Age and stand structure in a multi-aged wet eucalypt forest at the Warra silvicultural systems trial

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Abstract

Ring counts were used to examine tree age and size relationships for five multi-aged wet Eucalyptus obliqua *forest stands within the 200 ha Warra silvicultural systems trial site. Fifty-six* E. obliqua *stumps were sampled from five 0.1 ha plots on which the diameter and crown class of trees greater than 10 cm dbh had been assessed prior to felling. The sampled stumps ranged in diameter from 14 to 279 cm.*

The forest structures included several regrowth (up to 110 years old) and several possible oldgrowth (> 110 years old) cohorts. All five stands had cohorts arising from fires in 1934 and 1898, as well as older trees pre-dating the 1898 fire. A 1914 cohort was also present in four of the stands.

There was a large diameter range within any single regrowth cohort and a large overlap in diameter range between regrowth cohorts across all five stands. This indicated that age inferences based on tree size alone are unreliable. Tighter diameter ranges for cohorts were observed on a plot basis, indicating that diameter and age are more closely related on a stand scale. The relationship between age and diameter was much stronger for dominant and codominant trees than for subdominant and suppressed trees.

The measured age range of individual regrowth cohorts varied from seven to ten years. This variation was attributed to a combination of ring-counting error, variable growth rates to achieve the sampled stump height and to protracted germination periods following non-stand-replacing fires.

The ring counts for oldgrowth trees were of low reliability due to the presence of hollows, rot and narrow annual growth rings. The counts indicated that eucalypts originated, presumably after wildfires, in each century from the 1500s to the present. There has been a modest increase in fire frequency at the site in the 200 years since European settlement.

Introduction

Fire is the most prevalent major disturbance event in wet eucalypt forests in Tasmania and usually results in their regeneration (Gilbert 1959; Wells and Hickey 1999). Evidence from ring counts of scrub species suggests that wildfires occurred in the tall wet eucalypt forests at the Warra Long-Term Ecological Research (LTER) Site in southern Tasmania in 1898, 1906, 1914 and 1934 (Hickey *et al.* 1999). The pre-1898 fire history for the Warra area is poorly known, although Marsden-Smedley (1998) indicates that major fires were recorded in other parts of south-western Tasmania in 1837, 1851, 1859, 1861–62 and 1887–88.

The 15 900 ha Warra LTER Site contains a 200 ha silvicultural systems trial (SST) where alternative harvesting systems to large clearfells are being established in wet eucalypt forest (Hickey *et al.* 2001). The

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purpose of this study was to document the pre-logging age and stand structure of the forest at the Warra SST and to determine the fire history of the site from 1898 back to the origin of the oldest extant eucalypts. This information can be used in the future to compare natural stand structures with those that result from alternative silvicultural treatments applied at the site. Knowledge of the natural structures is also important when interpreting pre-harvest and future biodiversity assessments.

Age structures are often inferred from variations in tree diameter. However, Harper (1977) notes that the assumption that tree diameter reflects age is often false, even for even-aged forests where marked differences in the sizes of individuals quickly develop. The frequency distributions of tree sizes in such even-aged stands frequently become exponential (Harper 1977). Smith *et al.* (1997) note a stand's height profile is a better indicator of age structure, at least for young stands, but the best assessments of the age structure come from a knowledge of tree age.

Various options are available to estimate tree age. Indirect methods include radiocarbon dating (e.g. Wellington *et al.* 1979), tree diameter – tree age relationships (e.g. Bradshaw and Raynor 1997), and tree size – radial growth rate relationships (e.g. Mawson and Long 1994). Direct methods include counting the number of annual growth rings from the pith to the outer cambium of cross-sections from high wood-density species or increment cores from low wood-density species (e.g. Ogden 1981; Banks 1982; Woodgate *et al.* 1994).

The presence of kino in the annual growth rings of eucalypts can be used to reconstruct fire history for particular eucalypt forests. Jacobs (1955) reported from field experiments that fire, together with insects and branch shedding, has a significant effect on the formation of kino in eucalypts. Studies in the Florentine Valley of southern Tasmania found correlations between resin occurrence and fire history for different aged eucalypt trees (Mount 1964).

The specific objectives of the current study at the Warra SST were to identify the regrowth (up to 110 years old) and oldgrowth (> 110 years) cohorts, determine the diameter at breast height (dbh) spread of a single cohort, investigate the degree of overlap in diameter at breast height between different cohorts, investigate the relationship between diameter and age, and provide inferences on stand structure.

Methods

Study site

The Warra silvicultural systems trial is located in southern Tasmania at latitude 43°04′S, longitude 146°41′E and covers 200 ha at an elevation of 80–240 m on a southerly aspect, uniform slope and on soils mostly derived from Jurassic dolerite. Average annual rainfall is 1080 mm. The wet *Eucalyptus obliqua* forest has a height of 40–65 m and is multi-aged (Hickey *et al.* 1999). Eucalypt diameters (dbh) vary widely from less than 20 cm to more than 2 m. Understoreys range from dense *Gahnia grandis* and *Melaleuca squarrosa* on soils with impeded drainage to *Pomaderris apetala* and *Nematolepis squamea** on well-drained soils (Neyland 2001). Long unburnt patches have thamnic or callidendrous (*sensu* Jarman *et al.* 1994) rainforest understoreys.

A 20 m x 50 m (0.1 ha) permanent inventory plot was established prior to logging in each of the five coupes of the Warra SST logged between 1998 and 2000 (Table 1). Information on the location, diameter, assessed volumes and crown classification of the trees was recorded for each plot prior to felling. The crown classes were 1 = dominant, 2 = codominant, 3 = sub-dominant, 4 = suppressed. The plots,

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* Formerly known as *Phebalium squameum* (see Wilson 1998).

Table 1. Location, forest type, harvest end date and plot establishment dates for the five 0.1 ha CFI-SST plots sampled for age estimates at the Warra SST. (R = regrowth eucalypts; M = mature eucalypts)

Plot number	Plot location*	Forest type†	Plot measurement	Harvest end date
1A	E475936 N5228268	R/M	05/1997	06/1999
1B	E475431 N5228321	R/M	05/1997	03/1998
8B	E474951 N5228536	R/M	11/1997	12/1998
8C	E473708 N5228689	R/M	05/1997	11/1999
8H	E474200 N5228400	R/M	05/1997	12/2000

* Grid references from *Picton* sheet 4622, all positions are by GPS except WR008H which is estimated from a 1:25 000 map.

† As defined by Hickey *et al.* (1999).

Table 2. Number of stumps sampled from the five CFI-SST plots located in the Warra LTER Site and the reliability of the ring counts performed on each of the discs sampled. (L = low reliability, M = moderate reliability, H = high reliability)

Plot number	Eucalypts present in plot	Stumps sampled	Reliability (L, M, H)
1A	11	9	L = 6, M = 3
1B	11	11	L = 6, M = 4, H = 1
8B	13	9	L = 8, M = 1
8C	41	20	L = 10, M = 10
8H	21	7 *	L = 3, M = 4
Total	97	56	L = 33, M = 22, H = 1

* Trees sampled from around the CFI-SST plot due to difficulty in defining the plot boundary.

known as CFI-SST plots, are similar to Continuous Forest Inventory (CFI) plots established on a stratified random basis in eucalypt forests containing regrowth (Forestry Commission 1985), the differences being that the CFI-SST plots are half the length and subjectively located. The CFI-SST plots were located in each planned coupe by choosing the central point of the dominant photo-interpreted (PI) forest-type in each coupe (Edwards 2001). The point was then located in the field and a plot established perpendicular to the contours after deciding, on the toss of a coin, whether to lay the plot uphill or downhill. The CFI-SST plots were selected for this study to allow ring counts on the stumps and to utilise previous measurements (location, dbh, volume and crown class data) to investigate stand structure. *Eucalyptus obliqua* was the dominant overstorey species in all five CFI-SST plots.

The CFI-SST plots are named according to their relevant coupe identification numbers. For example, the plot in WR001A (Warra 1A) is referred to as 1A.

Sampling and aging of trees

Plot boundaries were relocated in January 2001 and the positions of eucalypt stumps within each of the plots were identified. Discs or partial discs of 5–10 cm thickness were cut from 56 *E. obliqua* stumps using a chainsaw (Table 2). Only stumps with minimal damage following coupe harvesting and burning operations were sampled. Stumps were sampled at heights that ranged from two to 110 cm above

Photo 1. A planed stump of regrowth Eucalyptus obliqua *is ring counted at CFI-SST plot 1B.*

ground level. Four of the five coupes had been burnt, to establish regeneration, prior to January 2001 but coupe 8H had yet to be burnt. Here the precise boundaries of the CFI-SST plot could not be relocated beneath large amounts of harvesting slash. The seven stumps sampled from WR008H were within close proximity of the plot but not necessarily on it; hence, no diameter measurements could be ascribed to the sampled stumps.

Discs were then planed and in some cases sanded to produce a smooth surface. Tree growth rings were identified by the denser and darker coloured latewood bands, assuming tree growth to be seasonal. It was found that the rings were more easily discerned when the discs were moistened with water.

Two ring counts were made by eye on each disc, along radii with the most distinct growth ring sequence free of knots, bark inclusions and rot. The most reliable sequence of growth rings was chosen for the final age estimate of regrowth stumps but averages were applied to oldgrowth eucalypt stumps because it was less clear which radii were most reliable. Intra-annual bands or 'false rings' were identifiable when they were abnormally narrow, faint or failed to be recognised around the entire circumference of the disc. Adjustment was made for age to stump height by assuming trees grew 0.3–0.5 m by age 1. When rot or hollow piths made ring counting impossible, the distance from solid wood to the estimated tree centre was predicted based on the annual ring widths closest to the pith. A notional reliability class was assigned to each count as follows: high (up to 5% error), medium (up to 10% error) and low (up to 15% error). Plot number, tree number, previous diameter at breast height and crown class, stump height and stump diameter over bark, pith radius and pith age estimate (where appropriate), total age estimate, and reliability were recorded for each sampled stump.

Examining stem injury

The fire history of five stands in the Warra SST was investigated using the presence of kino within the annual rings of the sampled discs. Kino rings were recorded and the date of occurrence estimated based on the tree age estimate.

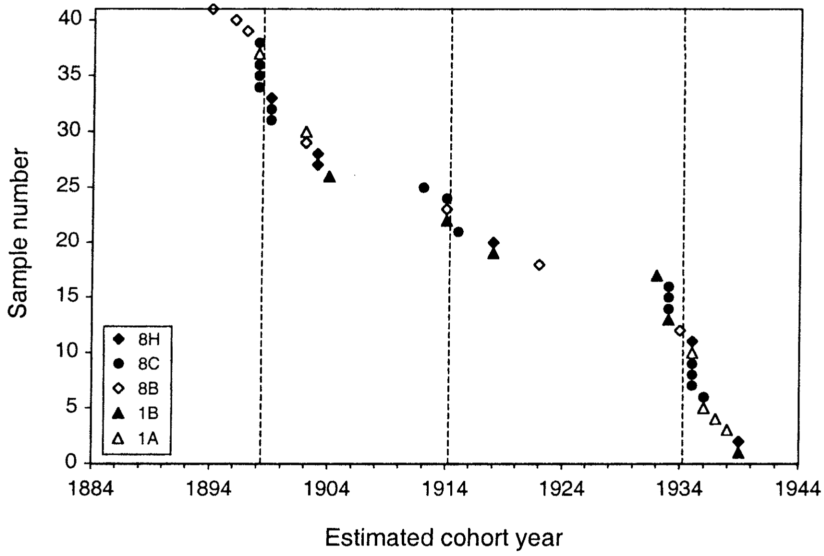

Figure 1. Predicted regrowth cohort ages estimated from regrowth Eucalyptus obliqua *in five CFI-SST plots in the Warra silvicultural systems trial.*

Stand structure

Mature Forest Inventory (MFI) plots were also measured in each of the five coupes prior to logging. Generally, MFI plots were 20 m x 100 m in size, with a plot in each major PI type contained within the coupe (three to four plots in total per coupe). Oldgrowth eucalypt stems 10 m either side of the plot centre line, regrowth eucalypt stems 5 m either side of the line and blackwood and rainforest 5 m to the left of the line were measured for diameter and crown class. Stems less than 10 cm dbh were not recorded. The data from the CFI-SST and MFI plots of the same photo-interpreted PI type were combined for each coupe to give an estimate of stand density and diameter distributions. The combined sample areas are at least five times the areas of the CFI-SST plots alone.

Diameter growth

The age and diameter data from the sampled trees allowed an estimate of eucalypt growth rates in the multi-aged stands at the SST. The relationship between diameter and age was investigated by plotting lines of best fit for sampled trees up to 250 years old within each of the four crown classes. The strength of the relationship was indicated by the R^2 value, which indicates the proportion of variation in diameter that is explained by the variation in age.

Results

Ring counts were made on a total of 56 stumps (41 regrowth and 15 oldgrowth) from the five CFI-SST plots. Table 2 provides a summary for each plot of the number of trees sampled and the ring-count reliability breakdown. Fifty-nine per cent of the counts (21 regrowth and 12 oldgrowth) were deemed to have low reliability, 39% (19 regrowth and three oldgrowth) were of moderate reliability and less than 2% (one regrowth) were considered highly reliable.

Regrowth cohorts

Figure 1 shows the distribution of regrowth trees by estimated cohort year. There are three distinct clusters of tree ages that correspond to three of the four regrowth

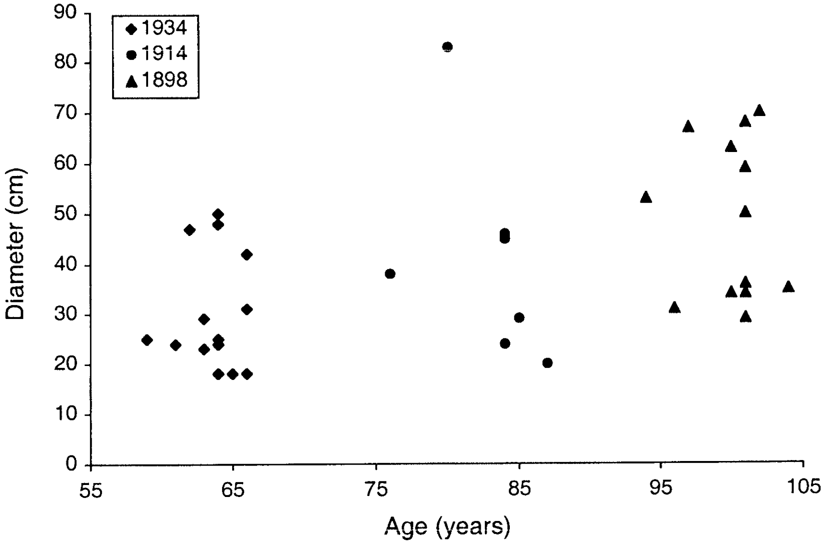

Figure 2. Diameter range for the three regrowth cohorts present at Warra SST. Data from WR008H are not included because the diameters were not known.

cohorts identified by Hickey *et al.* (1999). The mean age estimates, determined from the three distinct groups in Figure 1, coincide with the 1898, 1914 and 1934 major wildfire occurrences at the Warra site. The only tree ages close enough to be associated with a 1906 wildfire (recorded by Hickey *et al.* (1999) for an adjacent stand) appear to have established prior to this time. In the other three cohorts, the cluster of trees was generally skewed to the right; that is, the majority of trees were estimated to be established either during the wildfire year or later. Hence, it does not appear that a cohort from the 1906 fire is present in the Warra SST. All three regrowth cohorts are present in four of the stands sampled (1B, 8B, 8C and 8H). Plot 1A has only two cohorts, 1898 and 1934.

The diameter spread of the three regrowth cohorts is shown in Figure 2. It is apparent when pooling the data from all coupes sampled that there is both a large diameter spread within a single cohort and a large overlap in diameter range between the three cohorts. The maximum diameter range of a single regrowth cohort spanned 63 cm (1914 cohort) and the minimum range had a spread of 32 cm (1934 cohort). The 1898 cohort spanned 41 cm. Although there was an overlap in diameter among cohorts, the average diameter increased with age (Table 3). Table 4 shows the diameter ranges of each of the cohorts by coupe and shows there is a smaller overlap between cohorts within a single plot. Generally, there is better segregation between the diameters of the trees from the 1934 and 1898 cohorts, although in many cases only one or two trees have been sampled from each cohort. The maximum diameter range of any cohort in a CFI-SST plot is 39 cm.

The range of ages attributed to each regrowth cohort is presented in Table 5 and can be seen clearly in Figure 2. An age spread of between seven and ten years is associated with the three regrowth cohort age estimates. It is impossible to separate the errors associated with ring counts, the variation in time over which eucalypts may regenerate following disturbance, the variable growth to stump height, and the occurrence of multiple ring years (spring and autumn growing seasons). Hence, it is uncertain whether this age spread is a real effect. The increasing age range associated

Table 3. The diameter range for the three regrowth cohorts in the multi-aged wet eucalypt forest at the Warra SST.

Cohort	Number of sample trees	Minimum dbh (cm)	Maximum dbh (cm)	Dbh (cm) range	Mean dbh (cm)*
1934	15	18	50	32	29 (15.7)
1914	7	20	83	63	41 (21.2)
1898	13	29	70	41	48 (15.7)

* Standard deviation shown in parentheses.

Table 4. Diameter ranges of the three regrowth cohort years by plot. The number in the parentheses is the number of sample trees per cohort.

Plot	Min. and max. of dbh, 1934	Range	Min. and max. of dbh, 1914	Range	Min. and max. of dbh, 1898	Range
1A	23–48 (4)	25	-		50–67 (2)	17
1B	18–42 (3)	24	45–83 (2)	38	53 (1)	
8B	50 (1)		38–46 (2)	8	31–70 (4)	39
8C	18–31 (7)	13	20–29 (3)	9	29–63 (6)	34

Table 5. Age spread associated with stem-age estimates from the three regrowth cohorts in the multi-aged wet eucalypt forest at the Warra SST.

Cohort	Maximum age estimate	Minimum age estimate	Age spread	Number of sample trees
1934	1932	1939	7	17
1914	1912	1922	10	8
1898	1894	1904	10	16

with increasing cohort age is possibly the result of increased difficulty of counting rings from older trees because they had more occurrences of rot and pith hollows and narrower and fainter growth rings.

Oldgrowth cohorts

The oldgrowth trees were estimated to have originated from about 1500 to 1876 (Figure 3) but the ring counts were mostly classed as being of low reliability. It is unclear what oldgrowth cohorts are present, but there could be up to six cohorts represented in the sample over the period 1500 to 1900 (Table 6). The small sample size for the oldgrowth eucalypts also limited the ability to segregate trees into particular cohorts. The absence of possible cohorts in some plots may be a sampling effect rather than a real absence from the coupe.

Crown class

Nine of the 49 trees sampled that had been previously scored for crown class were dominants. They included six oldgrowth trees between 89 and 214 cm dbh and three trees from the 1898 cohort that were between 60 and 82 cm dbh. The codominant (12) and subdominant (17) trees were spread across all cohorts and covered a large span of

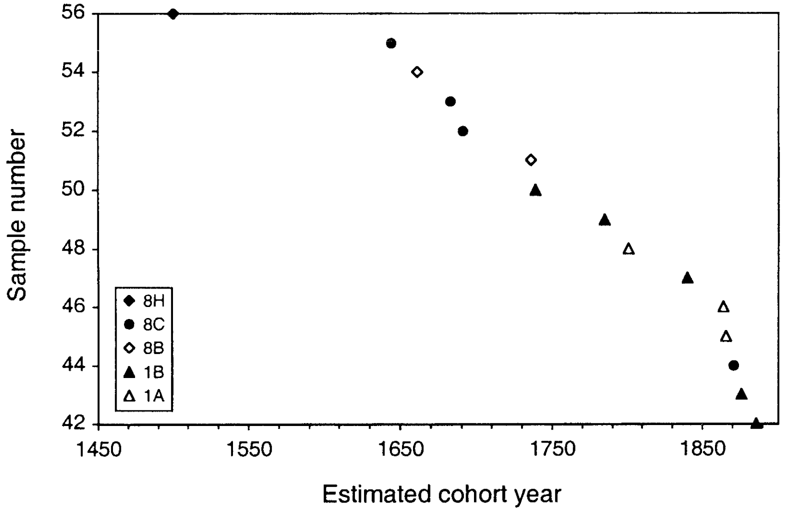

Figure 3. Ages estimated from oldgrowth Eucalyptus obliqua *in the CFI-SST plots.*

Table 6. Likely cohorts of oldgrowth trees using age estimates from five CFI-SST plots at the Warra SST.

Possible cohorts (average of grouped ages)	Grouped age estimate	Plots which had a tree from this cohort
	1500?	8H
1670	1644,1661,1683,1691	8C 8B
1740	1736,1739	8B 1B
1790	1785,1801	1B 1A
	1840	1B
1873	1864,1866,1871,1876,1886	8C 1B 1A

diameters. The majority of the eleven suppressed trees that were sampled were from the 1914 and 1934 cohorts and were no larger than 30 cm dbh.

Diameter versus age relationship

The relationship between diameter and age for sampled trees up to 250 years old is shown in Figure 4. The figure shows that the strength of the relationship varies with crown class. The relationship for dominant and codominant trees was strong, with R^2 values of 0.94 and 0.76 respectively, but was weak for subdominant trees, and non-existent for suppressed trees.

Kino occurrences

Relating the occurrence of kino with fire history was unsuccessful. A total of 48 occurrences was recorded within the annual rings of the 56 tree discs sampled. Nine discs showed kino occurrence between 1962 and 1970, eight discs between 1973 and 1978, four discs between 1920 and 1922, three discs between 1939 and 1940, three discs between 1914 and 1915, three discs during 1980, two discs during 1982 and two discs between 1984 and 1985. These results indicate that the majority of kino occurrences were not correlated with fire history. The 1914 fire event appears to be

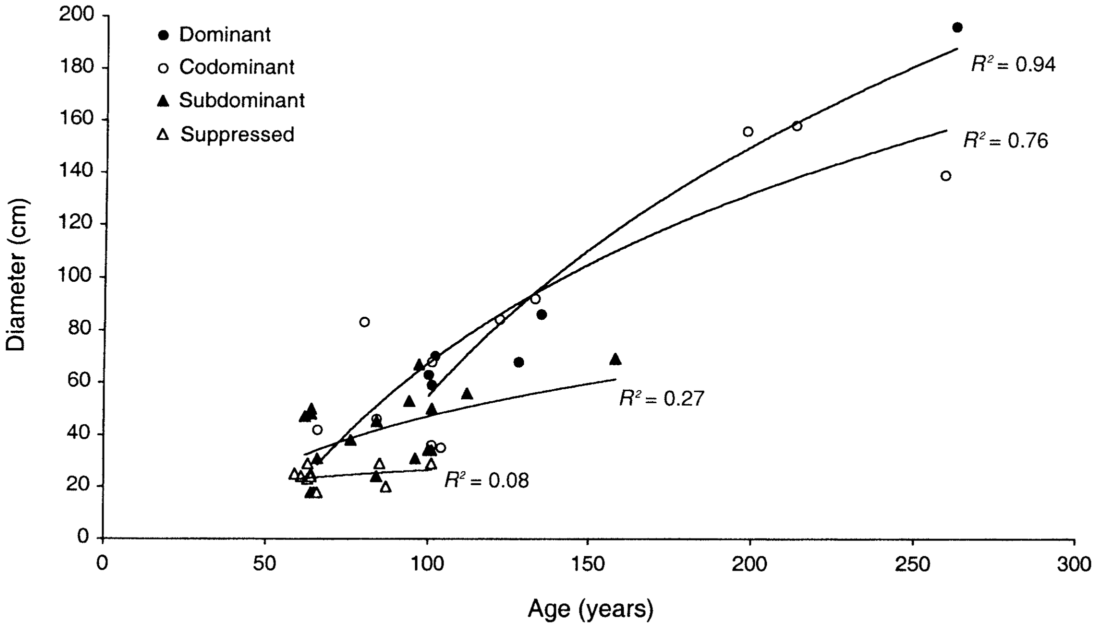

Figure 4. Diameter versus age for sampled trees of each crown class: dominant, codominant, subdominant and suppressed.

the only fire event recorded in the kino sequences from the Warra SST, with most identified kino occurrences being in the fire-free period after 1934.

Stand structure

Figure 5 shows the percentage of stems in 10 cm diameter classes for the 1A, 1B, 8B and 8C stands. The 1A and 8B stands have similar densities of eucalypts (107 and 138 stems/ha), 1B has almost double this, 303 stems/ha, and 8C has 562 stems/ha. The stand diameter distributions at 8C and 1B have a reverse J-shaped (or negative exponential) curve. The stand density at 8C was high, with 53% of the stems falling into the 11–30 cm size classes. Table 4 suggests the majority of the trees in this size class would have resulted from the 1934 or 1914 fire. Observations of severely burnt oldgrowth on these plots and the large numbers of small regrowth suggest that the 1934 fire disturbance was locally severe in this area. Seventy-one per cent of stems at 1B were less than 40 cm dbh. Table 4 suggests that stems under 42 cm in diameter are more likely to be from the 1934 fire and stems over 45 cm in diameter are likely to have been established after either the 1914 or 1898 fires.

The 8B stand shows a modal pattern and Table 4 suggests the regrowth stems include 1934, 1914 and 1898 cohorts. The 1A stand shows little pattern and, unlike the other three stands, does not have any trees less than 20 cm dbh. Table 4 suggests that stems greater than 50 cm dbh have arisen from the 1898 fire and those less than 48 cm dbh from the 1934 fire. Over half of the regrowth stems present are likely to have established from the 1898 fire which indicates that the 1934 fire was not stand-replacing. The lack of stems less than 20 cm dbh may be a result of a number of factors: perhaps a better site quality at the 1A stand or a lack of competition due to the absence of the 1914 fire.

Only two of the stands, based on the combined CFI-SST and MFI data, contained blackwood (*Acacia melanoxylon*) or commercial rainforest species greater than 10 cm dbh. The 1B stand had 14 stems/ha

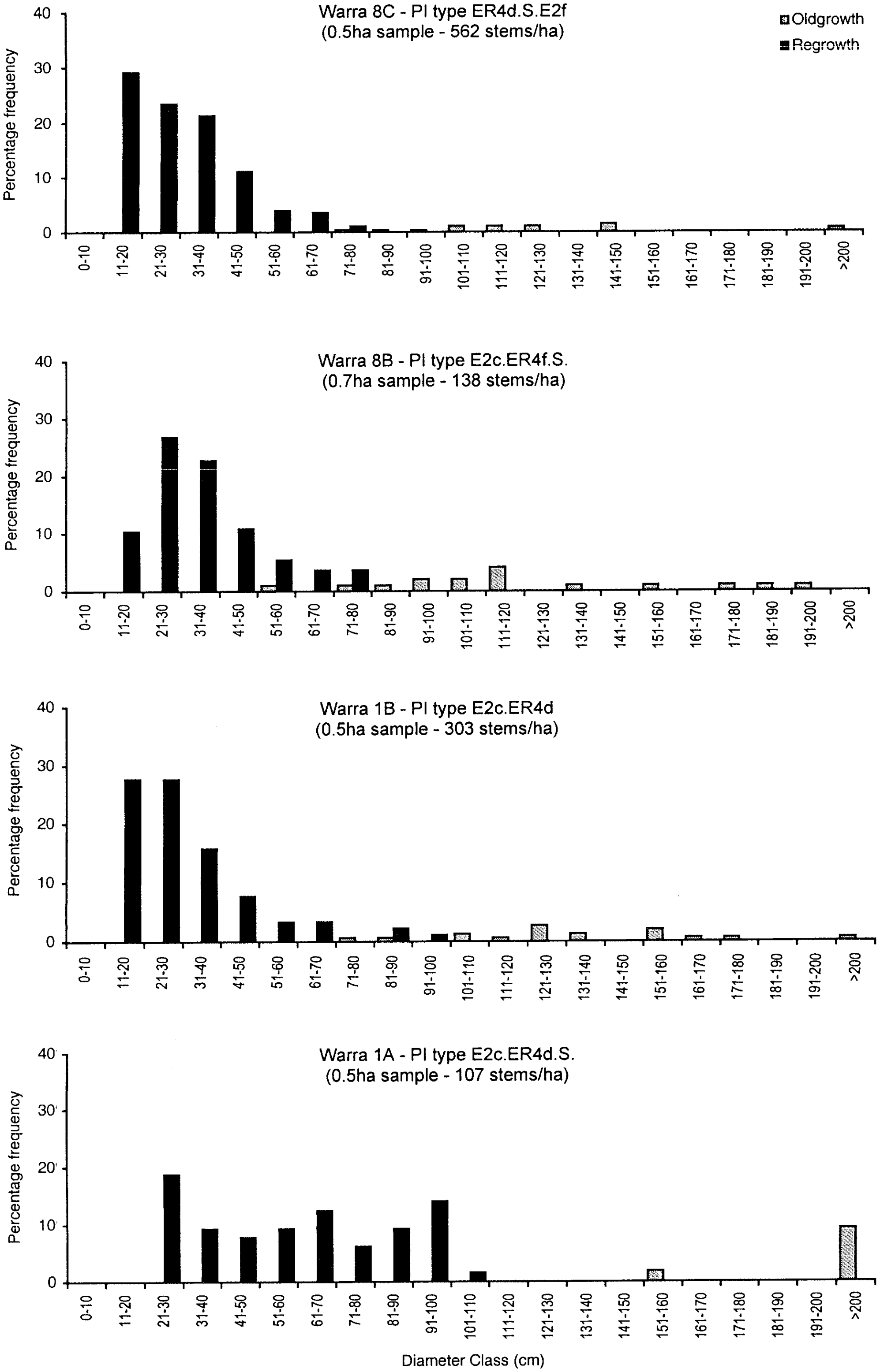

Figure 5. Combined diameter distribution histograms using MFI and CFI-SST data for the PI types in which the CFI-SST plots are located. The codes for PI types are explained in Stone (1998).

of blackwood and seven stems/ha of rainforest trees, including myrtle (*Nothofagus cunninghamii*), sassafras (*Atherosperma moschatum*) and leatherwood (*Eucryphia lucida*). All these stems were in the 11–30 cm dbh class. The 1A stand had 28 stems/ha of blackwood and 59 stems/ha of rainforest trees. The blackwood stems were in the 21–50 cm diameter class. Some rainforest trees had diameters up to 60 cm but the bulk of the stems were in the 21–30 cm diameter class.

Discussion

It has been recognised in descriptions of multi-aged wet eucalypt forests that two or three distinct age classes may be present if forests are partially damaged by fire (Gilbert 1959; Cunningham 1960; Ashton 1976, 1981). Results from this study show that the majority of stands at the Warra Site possess a large number of cohorts, possibly higher than previously reported for other multi-aged wet forests (e.g. Ough and Ross 1992; McCarthy *et al.* 1999).

The large diameter-spread of a single regrowth cohort and the large overlap in diameter between different cohorts at the Warra SST may be explained by variation in stand density, canopy position of trees, microsite factors and genetic differences. Within a single cohort of trees, dominant and codominant trees possess a competitive advantage over the subdominant and suppressed trees in terms of site resources, and hence are generally larger in diameter (Florence 1996). Over time, the self-thinning effect, where the trees of superior canopy positions continue to grow in diameter while the trees of the inferior positions are out-competed, increases the diameter spread of a single cohort.

The stronger relationships between diameter and age in both the dominant and codominant trees (Figure 4) suggest that this is the case at the Warra SST. The dominant and codominant trees have been able to grow unhindered whereas the subdominant and suppressed trees have been restricted and therefore are of a small size and exhibit little relationship between age and size. As the effect occurs in successive cohorts, an overlap in diameter occurs as the dominant and codominant trees of the younger cohort increase in diameter faster than the subdominant and suppressed trees of the older cohort.

No conclusive evidence on the length of time over which eucalypts may regenerate following disturbance could be drawn from this study. It is known that eucalypt seed will germinate or die within 1–2 years of being released from capsules (Cremer *et al.* 1990). It is thought that the age spread of a cohort in the wet forests of southern Tasmania is not longer than two years, after which time seedbeds are mostly overtaken by mosses or other competing species, reducing the chance of successful regeneration (Cremer 1962). However, given that most fire occurrences at the Warra SST appear to be non-stand replacing, seed is likely to be available in the canopy for dispersal years after disturbance, and there is the possibility of extended regeneration given the availability of receptive seedbeds and limited competition. Errors associated with age estimates from ring counts of both regrowth and oldgrowth cohorts need to be reduced considerably before the technique used in this study can provide precise information on the age spread of single cohorts. Such information may be obtained more reliably by careful observation of regeneration of stands after recent wildfires or partial logging. Evidence to date from a partially logged coupe, WR001B, at the Warra SST site indicates that some recruitment takes place for at least three years after disturbance.

The occurrence of kino within the annual growth rings of *E. obliqua* appears to have little correlation with fire occurrence. Mount (1964) reported correlations between wildfire events and kino occurrence within the growth rings of different aged *E. regnans* trees in the Florentine Valley of southern Tasmania. Jacobs (1955), however, concluded from field experiments that branch shedding and insects, as well as fire, have significant effects on the formation of gum veins. It appears that at the Warra Site other stem injuries such as insect attack, branch shedding or bark damage from adjacent tree and branch falls may also have a strong influence on kino formation. Other factors such as severe drought stress and frost may also contribute but are not likely on this site. Disc sampling height may also have influenced the results. Cremer (1962) found that gum vein formation commonly occurred after fire. However, the location of gum veins is not predictable and may be a long way above the contact with fire. Considering that all the discs sampled were removed at a stump height of between two and 110 cm, the discs collected may not have adequately sampled the positions of kino formation.

Estimating ages of large oldgrowth trees was found to be difficult due to large amounts of rotten wood or hollows within the tree centre, narrow annual growth rings and poorly defined ring boundaries. For many of the oldgrowth trees containing hollow centres, age estimates were based on ring counts of sound wood plus an estimate made by extrapolating annual ring widths from the closest sound wood to the pith for the missing centre. As a consequence, error estimates of about 15% are predicted for the majority of age estimates on the oldgrowth trees within the five CFI-SST plots. This uncertainty in the data meant that limited information could be inferred for the oldgrowth cohorts in the stands sampled. The age of about 500 years for one oldgrowth stump at WR008H is uncertain because the stump had a hollow core. However, an oldgrowth eucalypt about 10 km away has been estimated (Hickey *et al.* 1999) to be about 450 years, based on ring counts from an adjacent celery-top pine (*Phyllocladus aspleniifolius*), suggesting that it is possible for oldgrowth eucalypts in this region to be of this age. Woodgate *et al.* (1994) and Hickey *et al.* (1999) also reported difficulties when performing ring counts on oldgrowth eucalypts, although Mount (1964) recognised age estimate errors of up to only 10 years when performing ring counts on oldgrowth eucalypts from the Florentine Valley in southern Tasmania. More reliable methods for determining the age of oldgrowth eucalypts are necessary before an understanding of the pre-1898 age structures of the stands at the Warra SST can be fully explored. One simple technique may be to sample oldgrowth trees, which have either been windthrown or felled, at heights of 10 m or more above the base, where the likelihood of sound wood from the bark to the pith is high. Because eucalypts in lowland wet eucalypt forest have rapid early growth, at least after stand-replacing fire, it could be surmised that ring counts at this height would be about 10–20 years less than ring counts at the base (if solid wood were available). The period to reach sampling height would be considerably greater if overwood were present.

Growth rings were mostly clear and distinct on the smaller regrowth trees, with few zones of indistinct growth rings. It was estimated that the true age would be within ± 10% for ring counts on regrowth eucalypt trees. This reliability estimate appears consistent with those from other studies of regrowth eucalypts (John Banks, pers. comm. 2001).

Cross-matching of ring-width patterns with trees of a known age can improve age estimates. Cross-matching is a central principle of dendrochronology (Fritts 1976, cited in Ogden 1978) which ensures greater accuracy when reconstructing chronologies (Ogden 1981). This technique was not applied here but is recommended for future dendrochronological studies of eucalypts. The technique can be applied visually, using simple skeleton plots of wide and narrow rings, or more sophisticated methods may be undertaken utilising computer programs for cross-correlations of measured chronologies (Ogden 1978). Bradshaw and

Rayner (1997) applied this technique when aging whole stem sections of *E. diversicolor,* using stems of a known age (resulting from regeneration following harvesting) to provide sequences within a site to correct for false or missing rings.

Hickey *et al.* (1999) reported the structure of the wet eucalypt forest of the Warra SST to be multi-aged based on ring counts from understorey species and inferences drawn from observed diameter distributions. However, the age structure found in the current study by ring counting the eucalypts at the same five stands showed some differences from the earlier interpretation. Overall, more regrowth cohorts were reported for all five stands and, in some cases, different regrowth cohort occurrences were reported than in the earlier study. Hickey *et al.* (1999) found stands 8C, 8H and 8B to contain both the 1898 and 1934 cohort, stand 1B the 1914 and 1934 cohort and stand 1A the 1914 cohort. In contrast, it was found in this study that 8C, 8H and 8B also contained the 1914 cohort and that the 1B stand included the 1898 cohort. The 1914 regrowth cohort was not present in stand 1A but it did have 1898 and 1934 cohorts.

The cause of discrepancy between the two studies of the same five stands is partly due to the small sample of understorey species used in the earlier study. Furthermore, the use of understorey species is unlikely to detect older cohorts because the understorey species often have a shorter life-span and are more likely to be replaced by lower intensity fires which allow at least some of the eucalypt overstorey to survive. The estimation of a 1914 cohort in stand 1A by Hickey *et al.* (1999) was made using only two *Pomaderris apetala* stems. It is possible that there may have been an error in ring counting these stems or, alternatively, that a 1914 fire did pass through the area but was not hot enough to cause any eucalypt regeneration.

The discrepancy between the studies also highlights the danger of inferring age-class stuctures from diameter classes. Smith *et al.* (1997) report that most even-aged or single cohort stands have a wide range of diameter classes. The age-class structure cannot be determined reliably from the range of diameter classes present. Theoretically, the diameter distribution of a pure, even-aged stand often approximates a bell-shaped curve although the loss of small trees from competition typically results in an abrupt slope on the left-hand side. Balanced uneven-aged stands tend to have a reverse J-shaped distribution (Hett and Loucks 1976) and irregular uneven-aged stands that have cohorts that differ widely in age have humps on the diameter distribution curve (Smith *et al.* 1997). If Figure 5 is interpreted on this basis, the 8C and 1B stands might be classed as balanced uneven-aged stands, 8B would be an essentially even-aged stand (with some oldgrowth veterans) and 1A might be considered an irregular uneven-aged stand. In reality, all four stands are multi-aged and it is unlikely that a theoretical approach based on observed diameter classes is reliable for interpreting age-class structure for *Eucalyptus obliqua* forest at the Warra site. This is probably due to the multiple fires that have occurred during the life-span of the oldest trees, which have disrupted the development of stand structures that would otherwise have occurred. For this reason, some studies of stand structure in other forest types (e.g. Veblen *et al.* 1980; Read and Hill 1988) have excluded stands that have been burnt within the life-span of the oldest trees.

The current study has confirmed that the wet *E. obliqua* forest of the Warra SST site is multi-aged and has a varied fire history across the 200 ha site. The present age structure appears to have established following fires since the 1500s. At least two oldgrowth and two regrowth cohorts were present in all five sampled stands and up to seven different cohorts may be present in a single stand. None of the sampled stands was purely even-aged which indicates complete stand-replacing fires are uncommon at this site. It appears that about three or four wildfires occurred in the 1600–1800 period and about five or six wildfires in the subsequent 200 years. This suggests there has been a modest increase in fire frequency at the site in the 200 years since European settlement.

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