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Decline in tree-fern abundance after clearfell harvesting

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Abstract

Common and widespread plant species can change in abundance as a result of timber harvesting practices, with potentially broad effects on an ecosystem. Yet few studies have quantified such changes and their effects and as a result, subsequent management can be poorly defined. Tree-ferns are among a number of vegetative resprouters that have been shown to decline in abundance after clearfelling in Victorian Wet Forest. This study quantifies the initial survival of two common species of tree fern, *Dicksonia antarctica* and *Cyathea australis*, on six Wet Forest coupes in the Victorian Central Highlands, south-eastern Australia. Sixteen percent of the 2391 tree-ferns monitored remained alive 1 year after clearfelling and seedbed preparation, with only 5% remaining in an upright position. Mortality was still increasing up to 6 years after clearfell harvesting, particularly for *C. australis*. Sixty-seven percent of *D. antarctica* surviving to 1 year post-harvest were still alive after 4 or 6 years, whereas only 35% of *C. australis* survived this period. Low tree-fern survival is likely to result in declines in the abundance of other species that rely directly on tree-ferns for habitat. The altered forest structure resulting from reduced tree-fern numbers will affect local microclimates and forest processes. As tree-fern recruitment is low and growth rates are slow, these changes are likely to be long term. Survival of individuals through harvesting operations is crucial to the maintenance of the role of tree-ferns as a keystone species in Wet Forests and simple modifications to current practices could increase the survival of tree-ferns in clearfelled areas.

Keywords: Tree-ferns; *Dicksonia antarctica*; *Cyathea australis*; Clearfelling; Sustainable forest management

1. Introduction

The change in abundance of a common plant species can potentially have a more serious effect on an ecosystem than the change in abundance of a sporadically occurring or rare species. Flow-on effects are likely to be numerous (Ough and Murphy, 1996), and ecosystem functions may change over a wide area. At present, the management of rare or threatened species in Victorian forests is addressed in policy documents and legislation such as the Flora and Fauna Guarantee Act (1988) and associated Action Statements, the Code of Forest Practices for Timber Production (NRE, 1996), and regional Forest Management Plans. Change in abundance of common species is less well studied, hence the consequences are less well understood, and the management of such changes is less well defined.

In Australian timber production forests, the requirement to manage in an ecologically sustainable manner is becoming increasingly important. Policy statements such as the Regional Forest Agreements (e.g. DPIE, 1998), the National Forest Policy Statement (Commonwealth of Australia, 1992a), the National Strategy

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for Ecologically Sustainable Development (Commonwealth of Australia, 1992b), and the National Strategy for the Conservation of Australia's Biological Diversity (Commonwealth of Australia, 1996) commit forest managers to ensuring biodiversity, genetic diversity, ecosystem processes and ecosystem health are maintained within the native forest estate. Whether or not widespread changes in abundance of species can be tolerated within these policies has not been specifically addressed.

In Wet Forests (sensu Woodgate et al., 1994) of the Victorian Central Highlands, south-eastern Australia, the tree-fern species *Dicksonia antarctica* (Soft tree-fern) and *Cyathea australis* (Rough tree-fern) are common and widespread. These fire-tolerant species are characteristic of Wet Forest understoreys, often forming a dominant component (Ough and Ross, 1992; Ashton and Attiwill, 1994; Walsh and Entwisle, 1994; Ough and Murphy, 1996). Life spans of several centuries appear to be common for these slow growing plants (Cremer and Mount, 1965; Mueck et al., 1996; Ashton and Bassett, 1997), and a variety of epiphytes often inhabit the trunks of the taller tree-ferns (Ough and Ross, 1992; Chesterfield, 1996; Ough and Murphy, 1996; Ashton and Chinner, 1999; Ashton, 2000). Ashton (2000) also observed tree-fern trunks to be especially favourable establishment sites for almost all woody species in the forest. A decline in tree-fern numbers will therefore impact on a great many other species (Ough and Murphy, 1996).

Victorian Wet Forests produce timber of high commercial value, and large areas are managed for timber production. Currently, of the approximately 110,000 ha of Wet Forest in the Central Highlands, about 40% is available for timber harvesting (NRE, 1998), principally by clearfelling (Squire et al., 1991). Low tree-fern numbers in Wet Forest regenerating after clearfelling has been reported in south-eastern Australia for several years (e.g. Harris, 1989; Mueck and Peacock, 1992; Ough and Ross, 1992; Chesterfield, 1996; Murphy and Ough, 1997; Ough and Murphy, 1999; Ough, 2001). For the otherwise generally common species *D. antarctica* and *C. australis*, this is likely to represent a considerable decline in localised abundance.

In the first quantified study of tree-fern survival after clearfelling in the Victorian Central Highlands, Ough and Murphy (1996) reported a substantial decline in the number of tree-ferns within a single coupe (Spraggs) in Toolangi State Forest: 18% of the 563 monitored tree-ferns survived to 1 year after harvesting, 14% survived to 2.5 years after harvesting, and 6% remained upright. The mechanical disturbance associated with clearfelling, and perhaps the high intensity slash-burn, appeared to be lethal to the majority of tree-ferns. Similar studies were subsequently undertaken on a further five coupes, encompassing a range of topographies, seasons and logging contractors. Here, we quantify the initial survival of tree-ferns on all six coupes.

2. Methods

2.1. The study area

The study area is located between 50 and 80 km north east of Melbourne, in the Victorian Central Highlands, south-eastern Australia (Fig. 1). A high proportion of this mountainous area supports Wet Forest, dominated by *Eucalyptus regnans* (Mountain Ash). The area experiences a cool temperate climate with mild summers and cool winters. Average annual rainfall exceeds 1200 mm over most of the area. Soils are free draining, friable, brown gradational, have high water holding capacities, and have developed on a variety of volcanic parent rock materials.

Fire is the major natural disturbance associated with the study area. Several fires have occurred within the study area over the past 150 years, the most extensive being in 1926 and 1939 (McHugh, 1991; Jeremiah and Roob, 1992).

The study area is subject to intensive hardwood timber harvesting. Large-scale timber cutting, generally selective harvesting, and sawmilling occurred in these forests in the latter part of the nineteenth and early twentieth centuries. Massive salvage operations followed major wildfires, particularly the extensive 1939 fires. Since the 1960s, clearfelling has been the major silvicultural system practised (Squire et al., 1991).

2.2. The study sites

Tree-fern survival was monitored within six coupes (Fig. 1, Table 1). The vegetation prior to clearfelling

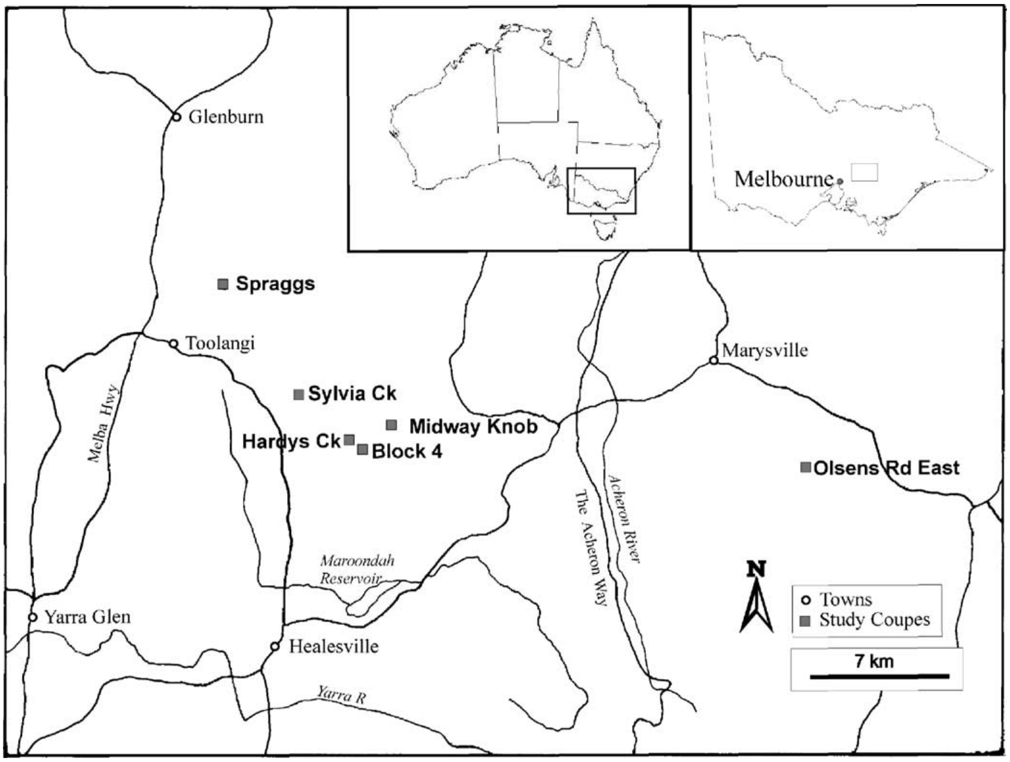

Fig. 1. Location of study coupes within the Victorian Central Highlands.

was similar in structure and composition within all coupes. All sites were dominated by *E. regnans* (Mountain Ash), with a tall understorey tree stratum of *Acacia dealbata* (Silver Wattle), *Acacia frigescens* (Frosted Wattle) or *Acacia melanoxylon* (Blackwood). Understorey shrubs included combinations of *Pomaderris aspera* (Hazel Pomaderris), *Olearia argophylla* (Musk Daisy-bush), *Olearia phlogopappa* (Dusty Daisy-bush), *Bedfordia arborescens* (Blanket-leaf), *Cassinia aculeata* (Common Cassinia), *Hedycarya angustifolia* (Austral Mulberry), *Polyscias sambucifolia* (Elderberry Panax), *Coprosma quadrifida* (Prickly Currant-bush), *Correa lawrenciana* (Mountain Correa) and *Zieria arborescens* (Stinkwood). All coupes supported a low to moderate cover of the tree-ferns *D. antarctica* and *C. australis* (canopy cover of 5–50%, which is typical for this region). The ground stratum consisted of varying proportions of *Histiopteris incisa* (Bat's Wing Fern), *Polystichum proliferum* (Mother Shield-fern), *Blechnum* spp. (Water-ferns),

Table 1
Site characteristics for coupes assessed for tree-fern survival after clearfelling

Coupe	State forest	Elevation (m)	Aspect	Slope	No. of plots
Spraggs	Toolangi	600	S	Gentle	5
Sylvia Ck	Toolangi	650	SW	Gentle	4
Hardys Ck	Toolangi	800	E	Moderate to steep	3
Olsens Rd East	Marysville	870	NW	Gentle	4
Block 4	Toolangi	780	E	Moderate	4
Midway Knob	Toolangi	800	NW–NE	Moderate to steep	3

Table 2
Harvesting information for coupes assessed for tree-fern survival

Coupe	Coupe size (ha)	Harvesting dates	Seedbed preparation type	Seedbed preparation date
Spraggs	12	October 1991–January 1992	Slash-burn	20/03/1992
Sylvia Ck	12	December 1992–November 1993	Part slash-burn, part mechanical disturbance	14/03/1993 (SB), 05/1993 and 11/1993 (MD)
Hardys Ck	25	January 1992–March 1995	Slash-burn	17/03/1995
Olsens Rd East	8	March 1994–January 1995	Slash-burn	23/03/1995
Block 4	18	March 1994–March 1996	Slash-burn	27/03/1996
Midway Knob	20	January 1996–January 1997	Slash-burn	27/03/1996 and 18/03/1997

Pteridium esculentum (Austral Bracken), *Dianella tasmanica* (Tasman Flax-lily), *Lepidosperma elatius* (Tall Sword-sedge) and *Tetrarrhena juncea* (Forest Wire-grass), usually forming a moderate to dense cover.

All study coupes had been burned in the 1939 wildfires, and the majority of eucalypts present originated from that time. Widespread salvage logging during the 10 years following these fires may have modified the understorey.

The study coupes were clearfell harvested between 1991 and 1997 (Table 2), using standard clearfelling procedures for this area. Generally, fixed track D6 bulldozers were used for main snig track and landing construction, and clearing understorey surrounding eucalypts that were to be manually felled. Rubber-tyred skidders were used for snigging logs and excavators debarked, stacked and loaded logs on the landing. After harvesting was completed, logging slash was burnt and eucalypt seed sown soon after.

Mechanical soil disturbance is used as an alternative to slash-burning in Victorian Wet Forest (CNR, 1994), and a large proportion of the seedbed at Sylvia Ck was prepared using mechanical soil disturbance between burnt windrows. Three of the four plots at Sylvia Ck were seedbed prepared in this way; the remaining plot was slash-burnt.

Four logging contractor teams were involved. Spraggs and Sylvia Ck were harvested by the same contractor, Hardys Ck and Midway Knob by another, and Olsens Rd East and Block 4 by a further two teams.

2.3. Tree-fern survival

2.3.1. Pre-harvest

The species and heights of tree-ferns within $30\,m \times 30\,m$ plots located on study coupes were recorded before clearfelling. Young ferns with frond length less than 15 cm were not included. Tree-fern heights were assigned to one of the following eight height-class categories: no trunk, 0–19 cm, 20–49 cm, 50–99 cm, 100–149 cm, 150–199 cm, >200 cm and prostrate.

2.3.2. Survival 1 year after harvest

Survival of tree-ferns on all plots was assessed 1 year after clearfelling and seedbed preparation (hereafter referred to as 1-year post-harvest). A tree-fern was judged as living if at least one of its fronds was alive, or if there were signs of new frond formation within the apex.

2.3.3. Height-class vulnerability

To indicate whether a particular size of tree-fern was particularly vulnerable to clearfelling, heights of tree-ferns which survived the harvest were assigned to height-class categories (as in pre-harvest assessment). A 'buried trunk' category was added.

2.3.4. Survival up to 6 years after harvesting

As tree-fern death is often slow (Neyland, 1986), characterised by ever decreasing frond length and stem diameter (Seiler, 1981; Robin, 1985), the survival of tree-ferns on each of the plots on two coupes (Spraggs and Sylvia Ck) was monitored for 6 and 4 years, respectively, after clearfelling. Tree-ferns were individually tagged and their locations mapped after clearfelling to ensure accurate monitoring in the dense forest regeneration.

2.4. Trunk area

Prior to clearfelling, all tree-fern height and girth trunk dimensions were recorded within the plots at four coupes (Spraggs, Sylvia Ck, Hardys and Block 4) to give an indication of the extent of this substrate potentially available to epiphytes. Measurements were recorded to the nearest centimetre. Girths were measured at a height of 1 m or, for tree-ferns less than 1 m in height, at the apex of the caudex immediately below the living fronds. Trunks were approximated as cylinders and the total trunk surface area calculated for each plot.

One year after clearfelling the trunk dimensions of all surviving tree-ferns were recorded and trunk surface areas were calculated. Trunks which had been buried during harvesting or lay on the ground were recorded as buried or prostrate, respectively. If trunks lay partly buried and partly prostrate they were categorised according to the position of the majority of the trunk. All prostrate trunks were measured and included in calculations of total trunk surface area. Buried trunks were excluded from these calculations as they were considered no longer suitable as substrates for epiphytes.

2.5. Analyses

Tree-fern survival and trunk surface area data were analysed using Two-way Repeated Measures Analysis of Variance (e.g. Looney and Stanley, 1989). Abundance data were transformed to square root to conform with the assumptions of the analysis. For analysis of survival from year 1 to year 4 or 6 on Sylvia Ck and Spraggs, P values were Greenhouse-Geisser adjusted.

3. Results

3.1. Tree-fern survival

3.1.1. Survival 1 year after clearfelling

The number of tree-ferns on all 23 plots decreased from pre-harvest to 1-year post-harvest. Overall, 16% of the 2391 tree-ferns monitored remained alive 1 year after the coupes were clearfelled (Table 3). The decline was significant on all coupes ($P < 0.001$ for *D. antarctica*, *C. australis* and combined tree-ferns). For *D. antarctica* and tree-fern species combined, this pre-post-harvest difference was consistent between coupes. For *C. australis*, the pre-post-harvest differences were not consistent between coupes ($P < 0.001$), but still significant overall.

Survival of *D. antarctica* on individual plots to 1 year after clearfelling ranged from no survivors to 42% survival. Survival also varied between coupes: combined plots at Olsens Rd East indicated 10% survival, on Hardys Ck 23% survival (Table 3). Overall, *D. antarctica* survival averaged 17% after 1 year.

C. australis occurred less commonly at the study sites, with substantial numbers only at Spraggs and Sylvia Ck. Survival of *C. australis* at these two sites 1

Table 3
Survival of tree-ferns from pre-harvest to 1 year post-harvest (plots combined for each coupe)

Coupe	Number of individuals								
	D. antarctica			*C. australis*			Total tree-ferns		
	Pre-harvest	Post-harvest	%[a]	Pre-harvest	Post-harvest	%[a]	Pre-harvest	Post-harvest	%[a]
Spraggs	343	59	17	220	42	19	563	101	18
Sylvia Ck[b]	147	34	23	42	8	19	189	42	22
Sylvia Ck[c]	100	3	3	210	1	0.5	310	4	1
Hardys Ck	381	88	23	8	0	0	389	88	23
Olsens Rd East	362	37	10	0	0		362	37	10
Block 4	369	62	17	8	0	0	377	62	16
Midway Knob	193	35	18	8	1	13	201	36	18
Total	1895	320	17	496	52	11	2391	372	16

[a] Percent remaining post-harvesting.
[b] Slash-burnt plot.
[c] Mechanically seedbed prepared plots.

year after clearfelling was 19 and 4%, respectively. Overall 11% of *C. australis* survived to 1 year after harvest, a slightly lower rate than the survival of *D. antarctica*.

The survival rates of tree-ferns on the three plots at Sylvia Ck subjected to mechanical seedbed preparation were very low: 0, 1 and 2% of tree-ferns survived to 1-year after clearfelling. These were amongst the lowest rates recorded. Two slash-burnt plots, both on different coupes, recorded survival rates of 3% or lower.

Although young tree-ferns of frond length less than 15 cm were not monitored for survival, none were observed to survive clearfelling operations.

3.1.2. Height-class vulnerability

The number of tree-ferns in all upright height classes declined after clearfelling (Fig. 2). Decline in number was proportionally greatest in height classes above 150 cm (99% for tree-ferns 150–200 cm tall and taller than 200 cm), although the decline was greater than 90% in all height classes. Overall, 5% of tree-ferns in plots pre-harvest remained in an upright position 1-year post-harvest. The number of prostrate and buried living tree-fern trunks increased substantially after clearfelling.

3.1.3. Survival up to 6 years after harvesting

Of the tree-ferns that initially survived clearfelling, many did not survive the following few years. Survival rates at Spraggs fell from 17% for *D. antarctica* 1-year post-harvest, to 10% 6 years after harvesting. At Sylvia Ck survival rates for *D. antarctica* fell from 15 to 12% after 4 years. A greater decline was observed for *C. australis*: at Spraggs survival fell from 19 to 7% from 1 to 6 years after clearfelling, and from 4 to 1% from 1 to 4 years after clearfelling at Sylvia Ck. This decline in survivors from 1 year to 4 or 6 years was significant for *C. australis* ($P = 0.007$) and combined tree-ferns ($P = 0.002$), but not significant for *D. antarctica* ($P = 0.177$).

Overall, 67% of *D. antarctica* surviving to 1-year post-harvest were still alive after 4 or 6 years, whereas only 35% of *C. australis* survived this period (Fig. 3).

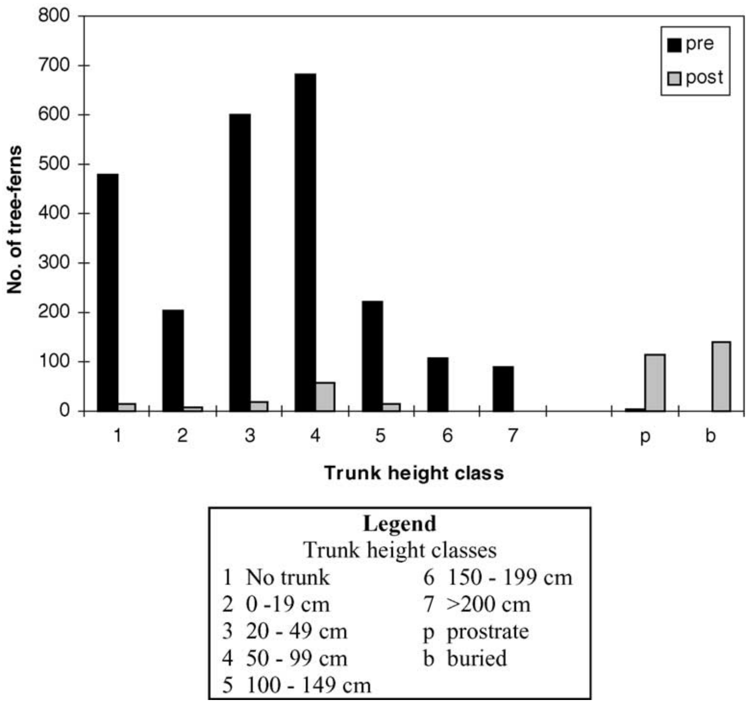

Fig. 2. Total number of tree-ferns in each height-class pre-harvest and 1 year post-harvest (23 plots across 6 coupes combined, although it should be noted that the original population demography varied between plots and between coupes).

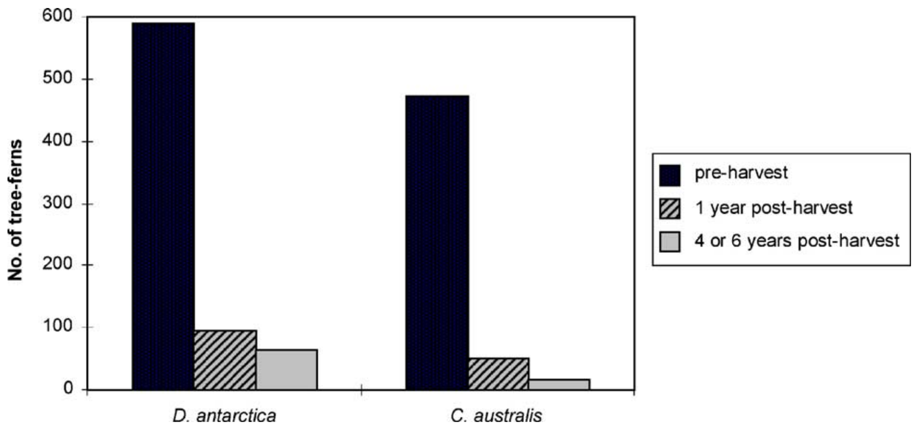

Fig. 3. Number of tree-ferns alive on combined plots at Spraggs and Sylvia Ck pre-harvest, 1 year and 4 or 6 years after harvest (4 years at Sylvia Ck, 6 years at Spraggs).

In total, 56% of tree-ferns surviving to 1 year after harvesting survived the next few years.

This additional mortality was spread across upright, prostrate and buried tree-ferns (Table 4). Buried tree-ferns, despite a slightly higher survival rate than either upright or prostrate tree-ferns, were in the poorest health, with many producing only one or two very short fronds which decreased in size annually.

3.2. Trunk area

The surface area of tree-fern trunks decreased significantly after clearfelling on all coupes ($P < 0.001$ for *D. antarctica* and for *C. australis*; Table 5). The decline within individual plots ranged from 74 to 100% loss. Combined plots within coupes revealed losses of 87–96% of the original trunk surface area

Table 4
Trunk orientation of live tree-ferns on Spraggs and Sylvia Ck pre-harvest, 1 year and 4 or 6 years[a] after harvest (plots and coupes combined)

Trunk orientation	Number of tree-ferns			
	Pre-harvest	Post-harvest (year 1)	Post-harvest (year 4 or 6)[a]	Survival (year 1 to year 4 or 6)[a] (%)
Upright	1060	35	19	54
Prostrate	2	42	21	50
Buried	0	70	42	60

[a] Four years at Sylvia Ck, 6 years at Spraggs.

Table 5
Tree-fern trunk surface area (m^2) pre-harvest and 1 year post-harvest (plots combined for each coupe)

Coupe	*D. antarctica*			*C. australis*			Total tree-ferns		
	Pre-harvest	Post-harvest	%[a]	Pre-harvest	Post-harvest	%[a]	Pre-harvest	Post-harvest	%[a]
Spraggs	106	13	12	116	11	9	222	24	11
Sylvia Ck	80	6	8	118	2	2	198	8	4
Hardys Ck	133	18	13	1	0	0	134	18	13
Block 4	99	11	11	2	0	0	101	11	11
Total	418	48	12	237	13	5	655	61	9

[a] Percent remaining post-harvest.

(Table 5). Overall, 9% of the pre-harvest trunk surface area remained on the plots after clearfelling.

4. Discussion

Tree-ferns declined significantly in abundance after clearfell harvesting operations. Across the six study coupes, 16% of the tree-ferns on 23 monitored plots remained alive 1 year after seedbed preparation. The survival rate was slightly higher for *D. antarctica* (17%) than for *C. australis* (11%). Only 5% of the monitored trunked tree-ferns remained upright; other survivors had trunks buried or lying prostrate. In contrast, in adjacent unharvested forest no tree-fern mortality was observed (personal observations), and Ough and Murphy (1996) recorded no natural mortality in monitored tree-ferns over a 2.5-year period.

Tree-fern mortality was still increasing up to 6 years after clearfell harvesting, particularly for *C. australis*. Almost 65% of the individuals of *C. australis* remaining alive 1 year after clearfelling died within the following 3–5 years. Thirty-three percent of surviving *D. antarctica* died within the same period. For some surviving tree-ferns, the observed combination of declining annual frond production (down to 1–3 fronds) and decreasing frond length (to less than 10 cm; Ough and Murphy, unpublished data), suggests that mortality will continue to increase, even now that the canopy has closed. A slow death is characteristic of tree-ferns (Robin, 1985; Neyland, 1986) and highlights the need for longer term monitoring to determine the true impacts of disturbance. In the case of tree-ferns, initial survival rates are not a reliable indication of the full impact of timber harvesting.

These results indicate that the post-harvest survival of tree-ferns on Spraggs coupe, reported by Ough and Murphy (1996), was typical of the impact of clearfell harvesting and slash-burning on tree-ferns in this region. Results are likely to vary to some degree with factors such as topography, understorey and eucalypt density, and the methods of individual logging contractors. Survival rates at the Sylvia Ck plots, which were subjected to mechanical seedbed preparation, were particularly low (1% one year after harvesting), and may be attributable to the more severe physical disturbance in this area of the coupe. Further investigation is required to confirm the correlation between higher mortality and mechanical seedbed preparation, but it is likely that any additional physical disturbance will disadvantage vegetatively resprouting species.

Persistence of a species after disturbance relies upon survival or recruitment. Many Wet Forest understorey species have no individuals that survive clearfell harvesting or high intensity wildfire (e.g. *A. dealbata*, *P. aspera*, *Prostanthera lasianthos*, *C. aculeata*, personal observation). These species rely entirely on recruitment by seed germination. Other species rely heavily on resprouting vegetatively from propagules such as lignotubers or rhizomes, a very widespread trait in the plant kingdom (Wells, 1969; Keeley, 1991). Resprouting is an adaptation to wildfire and is common in naturally disturbed Wet Forest. Tree-ferns regenerate after fire by resprouting from a terminal bud within the fibrous trunk. However, organs such as lignotubers, tree-fern trunks and rhizomes are frequently destroyed during clearfelling, often resulting in a lower abundance of the species adapted to survive, rather than germinate following, natural disturbance (Harris, 1989; Ough and Ross, 1992; Murphy and Ough, 1997; Ough and Murphy, 1999; Ough, 2001). Hence resprouting species like tree-ferns are often much more common in wildfire regeneration than in clearfell regrowth (Ough and Ross, 1992; Ough and Murphy, 1999; Ough, 2001).

The distinction between post-fire regenerative strategies is an important one. A community consisting of mainly obligate seed regenerating species may be expected to fluctuate greatly in relative population sizes after fire. By comparison, communities consisting of mainly resprouters will tend to remain quite constant (Lamont et al., 1999). For resprouting species, the rate of successful seedling recruitment into the population is often low (Keeley, 1986) and if populations of resprouters have been reduced in an area, for example, on a recently clearfelled coupe, their re-occupation of the site may be very slow. Life-history characteristics of long life, slow growth and low rates of sexual recruitment are likely to lead to very long recovery periods, if recovery occurs at all (Meier et al., 1995).

Although this study did not address recruitment of tree-ferns post-harvesting, germination appears to be uncommon on clearfelled coupes in the Central Highlands of Victoria for at least a couple of decades (personal observation). Low rates of recruitment may reflect a combination of narrow substrate or microclimatic requirements, limited dispersal capabilities and high mortality (Ashton, 1976; Peck et al., 1990; Unwin and Hunt, 1996). Additional studies are needed to assess whether, and why, the apparently low recruitment rate of tree-ferns in stands regenerating after clearfelling differs from recruitment rates in naturally disturbed forest.

4.1. Implications of tree-fern decline for other species

An important implication of tree-fern decline is the impact on the many other species that rely on tree-fern trunks as substrate for germination or growth (see Ough and Murphy, 1996; Ashton, 2000). Several authors have reported reduced occurrence or absence of epiphytic ferns after harvesting (e.g. Harris, 1989; Ough and Ross, 1992; Hickey, 1994). Tree-ferns greater than 1.5 m tall support epiphytic species much more commonly than smaller tree-ferns (personal observation). This study indicates that tree-ferns of this height were least likely to remain upright after clearfelling, with only 1% of individuals in height classes 150–199 cm and >200 cm remaining in an upright position. The greatest proportion of tree-ferns remaining upright were between 50 and 150 cm tall (approximately 8% of the original number). Monitoring is required to determine whether the current rotation length is sufficient to allow these ferns to reach a size suitable for colonisation by epiphytes. When considering strategies for maintaining populations of tree-ferns and epiphytic species on clearfelled areas, increased number of tree-ferns remaining upright should be a high priority.

Other species utilise tree-ferns for food or nest sites (see Ough and Murphy, 1996), or find the moist, sheltered environment beneath the tree-fern canopy a suitable microclimate in which to reside. Studies are yet to establish whether populations of such species, many of which are likely to be poorly studied invertebrates and non-vascular plants, can be sustained in harvested areas after substantial declines in tree-fern abundance.

In addition to the abundance of individual associated species, the functioning of ecosystems will undoubtedly change with the decrease in abundance of tree-ferns. No other Wet Forest plants are physiognomically similar to tree-ferns. Moisture and temperature within the lower strata (including soil), light regimes, litter type and associated organisms and processes will inevitably alter. The maintenance of structural elements is fundamental to the maintenance of ecosystem processes (Lindenmayer and Franklin, 1997) and thus to ecologically sustainable forest management.

4.1.1. Implications for forest management

Clearfell harvesting is common and widespread in Wet Forest in Victoria. For example, 60% of *E. regnans* dominated Wet Forest within central Victoria occurs in State forest, two-third of which is available for clearfell harvesting (NRE, 1998). Therefore, in intensively harvested areas, over time (say an 80-year rotation), the area modified by clearfelling will be substantial (up to 40% of this forest type), resulting in a reduction in tree-fern populations and decline in the number of tall trunked tree-ferns available as substrate for other species. Given the long-lived, slow-growing nature of tree-ferns, and the apparently low recruitment rates, a major structural change will occur in forests subject to this treatment.

While tree-ferns are unlikely to become extinct in forests subjected to timber harvesting, it is clear that forestry operations have lead to changes in tree-fern abundance. Forest structure, especially in terms of the horizontal and vertical distribution of tree-ferns, and tree-fern size and age distribution, has also been changed. Such changes, if shown to be persistent, may contravene State and Federal strategies and policies (e.g. Commonwealth of Australia, 1992a; Technical Working Group on Forest Use and Management, 1995; State of Victoria, 1997; DPIE, 1998). This is an interesting test case for ecologically sustainable forest management, in particular with respect to temporal and spatial scales over which policies should operate: what degree of change is acceptable, over what area, and for how long?

Functionally, large-scale changes in common plant species are a cause for considerable concern to forest managers because:

(1) the impacts on a range of other biota are potentially extensive (particularly when the species is known as a source of food and habitat for many other species),
(2) the effects of successive harvesting events may be cumulative (especially for slow-growing species),

(3) there may be associated losses in genetic diversity, and
(4) the functioning and health of the ecosystem may inevitably have been altered.

Consequently, it is desirable that management should ensure that common species remain common across their natural range (Loyn, 1985).

Modifications to clearfelling practices can be implemented that ameliorate the decline in tree-fern populations. Ough and Murphy (1996, 1998) suggest measures such as tree-fern reserves within coupes ('Understorey Islands'), reducing the mechanically disturbed area within coupes, reducing the heaping of slash, reducing the intensity of slash-burns, and longer rotation periods to allow for trunk height growth to be sufficient for epiphyte establishment. Franklin et al. (1997) suggest that in order to best conserve species, forest structure, age structure and genetic diversity, a mix of dispersed and aggregated retention of vegetation be incorporated into forest management practices. Reserved tree-ferns could be aggregated (e.g. in Understorey Islands), with additional individuals dispersed throughout the coupe. Similar guidelines for the retention of vegetation (usually including overstorey) are recommended in a variety of forests in North America (Franklin et al., 1997).

While the primary focus of achieving ecologically sustainable forest management is at the landscape or ecosystem level, modifying silvicultural practices at the coupe or stand level may help meet objectives at these broader scales (Roberts and Gilliam, 1995; Spies, 1997). Reducing mortality of tree-ferns through the preservation of some populations within coupes, and lengthening rotations in some areas, is compatible with the maintenance of populations of species which are slow-growing or slow to recolonise. In the case of tree-fern decline, prevention is likely to be more effective as a management tool than cure.

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