Effects of selective logging and regeneration treatments on mortality of retained trees in Tasmanian cool temperate rainforest

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Summary

The mortality of major Tasmanian rainforest tree species, principally myrtle and sassafras, was recorded over 10–26 y on transects established to monitor myrtle wilt in trials of a range of selective logging and regeneration treatments and in an untreated control area. At the sites monitored for over 20 y, cumulative mortality of myrtle and sassafras ranged from 25% to 45% and 25% to 69% respectively. Following the logging and/or regeneration treatments, annual mortality of myrtle and sassafras was initially high at all sites, including the untreated control area. However, some 3–9 y after disturbance, mortality of myrtle had declined significantly and stabilised at background levels previously reported for undisturbed myrtle forests. Annual mortality of sassafras also declined but less than myrtle. Mortality rates at the control site followed a similar pattern to treated sites. The greatest increase in myrtle and sassafras deaths occurred in the area most heavily selectively logged. Areas lightly selectively logged and/or regeneration treatments had mortality increases similar to the control area. The importance of minimising tree damage to myrtle trees in any future operations to minimise spread of myrtle wilt is emphasised.

Keywords: logging effects; regeneration; mortality; myrtle; myrtle wilt; sassafras; *Atherosperma moschatum*; *Chalara australis*; *Nothofagus cunninghamii*; Tasmania; Australia

Introduction

Cool temperate rainforests in Tasmania provide a range of special timbers for sawlog, veneer and craftwood. Myrtle, *Nothofagus cunninghamii* (Hook.) Oersted, is the dominant rainforest species and its timber, particularly deep red myrtle, is highly prized for furniture making and other specialised uses. The Forests and Forest Industry Strategy (FFIC 1990) addressed the maintenance of an ongoing supply of special-species timbers and recommended a minimum supply target for deep red myrtle and sassafras of 5000 m^3 y^{-1}. The Tasmanian Regional Forest Agreement (RFA 1997) required that Tasmania review the volume, quality and economic accessibility of the deep red myrtle resource. This review concluded that the sustainable yield of deep red myrtle from selective logging operations would be less than the Forests and Forest Industry Strategy estimate due to the effects of myrtle wilt on retained trees, the reduction in available myrtle volume from mixed eucalypt/rainforest areas, and a recognition that earlier estimates of myrtle sawlog recovery were optimistic (Mesibov 2002).

A major influence in both natural and disturbed myrtle-dominated rainforest is the disease myrtle wilt (Kile and Walker 1987) caused by the pathogenic hyphomycete fungus *Chalara australis* Kile & Walker, which enters trees through wounds, broken branches and via root grafts. This disease is responsible for the death of individual trees and clumps in uneven-aged myrtle rainforests, thus facilitating natural gap-regeneration (Packham 1994). Elliott *et al.* (1987) previously assessed the incidence of myrtle wilt disease across 20 undisturbed rainforest sites and found a mean of 24.6% (range 9.5–53.4%) of myrtles to be dead or dying, with an estimated annual death rate of 1.6%. This mortality rate was later revised to 0.61% (range 0–1.73%) after further investigation of the time that individual myrtle trees took to die from the disease (Packham 1994). At this rate it would take some 113 y for half the mature trees to die, given a density of about 200 myrtle trees per hectare. When myrtle forests are disturbed by roading, logging or other influences, myrtle death can increase due to damage to remaining trees providing infection sites for myrtle wilt with a consequent lift in disease incidence and inoculum (Kile *et al.* 1989).

Since 1975, there has been significant research into the silvicultural requirements of rainforest special species and development of harvesting and regeneration regimes (Hickey and Felton 1991; Hickey and Wilkinson 1999). A variety of logging and regeneration trials were set up in cool temperate rainforests in north-western Tasmania between the mid-1970s and mid-1990s. From these trials, two main silvicultural regimes were developed for lowland myrtle-dominated rainforests (Forestry Tasmania 1998). Where a market for pulpwood exists, a minimum of 30 healthy, evenly spaced, overstorey trees per hectare are retained with at least half of these being myrtle. If there is no pulpwood market or the main objective is to minimise alteration of pre-logging stand structure, all non-sawlog trees are retained for seed and shelter, and canopy gaps are limited to less than 30 m.

Although these silvicultural trials generally produced good results, there was concern about death of retained trees from myrtle wilt in the longer term (Hickey and Felton 1991). To evaluate this threat, myrtle wilt transects were established in several of the logging and regeneration trials in the 1980s and 1990s. This paper reports the mortality of retained trees on these transects over a 10–26 y period and discusses the requirements for minimising the influence of myrtle wilt in any future logging operations.

Methods

Myrtle wilt disease was monitored on transects at five rainforest sites (Fig. 1) located in the Circular Head region of north-western Tasmania. Treatment and site factor information is given in Table 1. At each site the health of trees on the transect was assessed at irregular intervals following the application of selective harvesting and/or regeneration treatments as described below.

Sumac Road

At Sumac Road, transects were located in an area selectively harvested for sawlogs (area 1. GDA: 333360 E; 5444800 N) and an unlogged control area (area 9. GDA: 333650 E; 5443500 N) within the 140 ha Sumac rainforest logging and regeneration trial. The forest in the trial is dominated by tall myrtle with a sub-canopy of sassafras (*Atherosperma moschatum* Labill.) and leatherwood (*Eucryphia lucida* (Labill.) Baill). Hickey and Wilkinson (1999) have described the treatments and results of the trial.

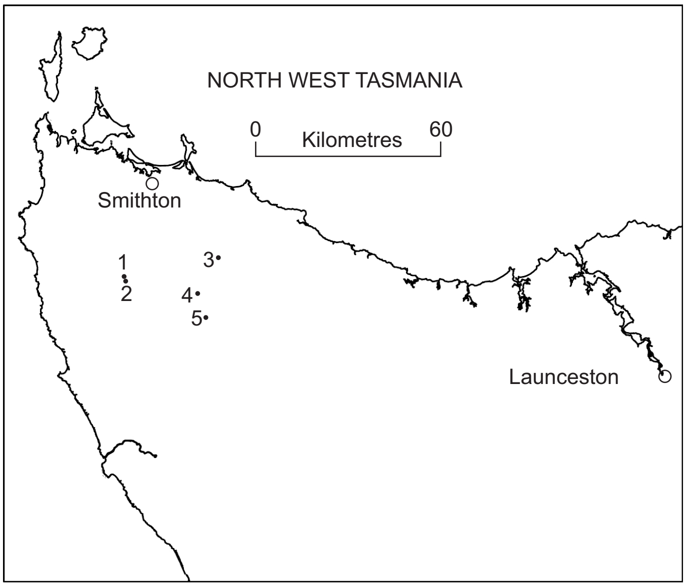

Figure 1. Location of myrtle wilt transect sites. 1 = Sumac area 1; 2 = Sumac area 9; 3 = Newhaven 016B; 4 = Pipeline 20-mile peg; 5 = Pipeline scarification trial.

The selectively-logged area (21 ha) was cut-over for sawlogs in November 1976. Due to the poor wood quality of many of the overmature trees, only 237 m^3 of sawlog (11 m^3 ha^{-1}) was recovered. Most of this volume was myrtle (92 m^3), sassafras (54 m^3) and leatherwood (59 m^3) — together with small volumes of blackwood (*Acacia melanoxylon*) and celery-top pine (*Phyllocladus aspleniifolius*). The forest structure was left largely intact following this light selective logging which retained at least 89% of the canopy. Patches of lightly disturbed and undisturbed seed bed with increased light availability were present after logging, and there was a large natural seed source in the many trees retained. This combination of seed source and available seedbed resulted in large numbers of myrtle and sassafras seedlings within two years of the logging.

Myrtle wilt transects were established in the selectively-logged area in August 1978 and in the unlogged control area in October 1980. All trees on each transect over 20 cm diameter over bark at breast height (dbhob) within 10 m each side of the centre line, and trees 5–20 cm dbhob within 3 m of the centre line were assessed and numbered with yellow paint. The species, dbhob and state of health of the trees (healthy, sick or dead) were recorded at assessments in 1978, 1983 and 2004.

Newhaven 016B

The Newhaven 016B logging and regeneration trial (GDA: 364300 E; 5451260 N) covered 48 ha of callidendrous rainforest and mixed forest (tall scattered *Eucalyptus obliqua* over a rainforest understorey) in the Newhaven Block. Selective logging took place in February–March 1994 producing a total volume of 920 m^3 (38 m^3 ha^{-1}), all of which was sawlog apart from 28 m^3 of eucalypt pulpwood. The area within the coupe where the transect was located contained rainforest species only.

Stems were retained at the rate of 126 ha^{-1} with the average number of myrtle, sassafras and blackwood stems retained being 73, 48 and 5 ha^{-1} respectively. The seed and shelter trees remaining after logging were of pulpwood quality or cull trees. The basic structure and visual quality of the rainforest were retained — with a canopy retention of at least 50%. A damage assessment in April 1994 showed that although the retained trees were generally in good condition, 27% had evidence of damage (stem wounds greater than 100 cm^2 or branches with a dob > 5 cm broken within 15 cm of the main stem). Some seed (mainly myrtle) fell in 1994 and a heavier seedfall occurred in 1995 resulting in good germination on most of the disturbed seedbed. A 600-m myrtle dieback transect through the trial was established and assessed in 1994. The first 400 m of this transect was assessed

Table 1. Treatments and site factors at the trial sites

Trial	Area (ha)	Treatment	Canopy retained	Parent material	Rainforest type*	Altitude (m)
Sumac area 1	21	Selective sawlogging	> 80%	Cambrian volcanic	Callidendrous/thamnic	200
Sumac area 9	19	Unlogged control	100%	Cambrian volcanic	Callidendrous/thamnic	200
Newhaven 016B	48	Selective logging	> 50%	Tertiary basalt	Callidendrous	240
Pipeline 20-mile	12	Selective logging	> 20%	Tertiary basalt	Callidendrous	460
Pipeline scarification	9	Mechanical scarification	100%	Tertiary basalt	Callidendrous	400

*After the Tasmanian rainforest classification of Jarman *et al.* (1984)

again in 2004 but no numbered trees could be located on the remaining 200 m.

Pipeline 20-mile peg

The pipeline 20-mile 12-ha trial (GDA: 360100 E; 5431400 N) was located on the western side of the iron-ore pipeline 32 km from the Savage River township and comprised tall, myrtle-dominated forest with a sub-canopy of sassafras and a few leatherwood trees. The trial was heavily selectively logged in March–April 1982 with a total of 1344 m^3 (112 m^3 ha^{-1}) of sawlog and pulpwood recovered. Myrtle comprised 92% of the 818 m^3 of sawlog (the remaining 66 m^3 being sassafras), and all of the 526 m^3 of pulpwood.

Before logging, seven well-crowned myrtle trees per hectare which did not contain sawlog were marked for retention as a seed source for regeneration. Following the logging, some 21 myrtle and 80 sassafras trees per ha with a dbhob > 20 cm remained, corresponding to a basal area of 12 and 7 m^2 ha^{-1} respectively. This level of retention implies that at least 20% of the canopy remained after harvesting. To extend the seedbed beyond that available from the logging disturbance, some areas of ferns, litter and logging slash were cleared with a bulldozer to expose mineral soil. An assessment of regeneration in March 1983 showed there was a good stocking of myrtle seedlings resulting from a heavy seedfall in February 1982, i.e. before the logging operation commenced.

A 360-m transect was established in March 1983 on which trees > 20 cm dbhob within 10 m each side of the centre line were assessed for health in a similar manner to the Sumac Rd trials. This transect was assessed on six occasions over the 20-y period from May 1984 to October 2004.

Pipeline scarification trial

The pipeline scarification trial (GDA: 357600 E; 5439300 N) was established in March 1984 within Rapid Compartment 25 to test the effectiveness of preparing a seedbed for regeneration by scarifying the soil prior to logging and then logging the stand once regeneration had established. The trial covered some 9 ha of callidendrous rainforest with some leatherwood on areas of poorer drainage. Mechanical scarification was carried out using a D6 bulldozer at the rate of 2 h ha^{-1} to remove litter and ferns and expose the mineral soil. Butt scrapes resulting from this operation were common on retained trees.

It was originally planned to selectively log the forest when the regeneration from the scarification was established. However, logging did not proceed as the market for myrtle pulpwood at the time was poor and the operation would have been uneconomic. Hence 100% of the canopy was retained after treatment. A 200 m × 20 m myrtle wilt transect was established and the diameter and health of all trees > 20 cm dbhob were recorded. The transect was assessed on five occasions between March 1983 and October 2004.

Results

The percentage tree mortalities on the transects over the monitoring period in each of the three selectively logged trials (Sumac area 1, Newhaven 016B, Pipeline 20-mile), the scarified unlogged trial (Pipeline scarification) and the unlogged control (Sumac area 9) are shown in Table 2. The percentage of myrtle tree mortality over time is shown in Fig. 2.

Mortality was variable across the trials. At the lightly-logged Sumac trial (area 1), the mortality of myrtle trees rose from 23.9% immediately following the logging in 1978 to 51.1% in 2004. However, the unlogged control area (area 9) showed a similar increase in myrtle mortality (7.9% to 33.3%) over a similar period (1980–2004). Despite these high mortality levels, the rainforest at both Sumac sites is multi-aged and structurally diverse, with little current sign of disturbance from the logging.

The two trials in the Pipeline area (20-mile and scarification trial) showed similar cumulative levels of myrtle mortality (44.8% and 37.5% respectively) some 20 y after establishment of the transects. However, at the 20-mile site (heavy selective logging) all myrtle trees were healthy when the transects were established; hence this site recorded the largest increase in mortality. On the other hand, 8.9% (of myrtle) were dead at the initial assessment at the scarification trial site (scarified only). The level of myrtle mortality has been stable in both these trials over the 12 y to the latest assessment in 2004. At the Newhaven site (moderate selective logging), myrtle mortality increased from zero at transect establishment to 17.2% in 2004, but the monitoring period was only 10 y compared with 20+ y at the other trial sites.

Mortality rates for myrtle in the five trials ranged from 1.05% y^{-1} at the lightly logged Sumac area 1 site to 2.13% y^{-1} at the heavily logged Pipeline 20-mile peg site. Where windthrown trees are removed from the calculation, annual mortality for myrtle ranges from 0.88% in the unlogged control trial at Sumac area 9 to 1.31% at the Pipeline 20-mile site.

Comparison of the annual myrtle mortality rates during the final assessment interval with those from transect establishment to penultimate assessment, shows rates stabilised dramatically at all sites. At the Pipeline scarification site the myrtle mortality rate was zero over the final 12 y compared with 3.67% y^{-1} over the initial period of 8 y. At the other sites, mortality rates over

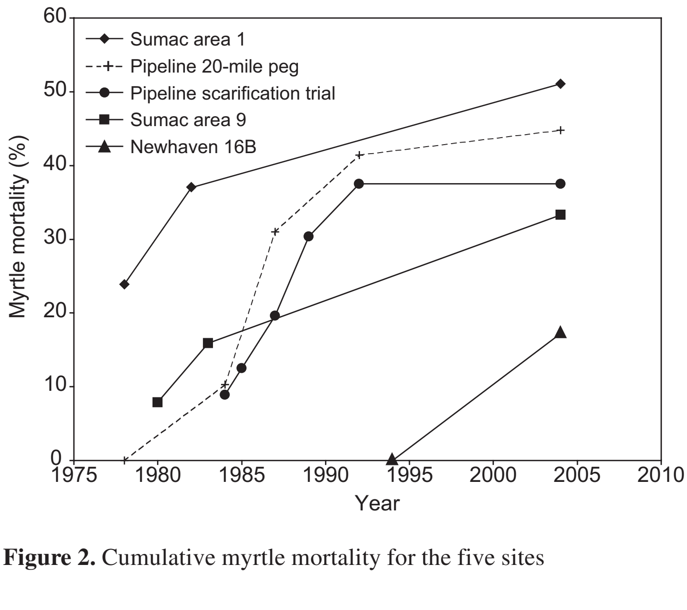

Figure 2. Cumulative myrtle mortality for the five sites

Table 2. Tree mortality on myrtle wilt transects

(a) Sumac area 1 (light selective logging)

Species	No. trees	Mortality (% cumulative)		
		24/6/1978	11/1/1982	3/8/2004
Myrtle	92	23.9	37	51.1
Sassafras	46	2.2	8.7	45.7
Leatherwood	37	0	0	27
Celery top	2	0	0	50
Total	177	13	21.5	45.2

(b) Sumac area 9 (control)

Species	No. trees	Mortality (% cumulative)		
		2/4/1980	15/6/1983	4/8/2004
Myrtle	63	7.9	15.9	33.3
Sassafras	11	0	9.1	54.5
Leatherwood	16	0	0	12.5
Pittosporum	1	0	0	100
Total	91	5.5	12.1	33

(c) Newhaven 016B (moderate selective logging)

Species	No. trees	Mortality (% cumulative)	
		19/4/1994	4/8/2004
Myrtle	29	0	17.2
Sassafras	15	0	0
Blackwood	2	0	0
Total	46	0	10.9

(d) Pipeline scarification trial

Species	No. trees	Mortality (% cumulative)					
		May 1984	Apr 1985	Sep 1987	Jul 1989	Feb 1992	Oct 2004
Myrtle	56	8.9	12.5	19.6	30.4	37.5	37.5
Sassafras	20	0	5	20	20	25	25
Leatherwood	9	0	11	22.2	22.2	22.2	22.2
Blackwood	1	0	100	100	100	100	100
Eucalypt	1	0	0	0	0	0	0
Total	87	5.7	11.5	19.5	27.6	33.3	33.3

(e) Pipeline 20-mile peg (heavy selective logging)

Species	No. trees	Mortality (% cumulative)				
		Mar 1983	Feb 1984	Dec 1987	Feb 1992	Oct 2004
Myrtle	29	0	10.3	31.0	41.4	44.8
Sassafras	51	0	5.9	27.5	41.2	68.6
Total	80	0	7.5	28.8	41.3	60

the final 21–22 y were considerably lower than those recorded in the initial 3–9-y periods. Annual mortality rates for sassafras followed a pattern similar to those of myrtle but did not decline to the same extent over the final assessment interval (Table 3).

The cause of death of trees on the transects is summarised in Table 4. Individual trees were not examined in detail to determine mortality factors, except to note occurrences of windthrow, felling by neighbouring trees and heavy attack on myrtle stems by the mountain pinhole borer, *Platypus subgranosus* Schedl. (a good indicator of myrtle wilt infection). From our previous experience with myrtle wilt, this disease appears to be the cause of death of most if not all dead standing myrtle trees (Elliott *et al.* 1987). For the purposes of this assessment it was assumed that all remaining standing dead myrtles on the transects were killed by myrtle wilt. A small number of trees were felled by falling neighbouring trees and they were included in the windthrown category. For all species other than myrtle, the cause of death was ascribed to windthrow or unknown causes.

A large number of sassafras trees died during the monitoring period on most transects, with mortality reaching 68.6% on the

Table 3. Comparison of annual mortality rates of myrtle and sassafras between final and previous assessment intervals*

	Period 1	Mortality rate (%)	Period 2	Mortality rate (%)
Sumac area 1	1978–1982		1982–2004	
Myrtle		3.74		0.62
Sassafras		1.81		1.64
Sumac area 9	1980–1983		1983–2004	
Myrtle		2.50		0.82
Sassafras		2.84		2.14
Pipeline scarification	1984–1992		1992–2004	
Myrtle		3.67		0
Sassafras		3.21		0
Pipeline 20-mile	1983–1992		1992–2004	
Myrtle		4.65		0.27
Sassafras		4.62		2.17

* Newhaven 016B was assessed only twice, i.e. it had only one assessment interval

Table 4. Mortality factors

Species	No. trees killed	Cause of death		
		Myrtle wilt	Windthrow	Unknown
Sumac area 1 (selectively logged)				
Myrtle	47	46	1	0
Sassafras	21	0	3	18
Leatherwood	10	0	0	10
Celery top	1	0	0	1
Sumac area 9 (control)				
Myrtle	21	16	5	0
Sassafras	6	0	0	6
Leatherwood	2	0	0	2
Pittosporum	1	0	0	1
Newhaven 016B (selectively logged)				
Myrtle	5	5	0	0
Sassafras	0	0	0	0
Blackwood	0	0	0	0
Pipeline scarification trial				
Myrtle	21	19	2	0
Sassafras	5	0	4	0
Leatherwood	2	0	2	0
Blackwood	1	0	1	0
Eucalypt	0	0	0	0
Pipeline 20-mile peg				
Myrtle	13	8	5	0
Sassafras	35	0	6	29

Pipeline 20-mile peg transect. Fallen trees rotted away very quickly and only limited or no evidence of their existence could be found in several cases. Across the three sites where leatherwood occurred on the transects, its mortality since transect establishment ranged from 12.9% at the Sumac area 9 control site to 27% at the selectively logged Sumac area 1 site.

Discussion

The cumulative mortality for myrtle and sassafras at the final assessment (2004) was high at all sites, including the undisturbed control (Sumac area 9). However, the percentage mortalities for myrtle were all within the range 9.5–53.4% (death from myrtle wilt only) found in a previous survey of undisturbed myrtle forests (Elliott *et al.* 1987).

Annual mortality rates for myrtle were all within the 0–1.73% range found in undisturbed myrtle forests (Packham 1994). However, there was a clear trend in myrtle mortality rates with time at all sites except Newhaven 016B where a pattern could not be determined because only two assessments were conducted. After an initial period of high myrtle mortality following disturbance the rates declined substantially to stabilise around or below the background levels operating in undisturbed rainforest. This result provides strong support for the hypothesis of Packham (1994) that mortality rates may stabilise after a reasonable period (about 10 y) following disturbance, although at some sites in the present study this has occurred within 3–4 y.

The trends in myrtle mortality occurred regardless of the type of treatment imposed, whether heavy or light selective logging or scarification alone. Myrtle mortality rates at the undisturbed control site followed a similar pattern, a result which is difficult to explain. Because myrtle wilt was present at the control site at the time of transect establishment, the increase in disease level, together with that on disturbed sites, may indicate a general rise in activity of the disease. Road access to the Sumac trial area was built some 3–4 y before establishment of the transects and, although very localised, this disturbance may have contributed to an overall increase in myrtle wilt incidence in the area. Packham (1994) noted that the effect of roading and other disturbances on the incidence of myrtle wilt in adjacent forest was very variable. In extreme cases, the disease spread up to 180 m from roading disturbance over 13 y before its incidence fell to the background level known from plots in the undisturbed forest. The transect at the Sumac Rd control site commenced 37 m from the road and continued at right angles to the road for 300 m. There was no obvious pattern of disease spread from the road to the start of the transect or along the transect, unlike the sites noted by Packham where there was a clear progression of tree death from myrtle wilt extending into the forest from the road edge. Apart from the roading disturbance there were no other obvious factors operating at the time, such as drought, which would influence disease levels in the control area.

The myrtle wilt transects at all sites, except Newhaven 016B, were assessed in 1987–1988 by Packham (1994) who reported annual myrtle mortality rates from myrtle wilt of 0.93–7.0% y^{-1}. However, these results were based only on assessments of numbered trees with diameters > 20 cm whereas in the present study all trees on the transect were assessed. In addition, Packham based mortality rates on the total of dead trees plus ‘sick’ trees, a category which included live trees but with major crown dieback. In the present study, only dead trees were included in the mortality figures as we now know that trees with major crown dieback can stay alive for many years.

Sassafras appears to have a high turnover in these rainforests, with generally high cumulative mortalities (up to 68.6%) recorded at all sites except Newhaven 016B where no mortality of this species occurred. Annual mortality of sassafras ranged from 0–3.26% with the highest levels recorded over a 20+ y period in the selectively logged Pipeline 20-mile site (3.26% y^{-1}) and the unlogged Sumac area 9 control site (2.27% y^{-1}). However, young individuals (mostly of vegetative rather than seedling origin) of this species were common along the transects, including areas where mature trees had died. Hence the high mortality levels of sassafras do not appear to be affecting its overall representation in the stands.

Although significant mortality of myrtle occurred at all sites, the greatest increase in cumulative mortality of this species was recorded at the most heavily logged site, Pipeline 20-mile from a combination of myrtle wilt and windthrow. It follows that although myrtle wilt is an important agent for the regeneration process, any imposed disturbances will require very high levels of operational care and effective monitoring — with strict damage level targets to prevent excessive escalation of mortality. Damage levels may need to be kept below 10% of retained stems, which is the tolerable level of damage allowed in monitored partial harvesting operations in highland *Eucalyptus delegatensis* R.Baker forests (Neyland and Cunningham 2004).

Importantly, in all trials the basic multi-aged structure of the rainforest has not been affected by the range of treatments imposed and evidence of disturbance is not readily apparent at the lightly logged and scarified sites. The normal process of gap regeneration was in evidence at all sites through significant recruitment of myrtle, sassafras and leatherwood seedlings.

This favourable result can be contrasted with the structure of regeneration following sparse seed-tree retention in similar rainforest. Jennings and Hickey (2003) reported that little semblance of the original forest structure was evident when 16 myrtle seed trees per hectare were retained. Most seed trees had died from myrtle wilt or windthrow over 20 y and the stand was dominated by very dense myrtle and leatherwood regrowth. On this basis, intensive seed-tree systems are not recommended for myrtle rainforest. In most cases selective logging for sawlogs retaining at least 50%, and sometimes more than 80%, of the forest canopy is prescribed (Mesibov 2002). We believe, on the basis of the data presented in the current study, that harvesting operations that retain at least 50% of the canopy, and where damage to retained stems is kept to a practical minimum, will maintain an ongoing multi-aged structure.

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