Stem Damage in Stand Growth Modelling Cooperative Trials

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NOTE : Confidential to participants of the Stand Growth Modelling Cooperative.
: This is an unpublished report and must not be cited as a literature reference.

EXECUTIVE SUMMARY

The SGMC has been supporting the development of stem and branch growth models for radiata pine. These models are incorporated into the model, TreeBLOSSIM. Comparison of TreeBLOSSIM predictions of branch diameters with measurements from PhotoMARVL or TreeD images has indicated that radiata pine often has occasional very large branches that are not predicted by TreeBLOSSIM. From examining the tree images, it appeared that these large branches are associated with the stem being damaged in some way.

In this study, SGMC trials have been used to quantify the amount of stem damage, and how it varies with site, silviculture treatment and seedlot. The descriptive codes recorded in the PSP system were used to estimate the percentage of trees that have been toppled or have received stem damage by specified ages.

Few trees were toppled in the four trial series considered (1975 final crop stocking trials, 1978 genetic gain trials, 1987 and 1990/1991 silviculture /breed trials. Stem damage was far more widespread with over 30% of trees having stem damage in some PSPs. Known windy sites tended to have a high percentage of trees with stem damage. There was generally less variation between different seedlots compared with the variation between different silvicultural treatments or between different sites.

TreeBLOSSIM was developed with the objective of being able to grow branching data, recorded in an inventory data, forward in time until the end of the rotation. Stem damage already present will be recorded in inventory data, but at present TreeBLOSSIM will not predict future damage.

Possible methods to incorporate future stem damage within TreeBLOSSIM are suggested.

Stem Damage in Stand Growth Modelling Cooperative Trials

J.C. Grace and C. Andersen

INTRODUCTION

The SGMC has been supporting the development of stem and branch growth models for radiata pine. These models are incorporated into the model TreeBLOSSIM. Comparison of TreeBLOSSIM predictions of branch diameters with measurements from PhotoMARVL or TreeD images has indicated that radiata pine often has occasional very large branches that are not predicted by TreeBLOSSIM (see SGMC reports 134, 135, 136 and 137). From examining the tree images, it appeared that these large branches are associated with the stem being damaged in some way. This damage is probably caused by wind, since wind-induced movement is the primary abiotic cause of tree damage (Sellier *et al.*, 2006).

OBJECTIVE

This study has three objectives:

- To briefly review literature on the influence of wind on trees.
- To determine how much stem damage has occurred within SGMC trial series, and whether the amount of stem damage varied with site, silvicultural treatment, or seedlot.
- To investigate how stem damage could be included within TreeBLOSSIM.

BRIEF LITERATURE REVIEW

Wind influences forest development in many ways, and numerous papers have been written concerning the influence of wind on trees. The following is a brief summary of some of the important issues.

Normal movement of trees by wind will influence wood formation and stem form. Guying studies have shown that, below the point of guying, trees have reduced diameter growth compared to un-guyed trees that are free to move in the wind (e.g. Jacobs, 1954). Flexing studies have shown that wood properties vary between flexed and non-flexed stems (e.g. Telewski, 1989). Such studies illustrate that the trees adapt their growth patterns in response to wind.

Stronger winds can cause either stem breakage or windthrow. Stem breakage / windthrow is more likely to occur when trees are subjected to sudden changes in wind loading to which they are not acclimatised (Gardiner *et al.*, 2000). Trees break when the forces exceed the stem strength but are not powerful enough to dislodge the roots (e.g. Asner and Goldstein, 1997).

Many studies have examined the differences between damaged and undamaged trees. The ratio of tree height to stem diameter is implicated, but different studies have produced different results. For example: Valinger *et al.* (1993) and Dunham and Cameron (2000) found no differences in the height to diameter ratios of damaged versus undamaged stems. Wonn and O'Hara (2001) the height to diameter ratio was higher for damaged trees compared to undamaged trees.

Valinger and Fridman (1997) found that stands comprising of trees with low height to diameter ratios were more prone to damage than stands with high height to diameter ratios.

Wood properties, as well as height to diameter ratio are important. Asner and Goldstein (1997) show that trees species with more flexible stems (lower modulus of elasticity) were able to shed wind loads and thus reduce stem breakage. In contrast, Cameron and Dunham (1999) compared outer wood properties of similar sized Scots pine and Sitka spruce, and found that the modulus of elasticity was lower in the trees with stem damage.

Two approaches have been used to model the effect of wind. One approach is to develop detailed models that describe the processes involved (e.g. Gardiner *et al.* (2000), Ancelin *et al.* (2004), Achim *et al.* (2005) Sellier *et al.* (2006)). Such models allow the predictions of the impact of silvicultural operations and can be used to design silvicultural operations that minimise stem damage. The second approach is to predict the probability of wind damage based on experimental data (e.g. Wonn and O'Hara, 2001; Peterson, 2004; Scott and Mitchell, 2005). This provides information on the likelihood of stem damage in similar forests.
To my knowledge no model has been developed predicting how a tree grows in response to stem damage.

STEM DAMAGE IN SGMC TRIAL SERIES

This study is a survey of stem damage and toppling in SGMC trials.

Methods

When permanent sample plots (PSPs) are re-measured, a descriptive code may be assigned. These codes have been assigned to three different categories:

- Defects that are considered to be related to stem form (Table 1)
- Defects that are considered to be related to stem verticality (Table 2)
- Other miscellaneous codes (Table 3)

The above descriptive codes represent the minimum amount of damage that has occurred. Only one code may be assigned at a given re-measurement, thus other, lesser, damage may not be recorded.

This analysis investigated the percentage of trees with stem damage and the percentage of trees that were toppled. These classes were defined as follows:

- Stem damage – if the tree was forked or had been assigned one of the descriptive codes in Table 1.
- Stem topple – if the tree had been assigned the TP descriptive code (Table 2).

In order to investigate the effects of site, silviculture treatment and seedlot on the occurrence of stem damage and stem topple, data were analysed from four trials series that are / have been managed by the SGMC (Table 4). (For further details of these trial series see SGMC Reports 24 and 100).

For each PSP in these trial series, the number of trees in the plot at the first measurement with status codes of A (alive) and W (windthrown) was calculated.

For each measurement date, the following were calculated, based on all trees measured at the current and all prior ages:

- The number of trees in the plot that had ever been assigned a stem damage code in Table 1.
- The number of trees in the plot that had ever been toppled (descriptive code, TP).

These variables were used to calculate the percentage of trees that had ever received stem damage or been toppled by a given age. The SAS procedure, PROC GLM was used to determine the variation between sites, silviculture and seedlot at specified ages. Age 13 years was selected as an age at which most trial series were measured; and age 24 years was selected as an age near the end of the rotation at which the 1975 and 1978 trials had been measured.

Table 1. Defect codes considered to be related to stem form

BW	Basket Whorl
DL	Double Leader
DT	Dead, broken or defective top (eg. <100mm diam)
FK	Forked – double leader
MF	Undefined malformation
ML	Multi leader
RC	Ramicorn
TO	Top out (catastrophic stem break)

Table 2. Defect codes considered to be related to stem verticality

CK	Crooked (hockey stick)
LN	Leaning - growing with excessive lean
SO	Socketing (tree collar not supported by surrounding soil,usually due to wind or shallow planting)
SW	Sweep (gentle) including butt sweep
TP	Toppled (roots damaged but tree alive)

Table 3. Other defect codes.

CA	Canker
CL	Crown Lightening
CP	Coppiced
DP	Diplodia
FL	Fluting
FP	Form Pruned
FR	Frost
PD	Possum damage
RB	Resin Bleeding
RD	Abrupt diameter reduction
SC	Scar (from lightning, logging or animal damage)
SP	Suppressed
UH	Unhealthy

Table 4. Trial series and ages selected for comparison

Trial Series	Ages considered
1975 Final Crop Stocking Trials	13 years and 24 years
1978 Genetic Gain Trials managed to a sawlog regime	14 years, 20 years and 24 years
1987 silviculture/breed trials	13 years
1990/91 silviculture / breed trials	13 years

Description of Trial Series considered

1975 Final Crop Stocking Trials

The 1975 Final Crop Stocking Trials contain 7 silvicuture treatments and were designed to examine the effect of thinning to different final crop stockings (Table 5). The trials contain one seedlot (GF13) and were planted at four locations:

- Woodhill (AK1056)
- Kaingaroa (RO2098)
- Golden Downs (NN529_1)
- Eyrewell (CY597)

Table 5. Silviculture treatments in the 1975 final crop stocking trials

Treatment Number	Initial Stocking (stems/ha)	Final Stocking (stems/ha)	Nominal mean crop height at time of thinning (m)	Age at thinning (years)
1	625	100	12	11
2	625	200	12	11
3	625	400	12	11
4	625	625	-	Unthinned
5	625	100	20	14
6	625	200	20	14
7	625	400	20	14

1978-80 Genetic Gain Trials

Trials were planted between 1978 and 1980 to assess the effects of genetic improvement on tree growth. The trials can be divided into three groups:

- 1978 trials managed to a sawlog regime
- 1978 trials managed to a pulpwood regime
- 1979-80 trials managed to a sawlog regime

Only the 1978 trials managed to a sawlog regime have been considered. The sawlog regime was:

- Plant at 1111 stems/ha
- Thin to 600 stems/ha at mean crop height of 6.2m
- Thin to 300 stems/ha at mean crop height of 12m
- Three pruning lifts: 2.2m, 4.2m and 6m

The location of the trials, seedlots present, and timing of the thinning operations is shown in Table 6.

Table 6. Locations of the 1978 Genetic Gain Trials managed to a sawlog regime

Location	**Seedlots**	**Stand age (years) at 1st thinning**	**Stand age (years) at 2nd thinning**
Aupouri, AK1058	GF2, GF7, GF14, GF22	5	12.1
Kaingaroa, R02103_1	GF2, GF7, GF14, GF22	6	10.0
Mohaka, WN377	GF2, GF7, GF14, GF22	5	8.4
Golden Downs, NN530_2	GF2, GF7, GF14, GF22	8	10.2
Longwood, SD564_1	GF2, GF7, GF14, GF22	8	10.0

Plots were established in the GF7 and GF14 seedlots at age 8 years for all sites except Longwood. Plots were established in the GF2 and GF22 seedlots between 14 and 17 years of age. Plots at Longwood were established between 14 and 17 years.

1987 Silvicultural / Breed Trials

There were 6 locations of the 1987 Silviculture /Breed Trials

- Woodhill, FR7
- Tahorakuri, FR8
- Kaingaroa, FR9
- Glengarry, FR10
- Ditchlings, FR11
- Otago Coast FR12

These trials contained 6 common treatments (Table 7) and 4 common seedlots:

- GF7
- GF13/ LI28
- GF14
- GF21

Table 7. Common silvicultural treatments in the 1987 silvicultural/ breed trial series.

Treatment Number	Initial stems/ha	Final stems/ha	Mean Crop Height at time of thinning (m)
1	500	100	6.2
2	500	200	6.2
3	1000	400	6.2
4	1500	600	6.2
5	500	500	-
6	500	200	20.0

1990/1991 Silviculture /Breed Trials

The 1990/1991 Silviculture /Breed trials contained 7 common silvicultural treatments (Table 8). All thinning treatments were scheduled to take place at a mean crop height of 6.2 m. The seedlots present varied with location; and some seedlot / treatment combinations were not included in all trial series (Table 9).

Table 8. Sivicultural treatments in the 1990/1991 Silviculture/ Breed Trials

Treatment	Initial stocking (stems/ha)	Final stocking (stems/ha)	Pruning
1	250	100	4m crown remaining
2	500	200	4m crown remaining
3	1000	400	4m crown remaining
4	500	200	unpruned
5	1000	400	unpruned
6	1000	600	unpruned
7	1000	1000	unpruned

Table 9. Location of 1990/1991 Silviculture / Breed Trials

Location	Year Planted	Seedlots included
Tungrove, FR121_1	1990	GF7, GF14, GF16, GF25, GF13/LI25
Atiamuri, FR121_2	1990	GF7, GF14, GF16, GF25, GF13/LI25
Gwavas, FR121_3	1990	GF7, GF14, GF16, GF25, GF13/LI25
Tairua, FR121_4	1990	GF7, GF14, GF16, GF25
Tarawera, FR121_6	1990	GF7, GF14, GF16, GF25, GF13/LI25
Huanui, FR121_7	1990	GF7, GF14, GF16, GF25
Mangatu, FR121_8	1991	GF6, GF14, GF16, GF25, GF13/LI25
Santoft, FR121_9	1991	GF6, GF14, GF16, GF25, GF13/LI25
Blue Mountains, FR121_10	1991	GF6, GF14, GF16, GF25, GF13/LI25
Shellocks, FR121_11	1991	GF6, GF14, GF16, GF25, GF13/LI25
Ashley, FR121_12	1991	GF6, GF14, GF16, GF25, GF13/LI25
Golden Downs, FR121_13	1991	GF6, GF14, GF16, GF25, GF13/LI25

Results

a. Stem Topple

Graphs (Appendix 1) illustrate that stem topple in these trials series was generally below 10%. Consequently these data have not been analysed further. Below are some comments on the trials exhibiting higher amounts of stem topple. The higher incidence of topple appear to be related to windiness in general or specific wind events.

<u>1975 Final Crop Stocking Trials</u>

Stem topple was highest in RO2098 (Figure A1.1). It was particularly high in the unthinned treatment after age 12 years, and more generally after age 21 years. The increase in damage at age 12 years was related to Cyclone Bola.

<u>1978 Genetic Gain Trials managed to a sawlog regime</u>

There was a sharp increase in stem topple in SD564_1 after 21 years, particularly in the GF22 seedlot. Bad wind damage was noted in the PSP system at this time.

<u>1987 Silvicultural / Breed Trials</u>

Stem topple was highest in FR12, in particular the plots from treatment 1 (which had a final crop stocking of 100 stems/ha). FR12 is known to be a very exposed site.

<u>1990/1991 Silviculture /Breed Trials</u>

Stem topple was particularly high in FR121/7 (Huanui) after age 7 years. But according to Ross Wade (pers comm.) this site is atypical compared to the surrounding forest. Wind and snow damage have been noted in the PSP system.

b. Stem damage

Graphs (Appendix 2) show that there was more stem damage than stem topple in these trial series. The data on stem damage have been analysed for each individual trial series at specified ages to investigate the influence of site, silviculture treatment and seedlot.

The SAS procedure PROC GLM was used to estimate least square means for the percentage of trees with stem damage. Site, silviculture treatment and seedlot were specified as class variables within PROC GLM, and least square means calculated for the different sites, silviculture treatments and seedlots within each trial series. A least square mean is very similar to a mean value, but is estimated in such a way that it accounts for any imbalance in the experimental design.

<u>1975 Final Crop Stocking Trials</u>

The percentage of trees with stem damage increased with increasing tree age (Table 10, Table 11, and Figure A2.1). At each site there are more trees with stem damage in the unthinned treatment, treatment 4 (Table 10 and Figure A2.1). At age 13 years, treatments 5, 6 and 7 were still at 625 stem/ha. The percentage trees with stem damage is thus quite variable between treatments at the same nominal stocking. At 24 years more trees had stem damage in the plots thinned to 400 stems/ha compared to the plots thinned to 100 or 200 stems/ha.

More trees had stem damage in the Kaingaroa and Eyrewell trials compared to the Woodhill and Nelson trials (Table 11).

Table 10. Least Square Mean values for the percentage of trees with stem damage in the 1975 Final Crop Stocking Trials by treatment at 13 years and 24 years.

Treatment	Percentage of trees with stem damage at 13.0 years	Percentage of trees with stem damage at 24.0 years
1	0.6	5.4
2	0.3	6.6
3	3.5	14.1
4	4.2	18.7
5	2.1	4.3
6	1.9	6.9
7	6.2	17.7

Table 11. Least Square Mean values for the percentage of trees with stem damage in the 1975 Final Crop Stocking Trials by site at 13 years and 24 years.

Site	Percentage of trees with stem damage at 13.0 years	Percentage of trees with stem damage 24 years
Woodhill AK1056	1.1	5.3
Kaingaroa RO2098	4.4	15.3
Golden Downs NN529_1	0.1	8.4
Eyrewell CY597	5.1	13.2

1978 Genetic Gain Trials managed to a sawlog regime

As with the 1975 Final Crop Stocking Trials, the percentage of trees with stem damage increased with increasing age (Figure A2.2).

The percentage of trees with stem damage varied with seedlot with the GF2 and GF22 seedlots showing more damage than the GF7 and GF14 seedlots (Table 13). The GF2 and GF22 plots were established at a later age (after the second thinning) compared to the GF7 and GF14 plots.
The percentage of trees with defects was previously calculated for this trial series with percentage of trees with defects being calculated as a function of trees present after the second thinning (SGMC Report 123). In these previous analyses, the GF2 and GF22 seedlots often showed more stem damage than the GF7 and GF14 seedlots. On this basis it is considered that these new results are not a consequence of the different age of PSP establishement.

The percentage of trees with damaged stems was highest in Hawkes Bay and lowest in Kaingaroa (Table 12). Even though the Kaingaroa trial had the lowest percentage of trees damaged it is still higher than that recorded in the 1975 Final Crop Stocking trial at Kaingaroa.

Table 12. Least Square Mean values for the percentage of trees with stem damage by location in the 1978 Genetic Gain Trials managed to a sawlog regime at 14 years and 20 years.

Location	Percentage of trees with stem damage at 14 years	Percentage of trees with stem damage 20 years	Percentage of trees with stem damage 24 years
Aupouri, AK1058	27.0	37.2	38.4
Kaingaroa, R02103_1	5.4	20.2	24.8
Hawkes Bay, WN377	14.7	43.1	44.6
Golden Downs, NN530_2	3.2	17.7	19.2
Longwood, SD564_1	8.2	39.1	44.9

Table 13. Least Square Mean values for the percentage of trees with stem damage by seedlot in the 1978 Genetic Gain Trials managed to a sawlog regime at 14 years and 20 years.

Seedlot	Percentage of trees with stem damage at 14 years	Percentage of trees with stem damage at 20 years	Percentage of trees with stem damage 24 years
GF2	12.5	39.8	43.1
GF7	7.2	20.7	22.6
GF14	8.9	26.5	28.8
GF22	18.2	38.9	43.0

1987 Silvicultural / Breed Trials

At 13 years, the percentage of trees with stem damage in the 1987 Silviculture /Breed Trials was around 30% for 3 locations: Kaingaroa (FR9), Glengarry (FR10) and Otago Coast (FR12). The Otago Coast trial is on a very exposed site close to the sea. The percentage of trees with stem damage was less than 20% for the other 3 locations (Table 14 and Figure A2.3).

A greater percentage of trees had stem damage in the unthinned treatment (treatment 5) compared to the thinned treatments (Table 15). In this trial series, where the thinning ratio was constant across silvicultural treatment, the treatments thinned to a lower final crop stocking showed more stem damage than plots with a higher final crop stocking.

The percentage of trees with stem damage varied little between the 4 seedlots (Table 16), but was highest in the long internode seedlot.

Table 14. Least Square Mean values for the percentage of trees with stem damage by location in the 1987 Silviculture /Breed Trials at 13 years.

Location	Percentage of trees with stem damage at 13 years
Woodhill, FR7	16.3
Tahorakuri, FR8	14.4
Kaingaroa, FR9	30.4
Glengarry, FR10	27.3
Ditchlings, FR11	18.9
Otago Coast, FR12	32.1

Table 15. Least Square Mean values for the percentage of trees with stem damage by silvicultural treatment in the 1987 Silviculture /Breed Trials at 13 years.

Treatment	Final stems/ha	Percentage of trees with stem damage at 13 years
1	100	24.0
2	200	20.2
3	400	17.2
4	600	15.5
5	500	37.7
6	200	24.7

Table 16. Least Square Mean values for the percentage of trees with stem damage by seedlot in the 1987 Silviculture /Breed Trials at 13 years.

Seedlot	Percentage of trees with stem damage at 13 years
GF7	22.0
GF13 / LI28	26.5
GF14	24.2
GF21	20.3

1990/1991 Silviculture /Breed Trials

The percentage of trees with stem damage varied with treatment between 16.3% and 28% (Table 17) with the unthinned / unpruned treatment, treatment 7 having the most damage. Damage was also high in treatment 4, where the trees were planted at 500 stems/ha, thinned to 200 stems/ha and left unpruned.

The percentage trees with stem damage varied between 17.6% and 25.1% with the GF25 seedlot having the least damage (Table 18).

The percentage trees with stem damage varied across sites from 9.8% of trees being damaged at Ashley to 39.4% of trees being damaged at Gwavas (Table 19 and Figure A2.4).

Table 17. Least Square Mean values for the percentage of trees with stem damage by silvicultural treatment in the 1987 Silviculture /Breed Trials at 13 years.

Treatment	Percentage of trees with stem damage at age 13 years
1	18.2
2	19.3
3	16.3
4	27.3
5	20.0
6	21.7
7	28.0

Table 18. Least Square Mean values for the percentage of trees with stem damage by seedlot in the 1987 Silviculture /Breed Trials at 13 years.

Seedlot	Percentage of trees with stem damage at age 13 years
GF6	21.2
GF7	25.1
GF13 /LI25	24.1
GF14	21.7
GF16	19.5
GF25	17.6

Table 19. Least Square Mean values for the percentage of trees with stem damage by location in the 1990/1 Silviculture /Breed Trials at 13 years.

Location	Percentage of trees with stem damage at age 13 years
Tungrove, FR121_1	18.5
Atiamuri, FR121_2	13.7
Gwavas, FR121_3	39.4
Tairua, FR121_4	10.4
Tarawera, FR121_6	23.6
Huanui, FR121_7	25.4
Mangatu, FR121_8	20.0
Santoft, FR121_9	12.1
Blue Mountains, FR121_10	36.6
Shellocks, FR121_11	37.4
Ashley, FR121_12	9.8
Golden Downs, FR121_13	11.4

Discussion

The SGMC has been supporting the development of an integrated tree and branch growth model, TreeBLOSSIM. PhotoMARVL and TreeD have been used to collect data to compare with TreeBLOSSIM predictions. These studies have shown that trees with stem damage have larger than expected branches, which are not predicted by TreeBLOSSIM. The objective of this study was to quantify how widespread stem damage is in SGMC trials.

The descriptive codes recorded in the PSP system have been used to estimate the percentage of trees that have been toppled or have received stem damage by specified ages. These values will probably be underestimates as the above PhotoMARVL /TreeD studies have identified trees with stem damage that have not been assigned a descriptive code.

The percentage of trees that had been toppled and the percentage of trees with stem damage by a given age was calculated for 4 trial series:

- 1975 final crop stocking trials
- 1978 genetic gain trials
- 1987 silviculture / breed trials
- 1990/1991 silviculture /breed trials

Few trees were toppled in these trial series. Graphs were plotted showing the percentage of trees toppled (Appendix 1), but the data were not analysed further.
There were far more trees that had received stem damage (see graphs in Appendix 2). For each trial series, least square means were calculated giving the % of trees damaged with respect to site, silvicultural treatment and seedlot. The ranges are summarised in (Table 20). The impact of seedlot is generally smaller than the impact of either site or silvicultural treatments. Known windy sites tend to have high percentage of trees with stem damage.

Table 20. Range of least square mean values for percentage of trees with stem damage

Trial Series	Site	Silviculture	Seedlot
1975 final crop stocking (age 24 years)	5.3 % to 15.3 %	4.3% to 18.7 %	-
1978 genetic gain (age 24 years)	19.2% to 44.9 %	-	22.6% to 43.1%
1987 silviculture /breed (age 13 years)	14.4% to 32.1%	15.5% to 37.7%	20.3% to 26.5 %
1990/1991 silviculture / breed (age 13 years)	9.8% to 39.4%	16.3% to 28.0%	17.6% to 25.1%

INCLUSION OF STEM DAMAGE WITHIN TreeBLOSSIM

TreeBLOSSIM was developed with the objective of being able to grow branching data, recorded in an inventory data, forward in time until the end of the rotation. At the end of the rotation, inventory data (including branching characteristics) are used to determine the likely product outturn.

There are several issues that need to be considered in determining the appropriate method of including stem damage within TreeBLOSSIM.

- Inventory data already includes stem damage.
- We do not know future weather conditions, so we will not be able to predict the heights of any future damage.
- Currently we do not have any data to be able to model how a tree grows after it has been severely damaged.
- Mechanistic models that predict stem damage are very useful for determining the conditions that will lead to stem damage, but some of the input parameters to such models are unlikely to be readily available.

A possible way forward is proposed:

- Accept that TreeBLOSSIM cannot predict stem damage.
- Previous PhotoMARVL / TreeD studies have been used to estimate a branch diameter, above which branches are likely to be the result of stem damage, rather than the regular branching pattern. The estimated branch diameters are:
    - 140 mm (SGMC Report No. 134)
    - 140 mm (SGMC Report No. 136)
    - 160 mm (SGMC Report No. 137)
- If mid-rotation and rotation age inventories were available for selected stands, then the above values could be used to estimate how the percentage of damaged stems and the number of occurrences of damage varies from mid-rotation to end of rotation.
- Such results could then be used to develop a "downgrade" factor that is used in the analysis of mid-rotation inventory data.
- When growing inventory data forward in time, it will be important to estimate the heights of future damage reasonably accurately, as this will affect the type of product that needs to be down-graded (A. Gordon, pers. comm.).

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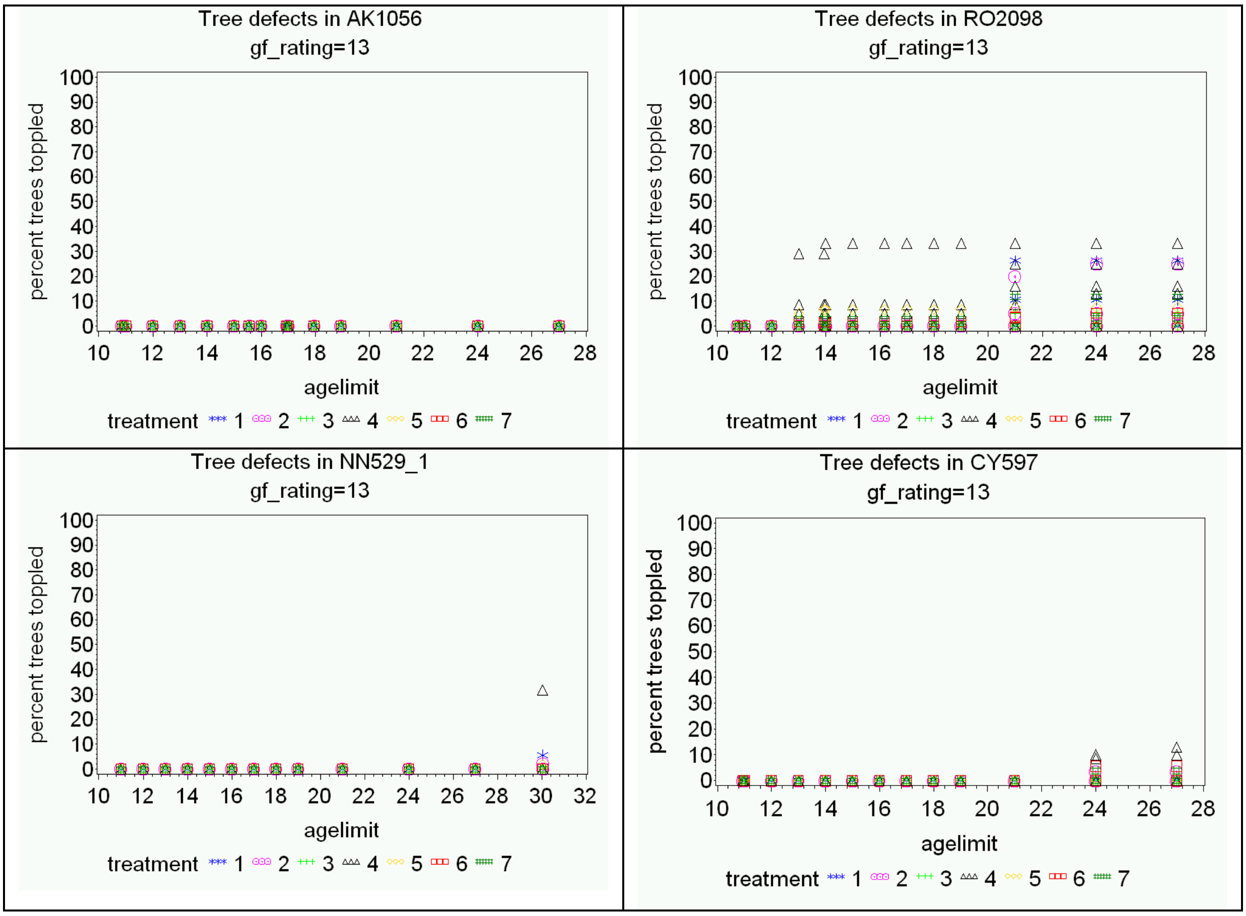
Appendix 1. Graphs showing the amount of stem topple in SGMC trial series

Note:
For the graphs in this Appendix, the vertical axis is the percentage of "alive" and "windthrown" trees present in the PSP at time of the first measurement that have ever been assigned a "topple code" up until the age (in years) given by "agelimit" on the horizontal axis.

Figure A1.1 Stem topple in the 1975 Final Crop Stocking Trials



FigureA1.2. Stem topple in the 1978 Genetic Gain Trials managed to a sawlog regime

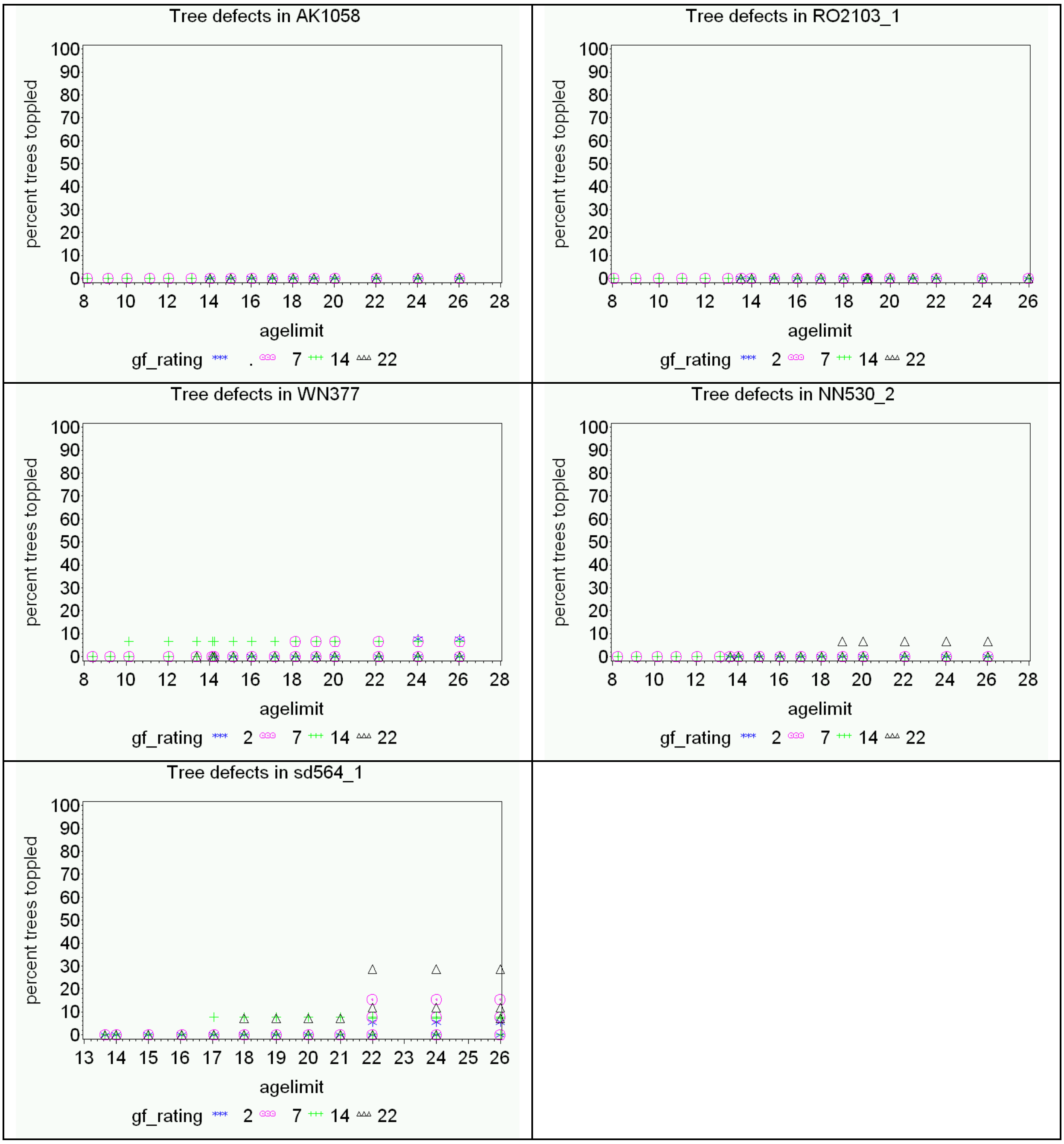


Figure A1.3. Stem topple in the 1987 Silviculture Breed trials

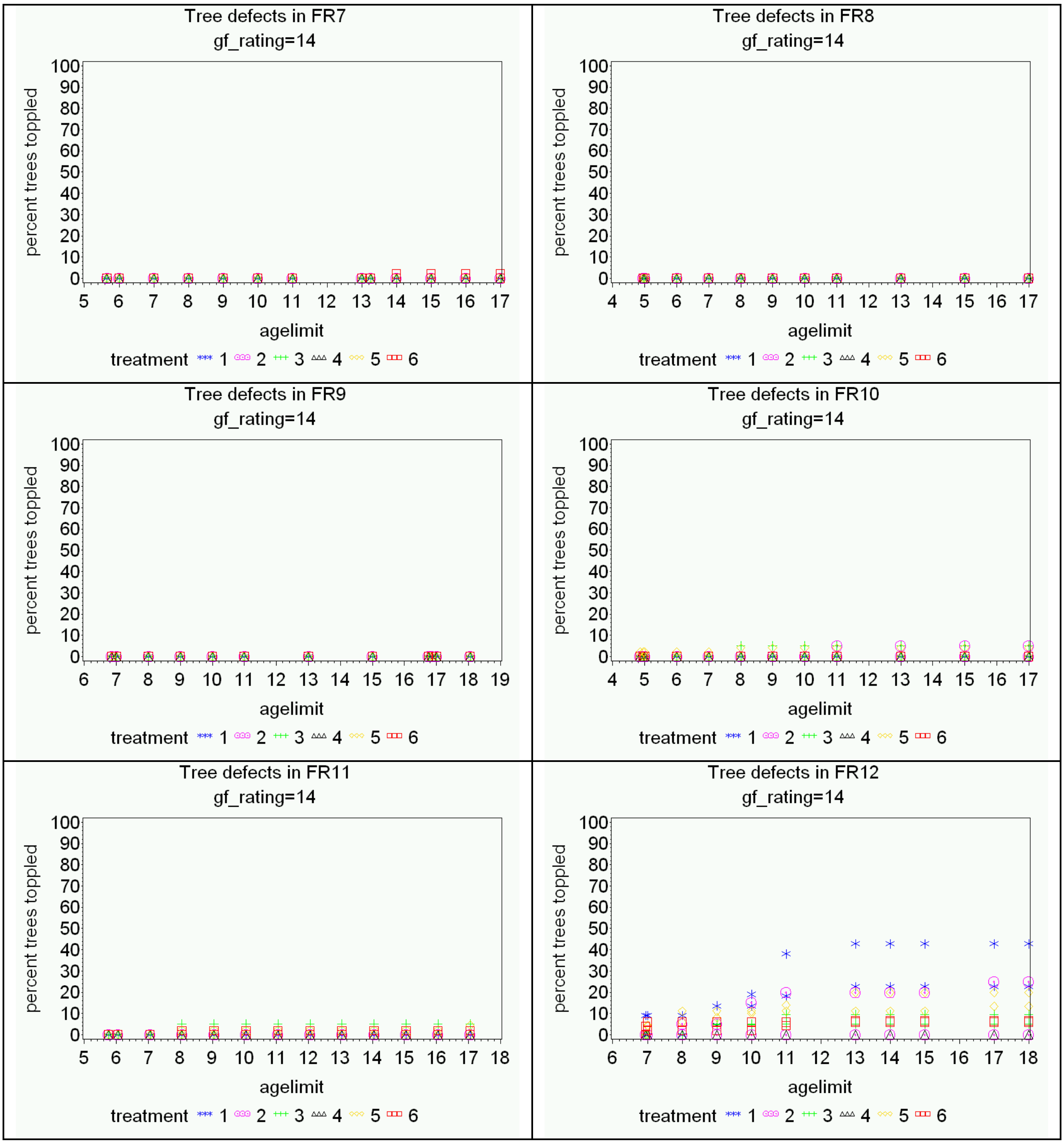


Figure A1.4. Stem topple in the 1990/1991 Silviculture / Breed trials

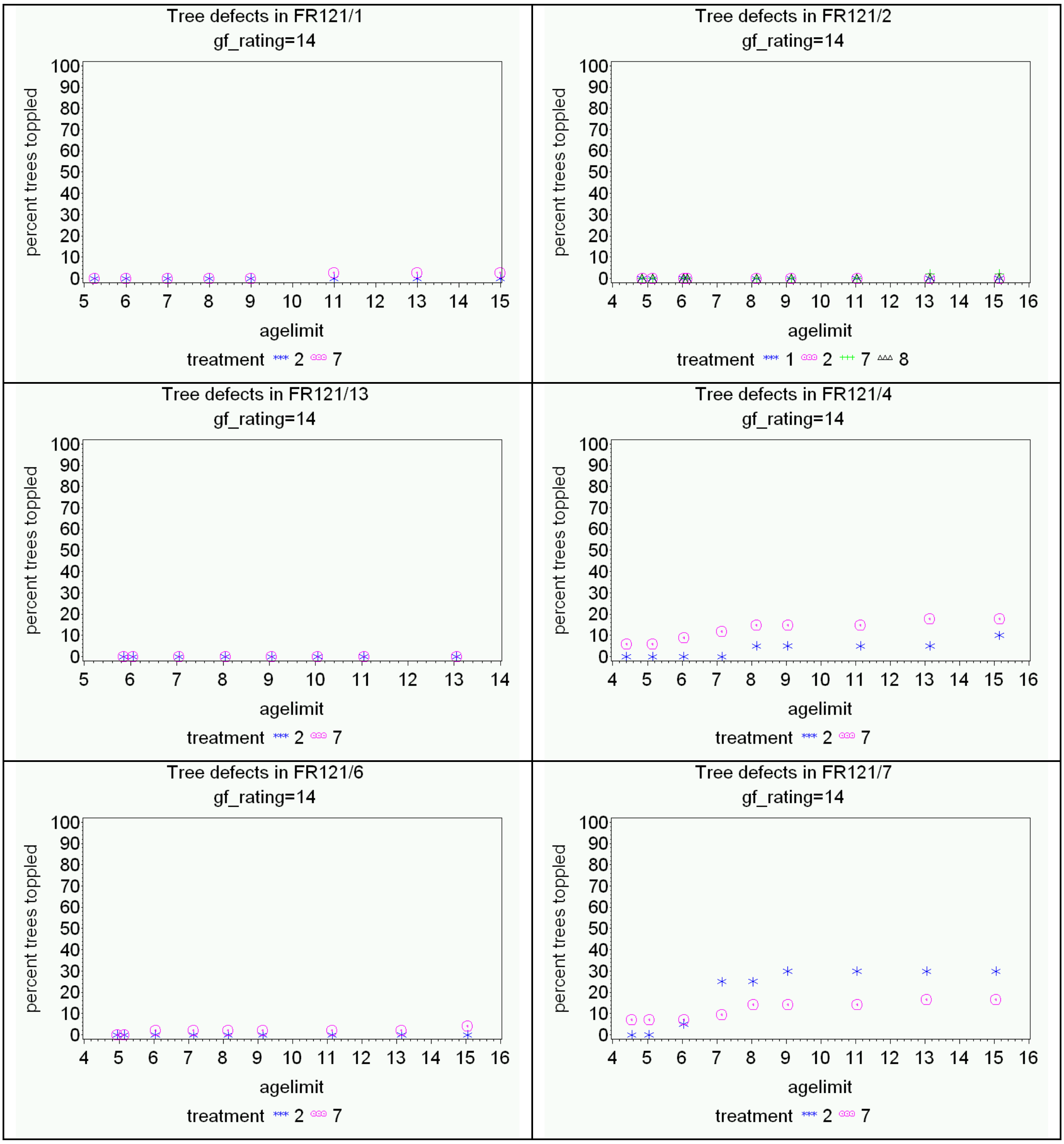
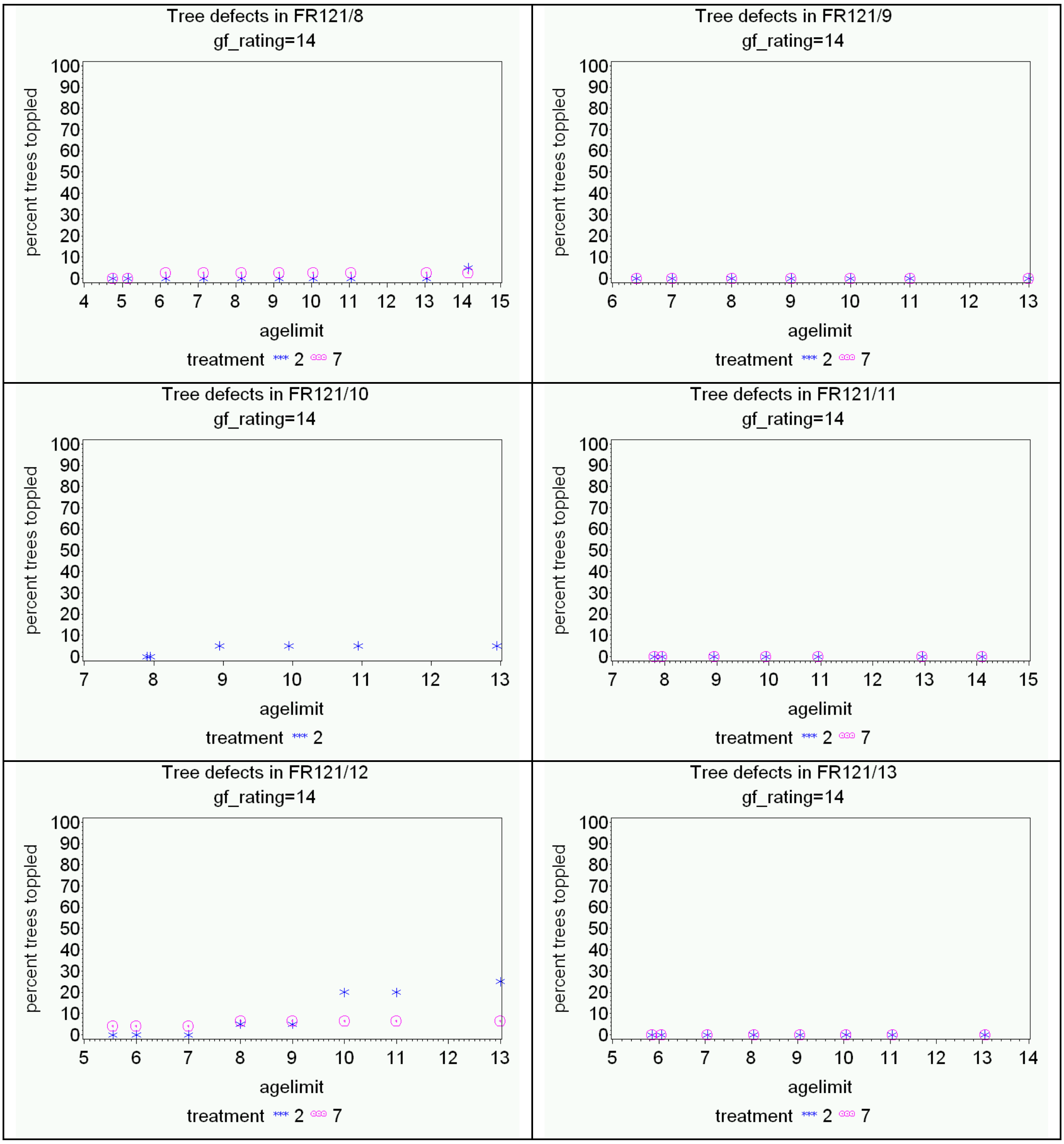


Figure A1.4 (continued). Stem topple in the 1990/1991 Silviculture / Breed trials



Appendix 2. Graphs showing the amount of stem damage in SGMC trials.

Note:
For the graphs in this Appendix, the vertical axis is the percentage of “alive” and “windthrown” trees present in the PSP at time of the first measurement that have ever been assigned a “stem damage code” (see Table 1) up until the age (in years) given by “agelimit” on the horizontal axis.

Figure A2.1 Percentage of trees with stem damage in 1975 Final Crop Stocking Trials

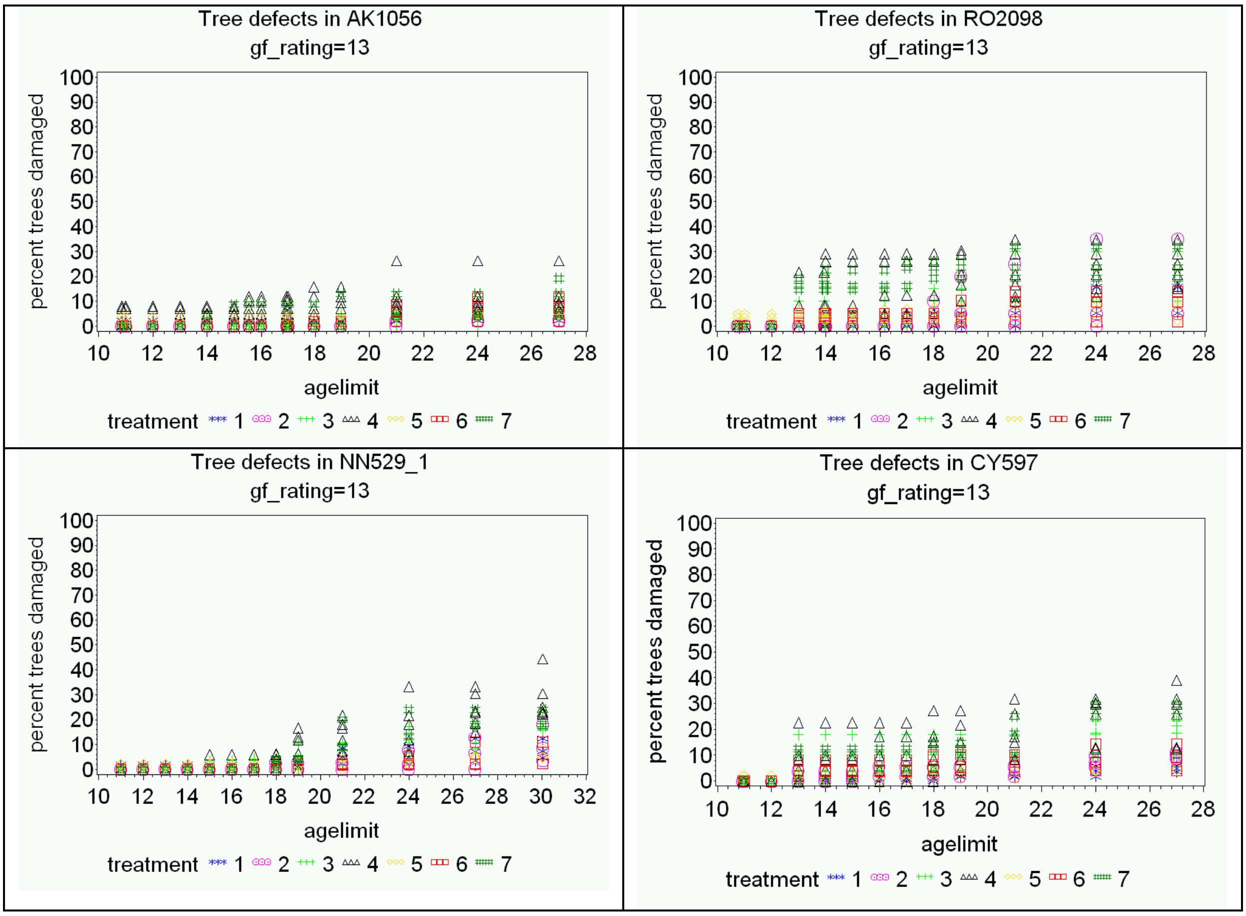


Figure A2.2. Percentage of trees with stem damage in the 1978 Genetic Gain Trials managed to a sawlog regime.

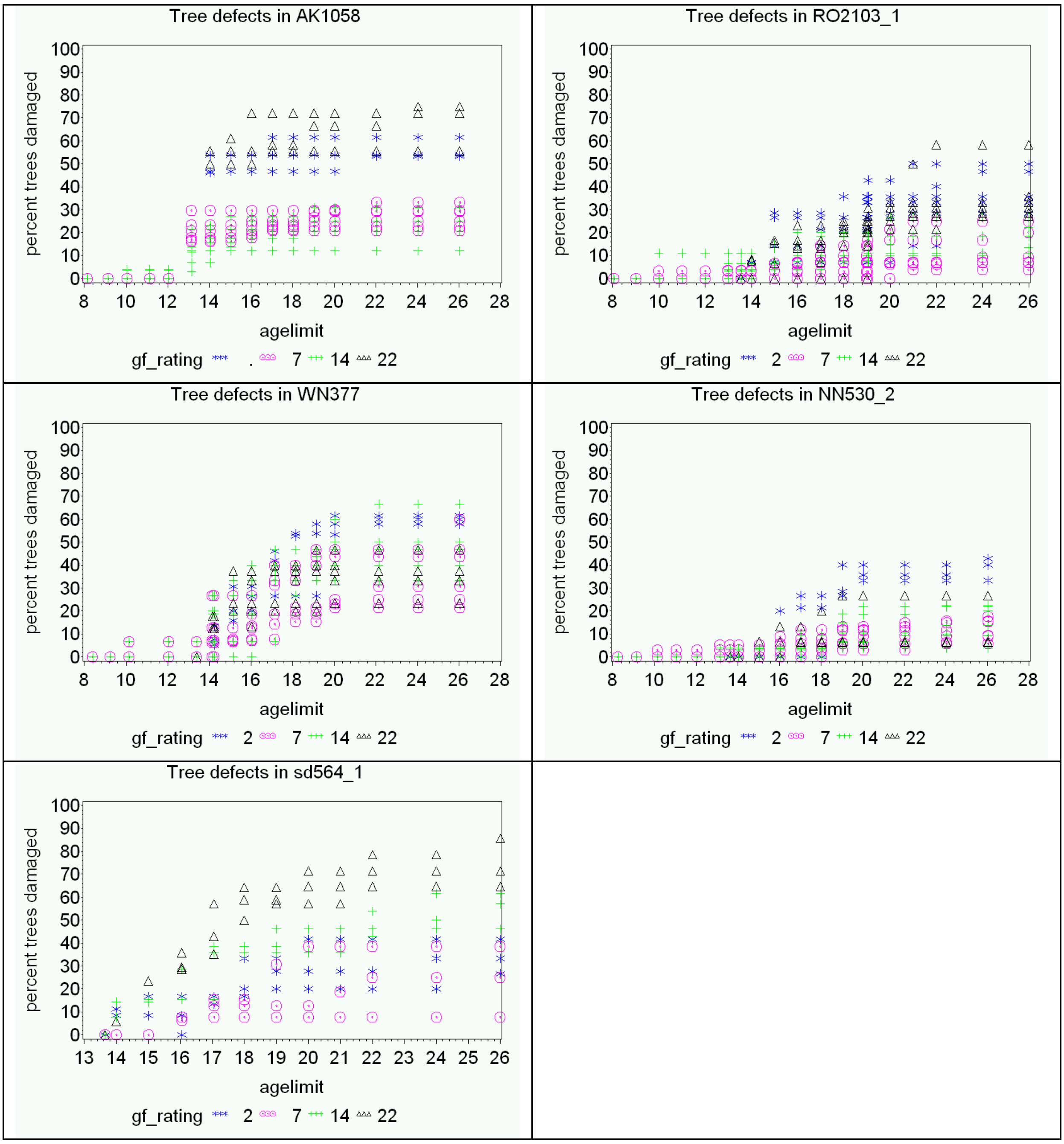


Figure A2.3. Percentage of trees with stem damage for GF14 seedlot in the 1987 silvicultural/breed trials

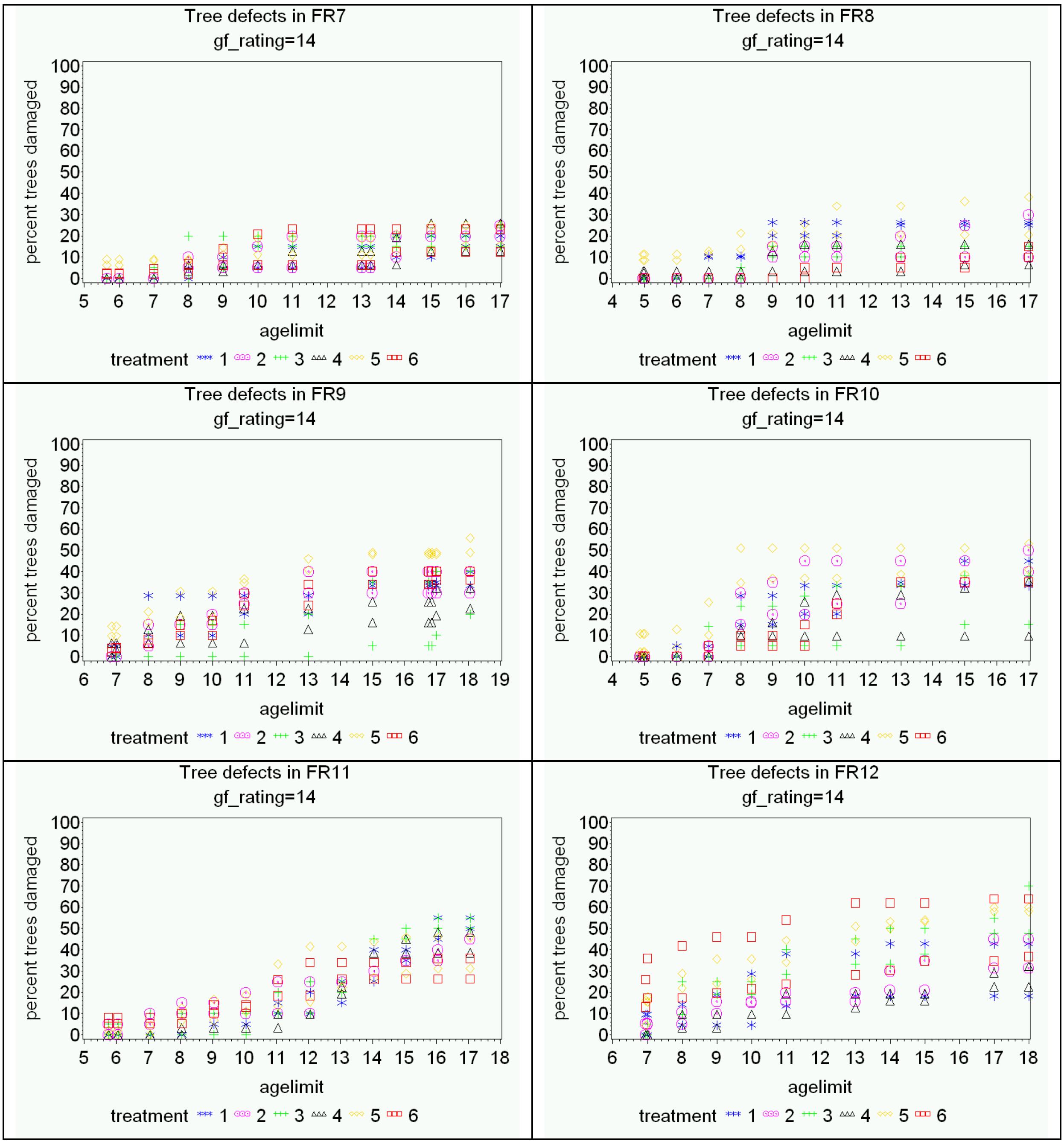


Figure A2.4. Percentage of trees with stem damage for GF14 seedlot in the 1990/91 silvicultural/breed trials

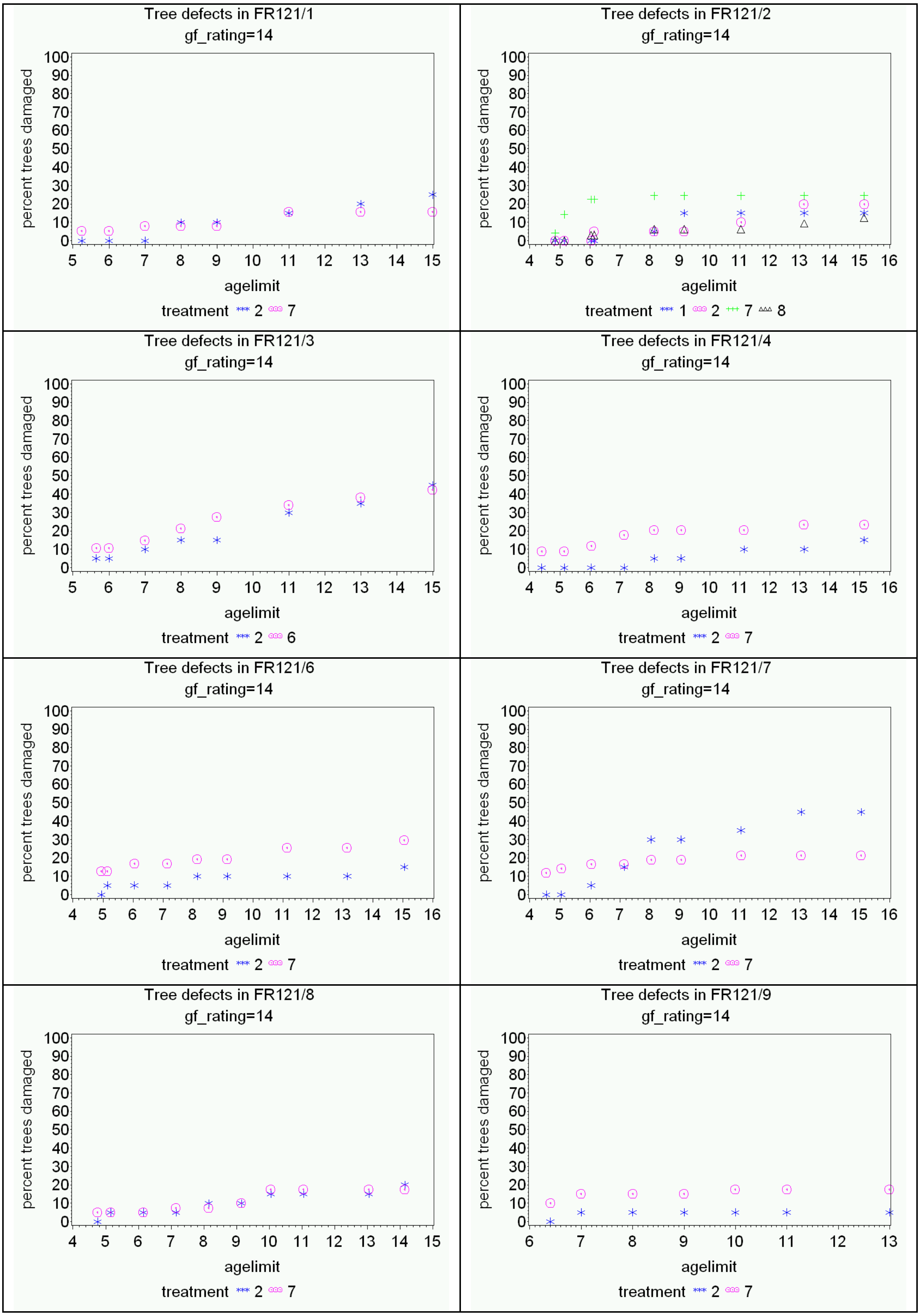


Figure A2.5 (continued). Percentage of trees with stem damage for GF14 seedlot in the 1990/91 silvicultural/breed trials.