The fact that, for other treatments, frequency of occurrence of ground fern species following logging was not significantly different to that before logging can be partly explained by different species showing different patterns of change. For example, in the clearfell treatment, *H. incisa* increased slightly, *P. esculentum* increased by 30%, *H. rugosula* was absent both before and after logging and *P. proliferum* decreased by 35%. In the group selection treatment, *P. esculentum* and *H. rugosula* did not alter substantially, *P. proliferum* increased by 15% and *H. incisa* increased by 40%.

Several authors (e.g. Dickinson and Kirkpatrick 1987; Stewart 1996; Appleby 1998; Burrows *et al*. 2002) found that exotics, particularly herbaceous species, increase in abundance following logging. We found no substantial increase in exotic species in any silvicultural treatment. Only the flatweed *Hypochoeris radicata* (ubiquitous in many forested areas of Tasmania) 'appeared' following logging. Other common opportunistic weeds, such as *Cirsium vulgare*, were present in the study area but were not recorded in plots. This is probably because plots were placed to avoid severely disturbed sites (e.g. landings or roadside banks). Exotic species occurred mainly along snig tracks and landings in the study area. The ruderal nature of most opportunistic exotic species (i.e. light-demanding, short-lived and short-statured) means that they are likely to become sparse with the re-establishment of tree and shrub canopy in the regenerating forest.

Native pioneer herbaceous species such as *Viola hederacea*, *Acaena novae-zelandiae*, *Geranium solanderi*, *Gonocarpus teucrioides*, *Hydrocotyle hirta* and *Senecio* spp. showed an increase in frequency of occurrence following logging in all treatments. As with exotic herbs, their abundance and frequency is likely to decrease with canopy closure. This trend is reported by Cremer and Mount (1965) following clearfelling of wet eucalypt forest in the Florentine Valley in Tasmania, with pioneer herbs such as *Senecio* dying suddenly after reaching a peak 2 y after burning. Loyn *et al*. (1983) reported rapid colonisation by small herbaceous species in logged areas in East Gippsland in Victoria, accounting for an overall increase in diversity in young regenerating forests. A similar situation has been observed in Tasmanian wet forests (e.g. Cremer and Mount 1965).

Neyland *et al*. (1999) reported on the success of regeneration of commercial species at the Forestier study site. They found that clearfelling and burning was the only silvicultural treatment that resulted in adequate stocking of eucalypt regeneration; that blackwood regeneration was observed only in the group selection treatment; and that trees retained in partially logged areas showed increased growth rates after release from suppression. In addition to the adequacy of regeneration of commercial species in non-clearfelled treatments, there are also likely to be planning, operational and safety issues associated with partial logging in wetter forests. Our paper deals primarily with the effects of different silvicultural systems on the composition of the vascular flora as a whole. Our results suggest that the impacts on the most sensitive species (such as epiphytic ferns and their associated host species) may be least in partially logged areas.

Ough (2001) argued that since many understorey species are long-lived, clearfelled regrowth forests may not develop a structure and composition similar to that of naturally disturbed and regenerated forests. At a regional or subregional level, it is possible to maintain wet forest vascular species and successional stages by reserving representative vegetation types (with preferential conservation of late successional stage vegetation, and vegetation that is most susceptible to major disturbance) and, in wood production areas, by dispersing coupes in time and space. Maintenance of biodiversity at a local level will also be assisted by these procedures, together with protection of localised environments (e.g. wet gullies, riparian environments) through regulatory constraints. Within coupes, the use of 'understorey islands' (small patches of machinery exclusion zones within a clearfelled area), as described by Ough and Murphy (1998), may be a simple and low-cost means of reducing the loss of in-coupe biodiversity.

Dickinson and Kirkpatrick (1987) state that a lack of substantial impact of timber harvesting on floristics in the short term does not guarantee the same in the long term. While we concur with this comment, we suggest that the vast majority of vascular plant species within wet sclerophyll forests of the type examined are likely to either survive harvesting by clearfelling, group selection or partial logging practices, or successfully recolonise harvested areas. Ecologically sensitive species are more likely to be retained in the harvested area by using logging systems that maintain a diversity of microhabitats (particularly humid microhabitats) and a range of canopy covers. This study was conducted in relatively equable and productive (i.e. high fertility and rainfall) wet sclerophyll forests in south-eastern Tasmania where many species may be resilient to major disturbance events. We believe that the trends revealed have application to other similar forest types within Tasmania, and possibly south-eastern Australia, but caution should be used in generalising from this specific forest type to other wet forest types occurring on different substrates and within different climatic zones.

This study has not addressed the time it may take the forest to redevelop structure and floristic composition similar to that present prior to disturbance, particularly in the context of natural disturbance regimes (e.g. fire frequency) and timber harvesting rotation periods. It is important that these factors are assessed in determining the impact of silvicultural regimes on wet sclerophyll forest. Continuing research into different silviculture systems in Tasmanian wet sclerophyll forest (e.g. Hickey *et al*. 2001) will provide some answers. Further monitoring of the Forestier Peninsula site may also assist in elucidation of the longer-term effects of different logging practices.

Acknowledgements

The authors thank Sarah Freeman, Sarah Crute and Joe Harries for field assistance. Graham Wilkinson and John Hickey are thanked for making useful comments on the manuscript. Two referees provided comments that improved the original manuscript. Steve Candy provided some statistical advice. Bruce Chetwynd and Jean Jarman assisted in the preparation of Figure 1.

References

Appleby, M.W.A. (1998) The incidence of exotic species following clearfelling of *Eucalyptus regnans* forest in the Central Highlands, Victoria. *Australian Journal of Ecology* **23,** 457–465.

Baxter, W.A. and Norton, D.A. (1989) Forest recovery after logging in lowland dense rimu forest, Westland, New Zealand. *New Zealand Journal of Botany* **27,** 391–399.

Belbin, L. (1995) *PATN Pattern Analysis Package: Users Guide*. Division of Wildlife and Ecology, CSIRO, Canberra, Australia.

Buchanan, A.M. (ed.) (1999) *A Census of the Vascular Plants of Tasmania*. Tasmanian Herbarium Occasional Publication No. 6, Tasmanian Museum and Art Gallery, Hobart.

Burrows, N.D., Ward, B. and Cranfield, R. (2002) Short-term impacts of logging on understorey vegetation in a jarrah forest. *Australian Forestry* **65,** 47–58.

Chesterfield, E.A. (1996) *Changes in Mixed Forest after Fire and after Clearfelling Silviculture on the Errinundra Plateau*. Flora & Fauna Technical Report No. 142. Department of Natural Resources and Environment, Victoria.

Cremer, K.W. and Mount, A.B. (1965) Early stages of plant succession following the complete felling and burning of *Eucalyptus regnans* forest in the Florentine Valley, Tasmania. *Australian Journal of Botany* **13,** 303–322.

Cunningham, T.M. and Cremer, K.W. (1965) Control of understorey in wet eucalypt forests. *Australian Forestry* **29,** 4–14.

Dickinson, K.J.M. and Kirkpatrick, J.B. (1987) The short-term effects of clearfelling and slash-burning on the richness, diversity and relative abundance of higher plant species in two types of eucalypt forest on dolerite in Tasmania. *Australian Journal of Botany* **35,** 601–616.

Duncan, F. and Brown, M.J. (1995) Edaphics and fire: an interpretative ecology of lowland forest vegetation on granite in northeast Tasmania. *Proceedings of the Linnaean Society of New South Wales* **115,** 45–60.

Gentilli, J. (1972) *Australian Climate Patterns*. Nelson, Melbourne.

Hickey, J.E. (1994) A floristic comparison of vascular species in Tasmanian oldgrowth mixed forest with regeneration resulting from logging and wildfire. *Australian Journal of Botany* **42,** 383–404.

Hickey, J.E. and Wilkinson, G.R. (1999) The development and current implementation of silvicultural practices in native forests in Tasmania. *Australian Forestry* **62,** 245–254.

Hickey, J.E., Neyland, M.G. and Bassett, O.D. (2001) Rationale and design for the Warra silvicultural systems trial in wet *Eucalyptus obliqua* forests in Tasmania. *Tasforests* **13,** 155–182.

Kellas, J.D., Jarrett, R.G. and Morgan, B.J.T. (1988) Changes in species composition following recent shelterwood cutting in mixed eucalypt stands in the Wombat Forest, Victoria. *Australian Forestry* **51,** 112–118.

King, G.C. and Chapman, W.S. (1983) Floristic composition and structure of a rainforest area 25 years after logging. *Australian Journal of Ecology* **8,** 415–423.

Kirkpatrick, J.B., Peacock, R.J., Cullen, P.J. and Neyland, M.G. (1988) *The Wet Eucalypt Forests of Tasmania*. Tasmanian Conservation Trust Inc., Hobart.

Loyn, R.H., Fagg, P.C., Piggin, J.E., Morton, A.G. and Tolhurst, K.G. (1983) Changes in the composition of understorey vegetation after harvesting eucalypts for sawlogs and pulpwood in East Gippsland. *Australian Journal of Ecology* **8,** 43–53.

Mueller-Dombois, D. and Ellenberg, H. (1974) *Aims and Methods of Vegetation Ecology*. Wiley and Sons, New York.

Murphy, A. and Ough, K. (1997) Regenerative strategies of understorey flora following clearfell logging in the Central Highlands, Victoria. *Australian Forestry* **60,** 90–98.

Neyland, M.G., Wilkinson, G.R. and Edwards, L.G. (1999) The Forestier silvicultural systems trial: alternatives to clearfelling. *Tasforests* **11,** 35–47.

Ough, K. (2001) Regeneration of wet forest flora a decade after clear-felling or wildfire — is there a difference? *Australian Journal of Botany* **49,** 645–664.

Ough, K. and Murphy, A. (1996) The effect of clearfell logging on tree-ferns in Victorian wet forest. *Australian Forestry* **59,** 178–188.

Ough, K. and Murphy, A. (1998) Understorey islands: a method of protecting understorey flora during clearfelling operations. Unpublished VSP Internal Report No. 29, Department of Natural Resources and Environment, Victoria.

Peacock, R.J. and Duncan, F. (1994) Impact of logging on *Dicksonia antarctica* and associated epiphytes in Tasmanian wet eucalypt forests. In: *International Forest Biodiversity Conference*: *Conserving Biological Diversity in Temperate Forest Ecosystems — Toward Sustainable Management*. Canberra, 4–9 December 1994. Department of Environment, Sport and Territories, Canberra, pp. 171–172.

Stewart, M.W. (1996) Regeneration of clearfelled logging coupes in shrubby dry sclerophyll forest, within Wielangta State forest. Honours thesis, Department of Geography and Environmental Studies, University of Tasmania.