<u>Technical report 196</u>

Assessing defoliation and discolouration for *Eucalyptus globulus* plantations: variance of tree, plot and age-class components in a pilot study at Wattle Range, South Australia

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Public report

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Summary

This report presents a record of research that has been initiated in CRC subprojects 1.1.2 and 1.2.2, which aims to determine remote-sensing methods to detect forest health issues in *Eucalyptus globulus* plantations. A pilot trial to assess defoliation and discolouration in plantations of a range of ages (planted from 1999 to 2006) was conducted at Wattle Range, near Penola in South Australia in 2007. Thirty plots were established and plot design and health assessment methods are detailed in this report. These methods will help to validate satellite imagery to detect forest health issues.

Total discolouration was generally lowest in plots of older plantations and increased in younger plantations, particularly in the 2003–2005 age classes. Total defoliation ranged from averages of approximately 10–50% per plot and an age-class trend was less prominent. Statistical analysis showed that the design of the pilot trial was sufficient to capture age and plot differences in the crown health response variables of interest.

Acknowledgements

We acknowledge invaluable assistance from Ben Bradshaw (Timbercorp) and Charlma Philips (Forestry South Australia) for access to Timbercorp plantations, assistance with plot establishment and local knowledge of pest and disease issues. We worked collaboratively with staff from subproject 1.1.2 (Darius Culvenor, Neil Sims, Jan Verbesselt, and others from CSIRO Sustainable Ecosystems) to establish the pilot trial plots. Christine Stone (Forest Resources Research, NSW) assisted with plot establishment and health assessments and provided expert guidance on remote sensing of forest health in eucalypts.

Introduction

Formal forest health surveillance (FHS) has been established for over a decade in Australia and is based primarily on aerial surveillance with fixed-wing or rotary-wing aircraft, drive-through surveys and ground inspections (Carnegie 2008). Forest health surveillance requires skilled staff for on-ground and airborne surveys, diagnostics, analysis and support and therefore assessments are limited to once or twice a year in most states. Carnegie (2008) states that a complete FHS program in Australia that includes both aerial and ground components can cost up to $1.50 per hectare per year. Incorporating remote sensing technologies to assist FHS has the potential to reduce this cost and provide information more frequently. Exploration of this potential for eucalypt plantations is beginning in Australia.

The utility of remote sensing technology for health assessment of plantation eucalypts has been explored to a limited degree with hand-held spectroradiometers (Barry *et al.* 2009; Barry *et al.* 2008) and airborne imagery (Pietryzkowski *et al.* 2008). Within project 1.1.2 of the CRC for Forestry, a range of satellite-based sensors are being explored to develop an automated damage alerting system, followed by quantitative information on damage (mortality, defoliation, discolouration) (D Culvenor, pers. comm.). MODIS provides free and continuous imagery at coarse resolution that could operate as such an alerting tool (Stone *et al.* 2008). Higher spatial and spectral resolution sensors (such as Hyperion, Quickbird, SPOT) are being explored to provide more detailed quantitative information on request.

The current exploration of satellite sensors within CRC for Forestry project 1.1.2 aims to assess methods for damage detection (i.e. defoliation and discolouration) across varying age classes and with a variety of causes of damage. The selected site to begin these investigations is in south-east South Australia (Wattle Range) where plantation *Eucalyptus globulus* has been planted every year from 1999 until 2007. While the ultimate aim of an automated remote sensing system would be to reduce on-ground assessment of plantation health, detailed ground-truthing of the imagery is required in the development of the system. Forest health assessments of eucalypt plantations are undertaken by many companies in a similar way (Carnegie *et al.* 2008; Phillips 2008; Smith *et al.* 2008; Wotherspoon 2008) and standard methods are not sufficient to function as ground-truthing for imagery. Detailed assessments such as the Crown Damage Index (Stone *et al.* 2003) are usually too time-consuming for routine use (Carnegie *et al.* 2008) but provide a level of detail more closely matched to that needed here. The health assessment methods developed specifically for ground-truthing eucalypt plantations for satellite imagery are described in this technical report. The results of the pilot study conducted in October 2007 are presented and an evaluation of the variance between plots and age classes is explored.

Aims

The aims of the pilot study at the Wattle Range site were to:

- develop a method to assess damage which will provide ground-truthed data for image analysis, by capturing information related to crown composition, defoliation and discolouration
- understand variation in crown composition including new and old leaves and adult and juvenile leaves
- determine variance in damage at the tree, plot, compartment and age-class level to assist future sampling strategies.

Site details

Wattle Range in South Australia is a region near Penola in the far south-eastern corner of the state (part of the Green Triangle region). Timbercorp and Great Southern Plantations have plantation estates of *Eucalyptus globulus*, planted commercially since 1999. Plots were established in compartments owned and managed by Timbercorp.

Sites for study plots were selected using an age-class GIS layer, and interpolated (inverse distance weighted) volume (m^3/ha) estimates derived from Timbercorp inventory plots measured in October 2007. Plots were spread spatially over the study area (Figure 1). Three plots per age class (in one compartment) were created for the 1999 and 2001–2006 age classes. As the 2000 age class is a large proportion of the estate, three plots in each of three compartments were selected. Therefore thirty plots were selected in total.

Plot design was circular, with five trees selected within a 20 m radius in four cardinal directions from a central point (Figure 2). Trees in the thirty plots were assessed for inventory data (not described in this report) and crown health in October 2007.

Crown health assessment method

Figure 3 shows typical crown composition for the main age classes of trees studied. For all age classes, the crown was split into upper and lower sections based on a visual judgement of 50% crown length. Within each crown zone, the percentage of adult and juvenile foliage was recorded, as well as the percentage of that which was old or new foliage. Once the percentage of foliage present was determined, defoliation and discolouration scores were scored for the old and new foliage (regardless of the foliage type for phase-change trees) for the upper and lower sections.

Defoliation was determined with reference to knowledge of healthy crowns with full foliage. Colour was assessed as the percentage of green, blue (for juvenile foliage), yellow, brown or red. Presence of red stems and the probable cause of damage was noted. The scoring sheet used is provided in Appendix 1.

Analysis and results

Causes of damage detected

Three types of fungal pathogens, twelve insects and three abiotic disorders were detected during the pilot trial survey. Of these, Mycospherella leaf blotch, autumn gum moth and herbicide damage were most frequently detected. See Appendix 2 for details of which damage agents were detected in each plot.

Variation in crown composition including new and old leaves and adult and juvenile leaves

Plantations from five to eight years old tended to have only adult foliage (except for plot 6 which is an exception), while those between two and four years of age or younger had a mix of adult and juvenile foliage, and one-year-old plantations had only juvenile foliage (Table 1). Four crown sectors were assessed, but the new lower foliage was not present in most of the older plots and was not assessed.

Variation in damage at the tree, plot, compartment and age class to assist future sampling strategies

Total discolouration and defoliation—old and new leaves

Discolouration was assessed as a percentage of leaves in each sector using green, blue, yellow, red and brown. Green and blue foliage is healthy; blue represents young waxy juvenile leaves and was usually only recorded for the 2006 age-class plots. Red may be healthy (new growth flush) or associated with stress/damage. Yellow in the upper crown of older trees is usually typical of healthy new growth, but in the lower crown or for younger trees it represents poor health. To simplify a calculation of discolouration, it was computed as the sum of red, yellow and brown foliage.

Data was compiled by firstly calculating total defoliation and discolouration for the new and old foliage (Figure 4). In the older plots there was minimal discolouration in the old foliage and a wide range of discolouration in the new foliage. Trees in younger plots tended to have substantial amounts of discolouration in both new and old leaves. Defoliation was more comparable for both foliage ages.

Discolouration and defoliation—whole tree scores

Tree and plot total defoliation and discolouration was calculated by taking into account the amount of the new and old foliage present in each zone. Using the plot means per zone, total discolouration and defoliation could be quickly calculated (Figure 5), but gives no indication of tree-to-tree variance within the plot. Total discolouration was generally least in plots of older plantations and increased in younger plantations, particularly in the 2003–2005 age classes (Figure 5). Total defoliation ranged from averages of approximately 10–50% per plot and an age-class trend was less prominent.

Rather than using plot means, whole-tree scores of defoliation and discolouration were also calculated per tree and then averaged. This allowed for a standard error calculation of the values of interest (Figure 6A–6F). Also, values for different colours were calculated. Percentage of green foliage was reasonably consistent in the older age classes (1999–2003) while it decreased in the plots of younger plantations (Figure 6A). Brown and red colouration was prominent in the younger plantations (Figure 6B and 6C) and blue foliage was particularly evident in the 2006 plantations (Figure 6D).

Yellow varied across all age classes with no clear trend (Figure 6E). Standard error about the plot means showed that plot differences were likely to be significant across the trial in many cases and this was also apparent for defoliation (Figure 6F). This is essential if the plot trial design is to highlight differences in health. The statistical strength of the trial design to detect damage was further tested as below.

Statistical analysis—variance components

An analysis procedure was used based on a similar pilot study of *Pinus radiata* crown health, conducted within the CRC for Forestry. In that study, the NESTED procedure of SAS was used to study the variance attributed to crown health data by tree, plot and age-class factors (Amrit Kathuria, unpublished). The same procedure was used here with the eucalypt pilot study.

Table 3 shows the results of the NESTED analysis using a balanced design, where data from plots 1 to 3 and 28 to30 were omitted so that the 2000 age class was not overrepresented in the analysis. The balanced design consists of eight age classes, three plots per age and twenty trees per plot for a total of 480 data points (from which six have been deleted due to missing values). Variance in defoliation in all crown sections due to age is much higher than variance due to plot (Table 3). Variance due to age was also higher than that due to plot for colouration in the lower crown section in all but one case (Table 3). Trends were less consistent in the upper crown sections. Variance due to the tree factor is in almost all cases higher than both age class and plot (Table 3).

The interpretation of the variance components and the percentage of total require use of the equation representing the variance of the grand mean. This allows interpretation of how results may differ if the number of age classes, plots or tree number were altered. For example, the variance of the estimate of the grand mean of defoliation for the new upper foliage (NUD) is given by the following formula:

$$\textbf{Variance (NUD)} = \textbf{Var(Age)}/N_A + \textbf{Var(Plot)}/N_P N_A + \textbf{Var(Tree)}/N_T N_P N_A$$

where N_A = no. of ages (8), N_P = no. of plots per age (3), N_T = no. of trees (20).

Substituting the estimates of the variance components into the variance equation leads to:

$$\textbf{Variance (mean of NUD)} = 213/N_A + 32/N_P N_A + 346/N_T N_P N_A$$

This can be used for future predictions if one alters the number of replicates of ages, plots and trees. For the number of replicates used in the preliminary study, viz. eight, three and twenty, respectively, we get:

$$\textbf{Variance (mean of NUD)} = 26.6 + 1.3 + 0.7 = 28.6$$

Using the variance of the mean of NUD, the large contribution of the ‘age’ term to the overall variance (viz. 26.6/28.6 = 93%) is apparent, despite the fact that its variance component is only 36% of the total and the tree factor is 58% of the total. This formula for the variance of the mean of NUD shows that the variance can only be substantially reduced by increasing the number of ages (which is not possible in this case). Increasing the number of plots reduces the contribution from the last two terms, but they collectively only contribute 7% of the overall values. Importantly, increasing the number of trees would have virtually no effect on the size of this variance. This shows that within the age-class limits of this trial and using one compartment per age class, the variance for all factors is acceptable with the current number of plots and trees per plot.

Theoretically, the best option to reduce overall variance around the mean values of response variables would be to increase the number of compartments for every age class and retain the number and size of plots within each compartment. For example, using eight age classes, five compartments per age, three plots per compartment, twenty trees per plot = 120 plots. In this case, the variance of the grand mean for any response variable will be the mean square for 'Age' from the ANOVA table divided by the number of experimental units, which will be 2400 if there are no missing values. This is five times as many experimental units as exist in the pilot trial design, and the standard error of the grand mean will therefore be smaller by a factor equal to the square root of 5, or 2.236, so that the confidence limits about the estimated mean will be less than half the size they were when there was only one compartment. Looking at Figures 6A–6F, we can assume that with this sampling design (120 plots), the standard error bars would be roughly half as big. While this may allow us to statistically separate some plots with similar means, the added sampling effort for data collection would need to be assessed.

Conclusions

The design of the pilot trial was sufficient to capture age and plot differences in the crown health response variables of interest. While improvements could be made to reduce variance further, this may mean an increased sampling effort that cannot be supported within project resources. Considerations about the best plot design for analysis with multiple types of imagery is also an important part of trial design.

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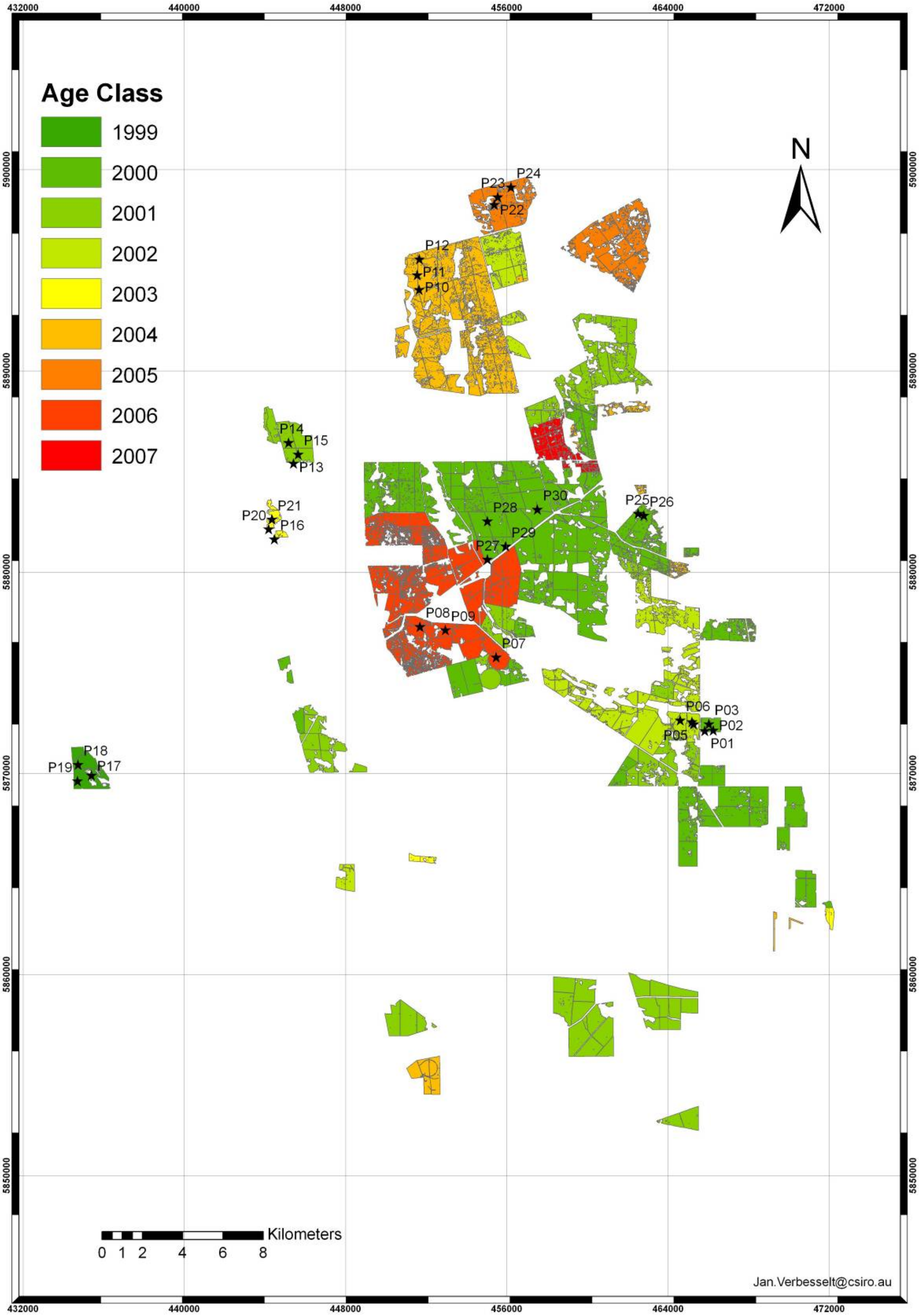


Figure 1. *Eucalyptus globulus* plantations in the Wattle Range, South Australia, classified into age class and with study plots marked

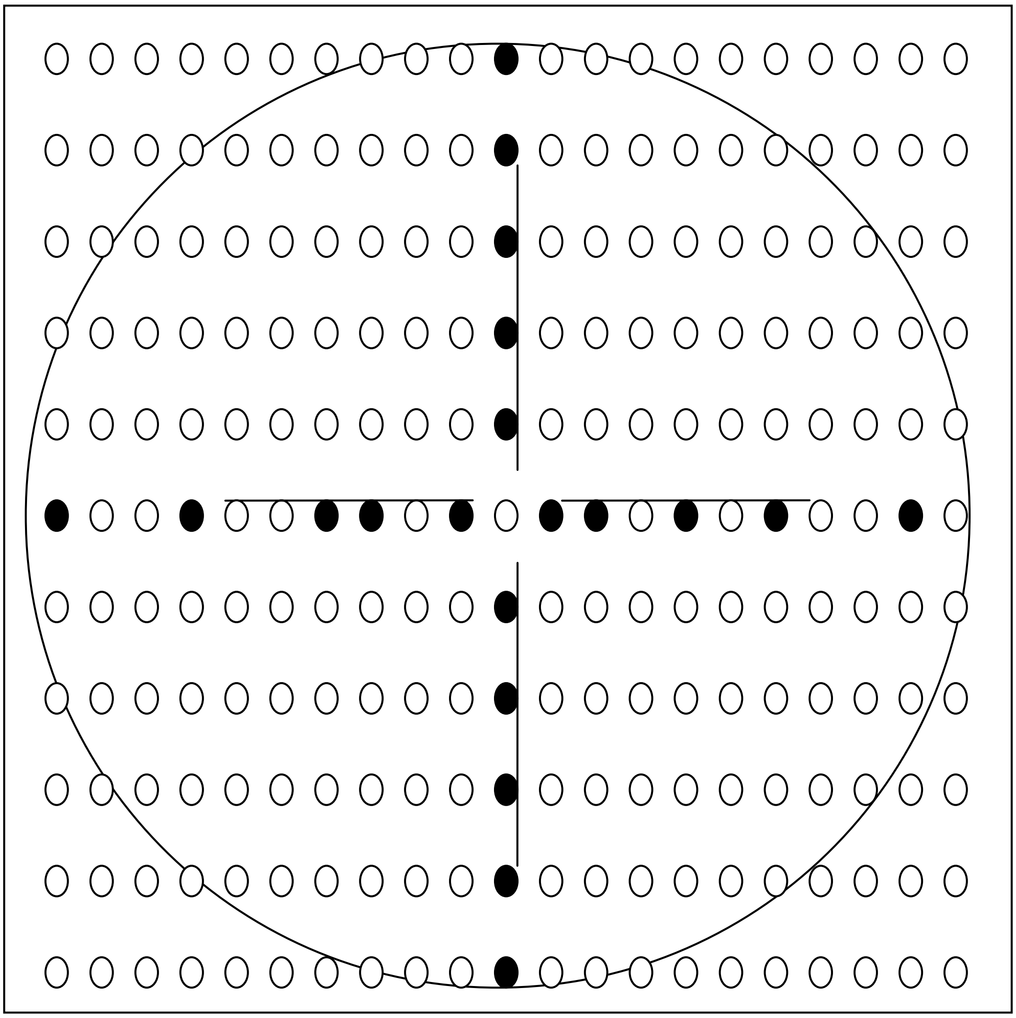


Figure 2. Outline of strategy to select trees within a plot (circles which are filled represent selected trees)

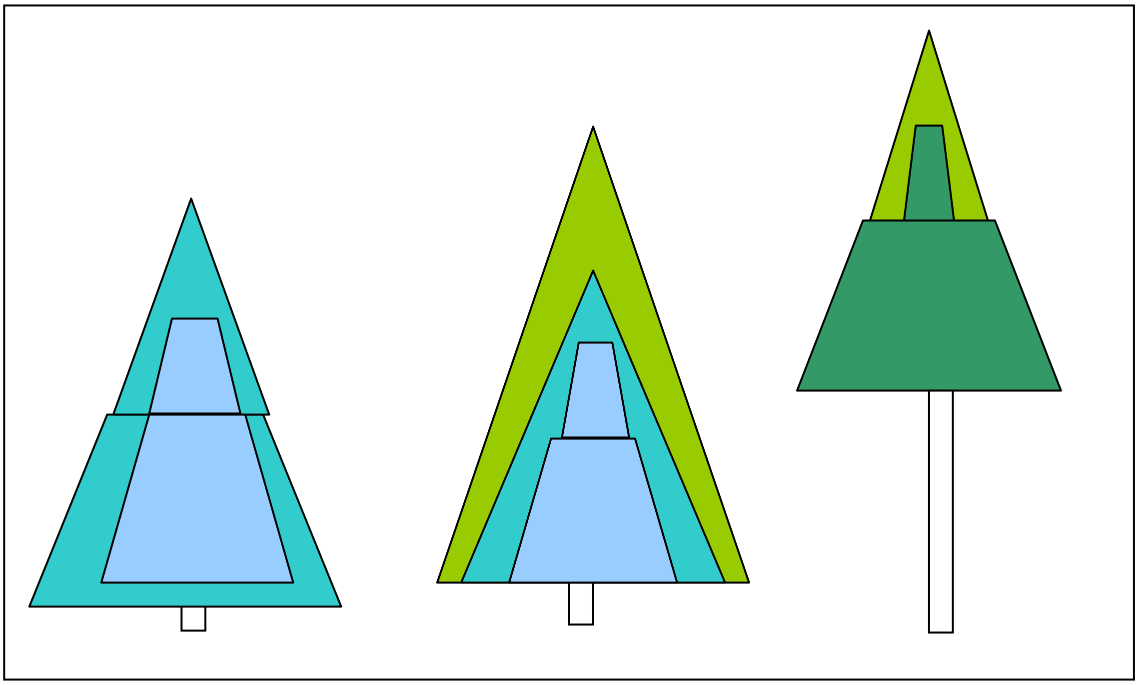
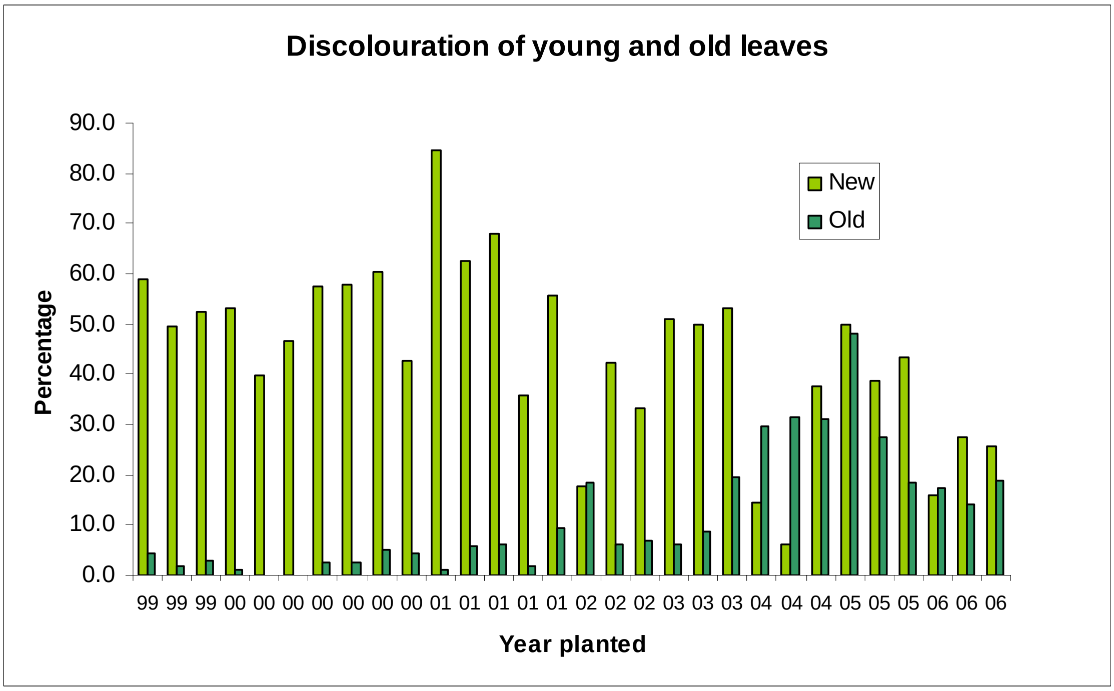


Figure 3. Examples of crown sections typically present (from left to right): a) pre-phase change trees (typically up to three years old) with all juvenile foliage, assessed as old and new growth; b) phase-change tree (between three and five years old), in this example with old and young juvenile foliage and some new adult foliage; c) older trees (typically five years plus) with only adult foliage present, only old in the lower section, young and old in the upper section. Blue colours are young and old juvenile foliage, green is young and old adult foliage.

Table 1. Foliage type and crown sections present

			Leaf types present (number of trees /20)			Crown sectors present			
Plot	Age class	Years old	Only adult	Both	Only juvenile	New upper	Old upper	New lower	Old lower
17	1999	8	20			✓	✓	x	✓
18	1999	8	20			✓	✓	x	✓
19	1999	8	20			✓	✓	x	✓
1	2000	7	20			✓	✓	7	✓
2	2000	7	20			✓	✓	7	✓
3	2000	7	20			✓	✓	8	✓
25	2000	7	20			✓	✓	x	✓
26	2000	7	20			✓	✓	x	✓
27	2000	7	20			✓	✓	x	✓
28	2000	7	20			✓	✓	x	✓
29	2000	6	20			✓	✓	x	✓
30	2000	6	20			✓	✓	x	✓
13	2001	6	20			✓	✓	2	✓
14	2001	6	20			✓	✓	x	✓
15	2001	6	20			✓	✓	x	✓
4	2002	5	20			✓	✓	11	✓
5	2002	5	20			✓	✓	9	✓
6	2002	5	1		19	✓	✓	10	✓
16	2003	4	20			✓	✓	x	✓
20	2003	4	20			✓	✓	x	✓
21	2003	4	18		1	✓	✓	12	✓
10	2004	3	17	3		✓	✓	1	✓
11	2004	3	18	2		✓	✓	1	✓
12	2004	3	12	5	3	✓	✓	3	✓
22	2005	2	1		20	2	✓	1	✓
23	2005	2	7	3	10	17	✓	2	✓
24	2005	2	1	15	4	✓	✓	✓	✓
7	2006	1			20	✓	✓	✓	✓
8	2006	1		3	17	✓	✓	✓	✓
9	2006	1		2	18	✓	✓	✓	✓



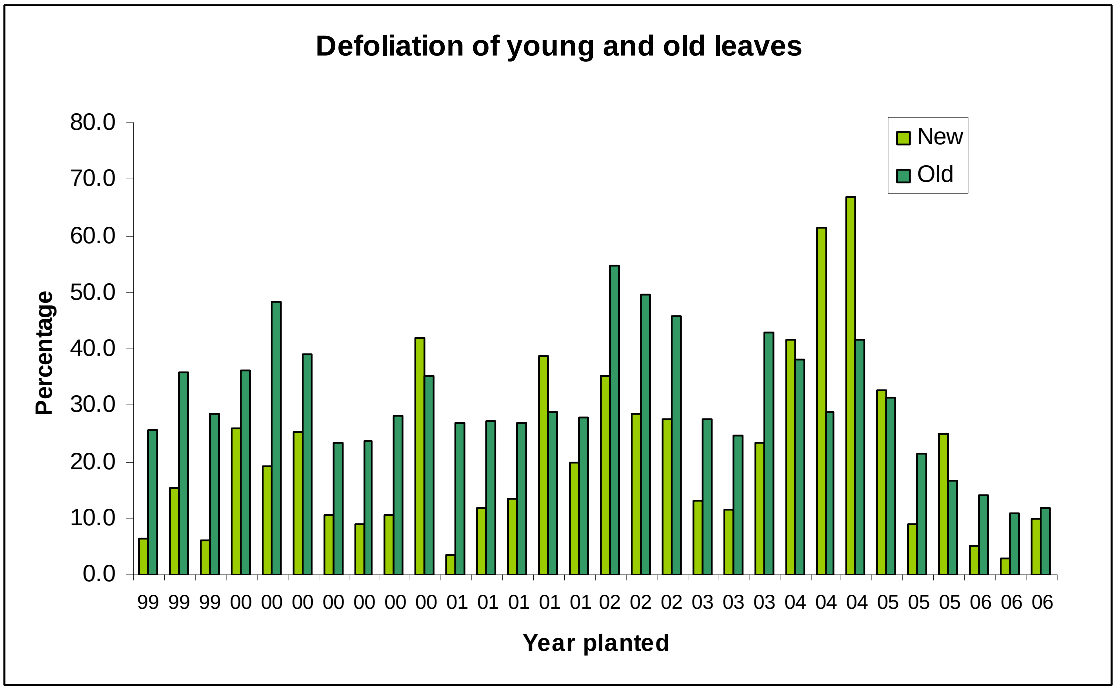
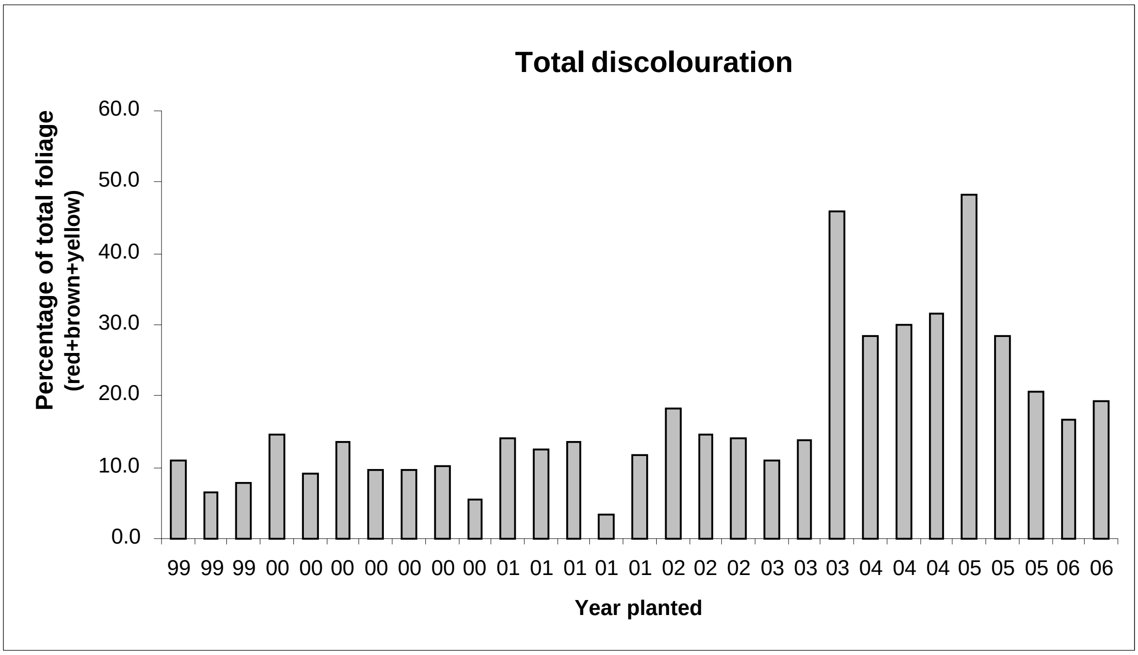


Figure 4. Defoliation and discoloration of young and old leaves, averaged per plot



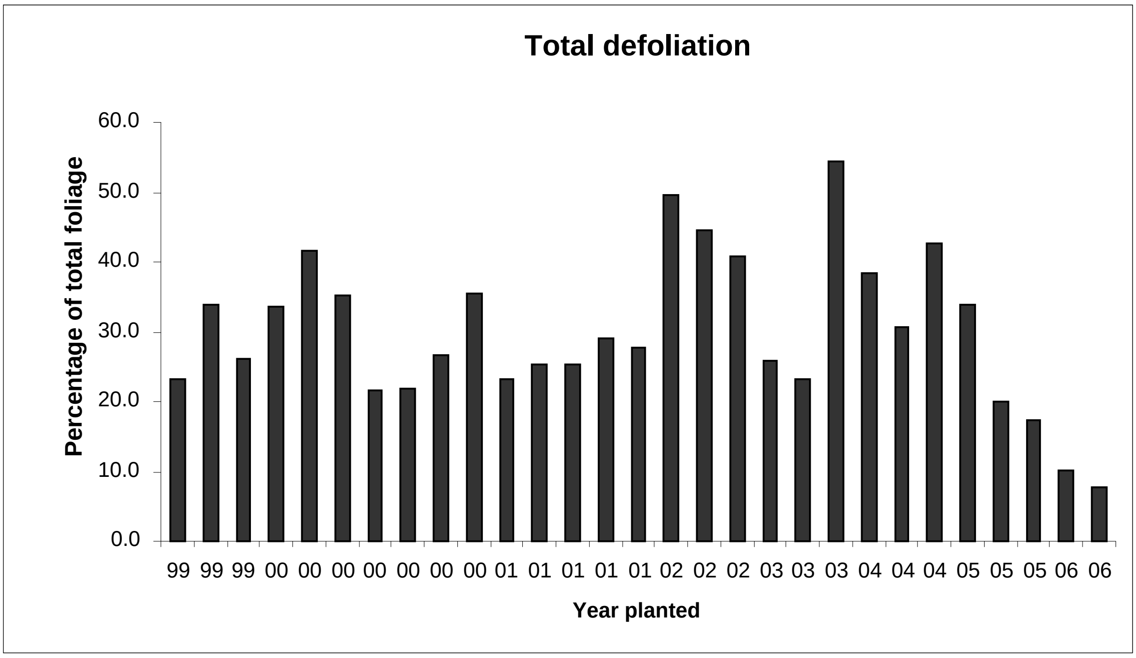


Figure 5. Total discolouration and total defoliation averaged per plot (sum of % of new and old foliage, related to the proportion of the crown of each type represented)

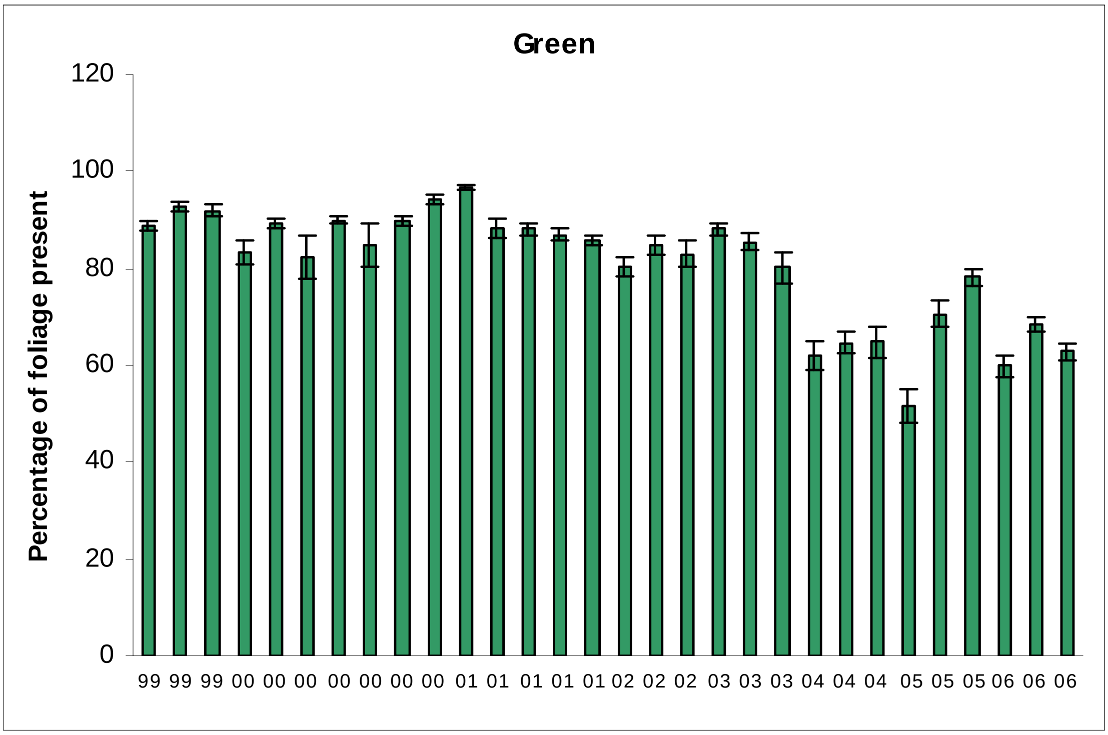


Figure 6A. Percentage of green foliage in crowns averaged per plot (± SE); sum of colour of young and old foliage in upper and lower crowns

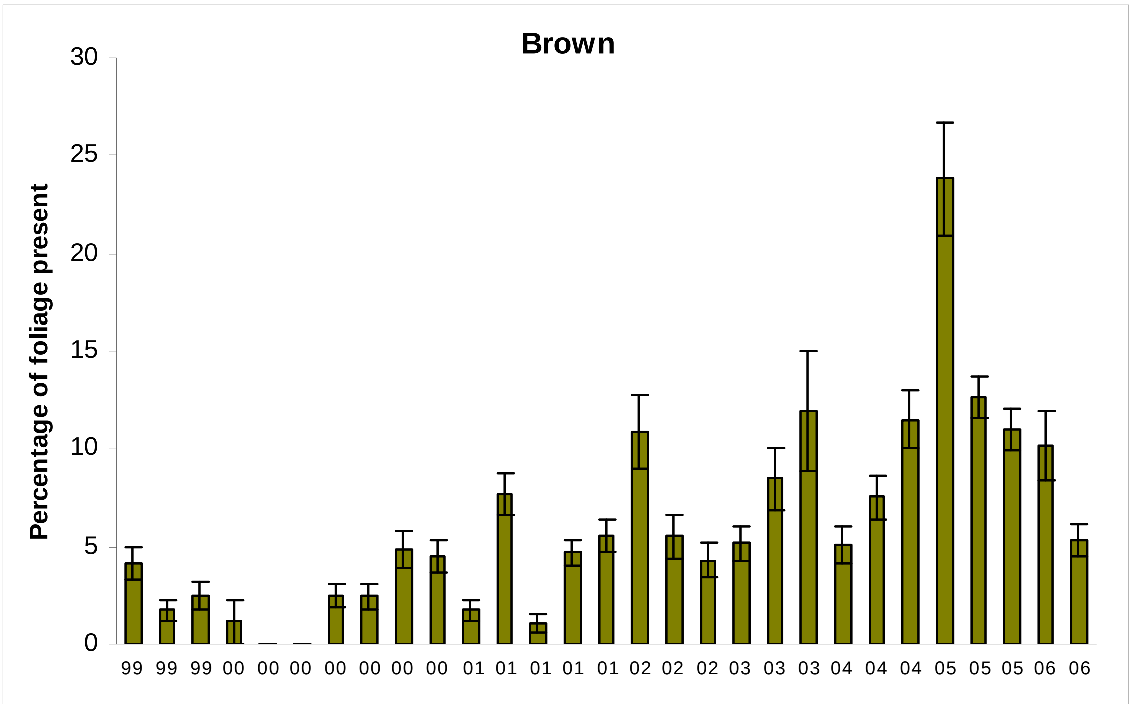


Figure 6B. Percentage of brown foliage in crowns averaged per plot (± SE); sum of colour of young and old foliage in upper and lower crowns

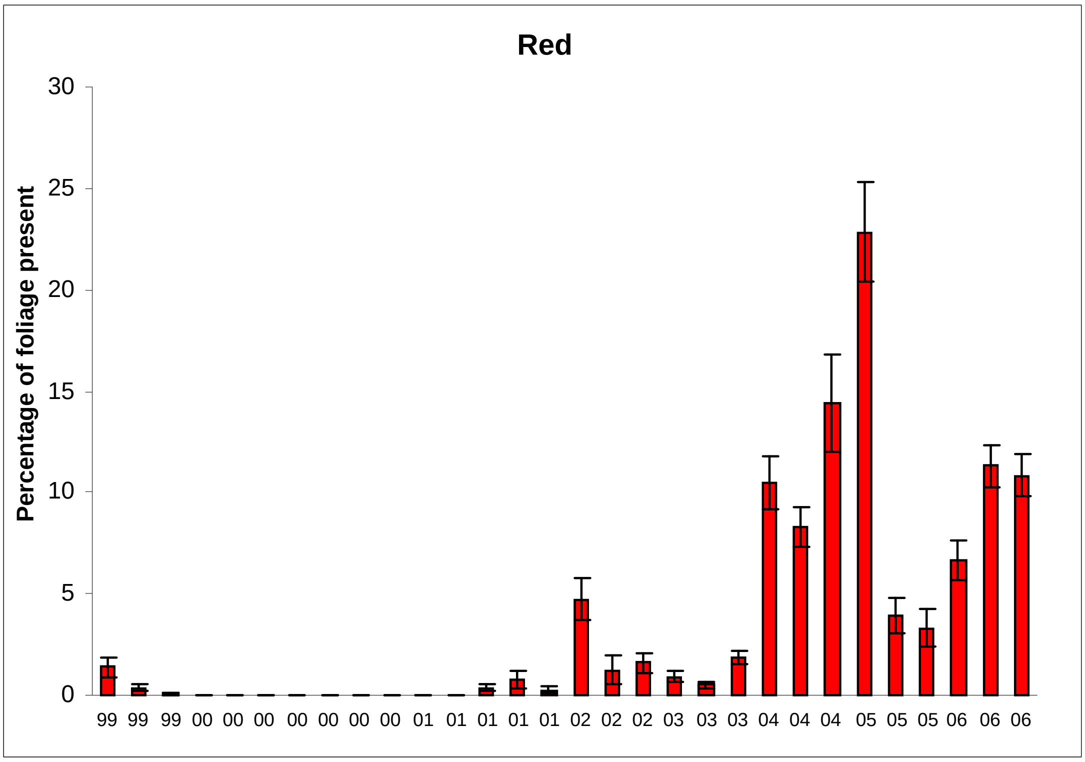


Figure 6C. Percentage of red foliage in crowns averaged per plot (± SE); sum of colour of young and old foliage in upper and lower crowns

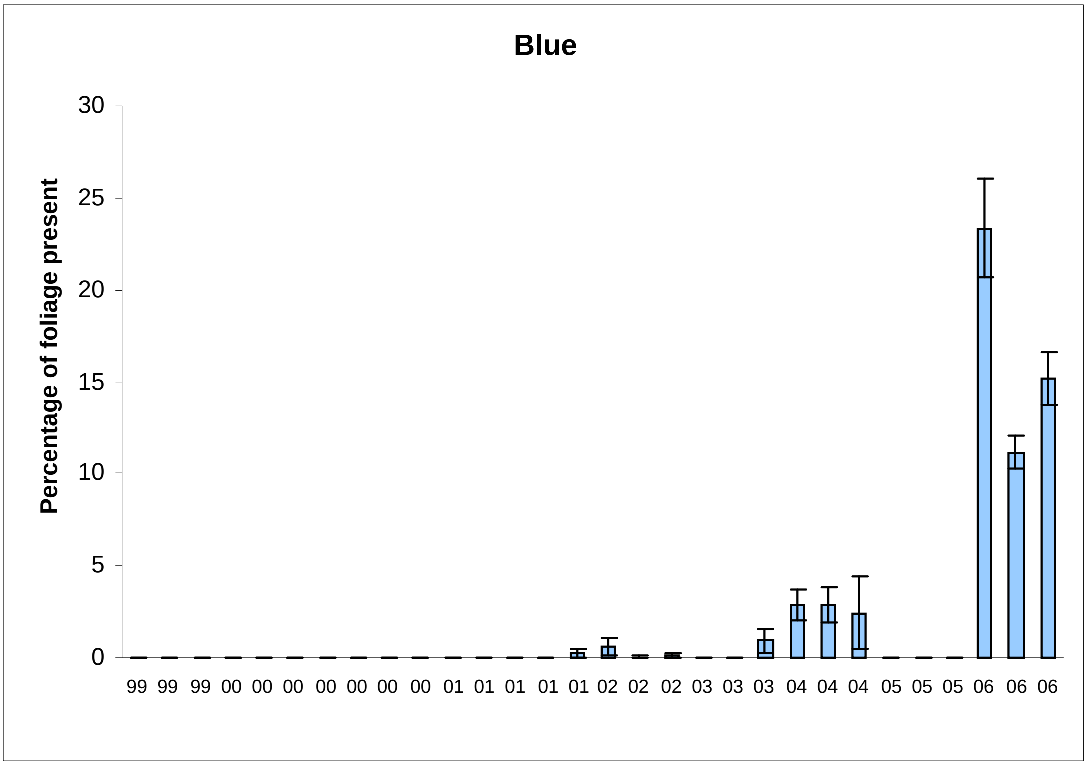


Figure 6D. Percentage of blue foliage in crowns averaged per plot (± SE); sum of colour of young and old foliage in upper and lower crowns

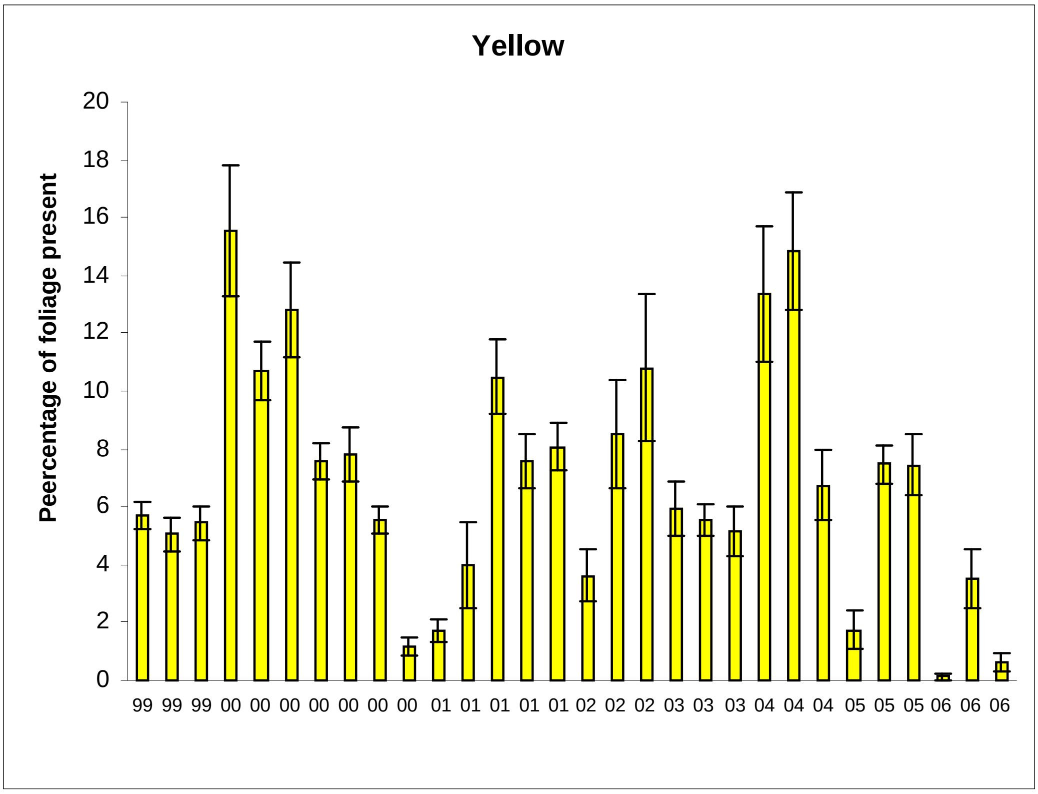


Figure 6E. Percentage of yellow foliage in crowns averaged per plot (± SE); sum of colour of young and old foliage in upper and lower crowns

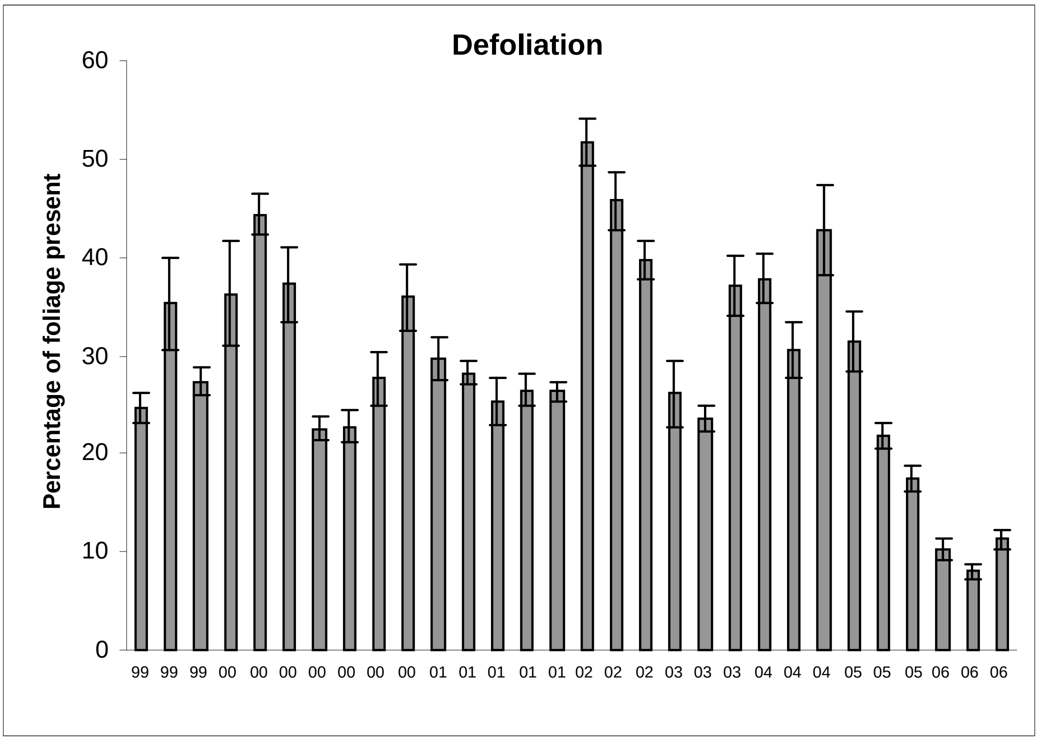


Figure 6F. Percentage of defoliation in crowns averaged per plot (± SE); sum of colour of young and old foliage in upper and lower crowns

Table 2. Analysis with age factor balanced (only one compartment of the 2000 age class is included, plots 25–27)

	New upper		Old upper		New lower		Old lower	
	Variance	% of total	Variance	% of total	Variance	% of total	Variance	% of total
Defoliation								
TOTAL	592	100	282	100	143	100	387	100
Age	213	36.1	76	27.1	23	16.2	155	40.1
Plot	32	5.4	33	11.8	2.4	1.7	33	8.7
Tree	346	58.5	172	61.1	118	82.0	198	51.1
Green								
TOTAL	768	100	273	100	654	100	510	100
Age	75	9.8	52	19.1	239	36.6	335	65.5
Plot	119	15.6	81	29.7	31	4.7	25	4.9
Tree	572	74.5	139	51.1	383	58.7	150	29.3
Red								
TOTAL	189	100	58	100	58	100	82	100
Age	39	20.7	3	6.4	26	44.5	34	42.1
Plot	25	13.2	22	38.2	7	12.3	16	20.0
Tree	125	66.0	32	55.3	25	43.2	31	37.9
Yellow								
TOTAL	930	100	4.43	100	194	100	122	100
Age	602	64.7	0	0	14	7.2	59	48.2
Plot	26	2.8	0	0	17	9.0	16	13.5
Tree	302	32.5	4.42	99.9	163	83.7	47	38.2
Brown								
TOTAL	69	100	113	100	18	100	94	100
Age	2.5	3.7	11	10.2	1	4.6	19	20.4
Plot	2.6	3.8	24	21.2	0.2	1.1	9	10.1
Tree	63.7	92.4	78	68.6	17	94.2	66	69.4

Appendix 1: Scoring sheet for crown health assessment

CRC Trial assessment form
Date:
Assessors: Plot Number: Site: Age Class:

Tree No.	Tree Condtion	Dominance:	Crown Position	Ratio J/A 0=100% J 1=100%A	% foliage juvenile New	% foliage juvenile Old	% foliage adult New	% foliage adult Old	Defoliation New %	Defoliation Old %	Discoloration New					Discoloration Old					Cause																		Comments
											Green	Yellow	Red	Blue	Brown	Green	Yellow	Red	Blue	Brown	C= Leaf Beetle	SH= Shot Hole	M= Mycosphaerella	F= Frost	CB= Christmas Beetle	N=Nutrient deficency	L=Leaf Blister Sawfly	A=Aulographina	Mi= Leaf mite	My= Microthyrium	AGM= Autumn Gum Moth	Sc=Scale	S=Steelblue Sawfly	W=Whitefly	H=Herbicde	P=Free living pysllids	G=Grasshoppers	Hx=Heteronyx	
1	L	C	Upper																																				
			Lower																																				
2	L	C	Upper																																				
			Lower																																				
3	L	C	Upper																																				
			Lower																																				
4	L	C	Upper																																				
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18	L	C	Upper																																				
			Lower																																				
19	L	S	Upper																																				
			Lower																																				
20	L	C	Upper																																				
			Lower																																				
Mean			Upper																																				
			Lower																																				
			Total																																				

Appendix 2: Causes of damage detected

Agent	Plots where detected	Comments
Fungal		
M= Mycosphaerella	4,5,6,7,8,9,10,11,12,16,21,22,23,24	
A=Aulographina	10,11,12,14,15,16,21	
My= Microthyrium	9,11,12	
Insect		
C= Leaf Beetle	All plots	
L=Leaf Blister Sawfly	10,11,12,24	In two- to three-year-old plots
SH= Shot Hole	All plots (except 22)	
P=Free living pysllids	8,9	In one-year-olds
Mi= Leaf mite	10,11	
AGM= Autumn Gum Moth	7,8,10,11,12,21,22,23,24	
Sc=Scale	10	
S=Steelblue Sawfly	10,11,12	In three-year-old plots
W=Whitefly	8,9,10,12,16,22,23,24	
G=Grasshoppers	7,8,9,21,23	
Hx=Heteronyx	12,15,19,20	
CB= Christmas Beetle	11,23,24	
Abiotic		
F= Frost	7,8,9,10,11,12,22,23,24	
N=Nutrient deficiency	10,11,12,23,24	
H=Herbicide	1,2,3,4,8,9,10,11,12,22,23,24	