Future use of the Inglehope thinning experiment

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Summary

The study consists of thirty 40 x 40 m thinned jarrah plots and controls dispersed over approximately 40 ha at Inglehope, 12 km east of Dwellingup.

This study was initiated in 1964 to quantify the response of 40 year old jarrah poles to a range of thinning intensities. Thinning resulted in five stand densities treatments. The plots were then re-thinned in 1986 and half were fertilized, resulting in an experiment with five thinning intensities X two fertilizer treatments with three replicate plots for each of the ten treatments.

A large record of measurements over a long time period is available from this experiment. The site has been used for studies of jarrah tree and stand growth, water relations, leaf area, seed production, and phenology.

Extensive regrowth of new stems since the last thinning in 1986 has produced a cohort of small diameter stems, particularly on the more heavily thinned treatments. The basal areas of the treatments are now well above those prescribed in the original treatments in 1964 and 1986. The future use, management, and potential re-thinning of this study site now needs to be considered.

Study area

This study area is located in a high quality even-aged regrowth stand of *E. marginata* in Inglehope forest block (32° 45'S, 116° 11'E; 423500m E, 6375900m N) 9 km south east of Dwellingup, Western Australia (see map below and Fig. 1). The overstorey trees on this site are predominantly jarrah with very few (~1%) marri occurring in the stand. The soil is yellow sandy ferruginous gravel and is of low fertility. The climate in the area is typically mediterranean with an average annual rainfall over the period of the seed collection of 1177mm at Dwellingup, and an average annual pan evaporation of 1277mm. Long term average annual rainfall at the site is 1100mm, 200mm less than that at Dwellingup. Average monthly maximum temperature varies from about 30° C in January and February to 14° C in July.

The Inglehope trial area is surrounded by a fire break and most of this area has been excluded from prescribed fire and wildfire for at least 25 years. The surrounding area was last burnt in 2003. At this time plots 15, 16, 20 and 28 were burnt under mild conditions when an ember ignited an area well inside the existing fire break.

Study design and history

- 30 plots, each 40 m x 40 m with an 8 m buffer (see attached map)
- Five thinning treatments by two fertilizer treatments by three replicate plots in a completely randomized design
- First thinned in 1964 (at stand age 40 years)
  - Stand densities of 7, 11, 15 and 18 m^2ha^{-1} basal areas under bark with unthinned controls of 22 m^2ha^{-1}.
- Second thinning in 1986 at 62 years old (i.e. + 22 years)
- Half of the plots were fertilized in 1987 and 1988.
  - unfertilized, and fertilized with 400 kg ha^{-1} N and 229 kg ha^{-1} P.
- Both thinnings removed the smallest and slowest growing trees (thinning from below).
- All trees and stumps from felled trees are numbered and tagged,
- The location of every single tree is mapped
- Plot corners and centres differentially GPSed
- Prescribed burn in October 2015, followed by re-marking of plots and re-tagging of trees.

Treatment history

1964

- The site was an even aged stand of jarrah poles in 1964; the result of intensive harvesting for Chadoora mill.
- First thinned in 1964, (stand age approximately 40 years). Thinned from below i.e. the thinning removed the slower growing trees.
- Treatments in 1964; six replicate plots of four treatments 7, 11, 15 and 18 m^2 ha^{-1} basal area under bark, and three control plots of about 22 m^2 ha^{-1}.

1986

- Re-thinned in 1986, 22 years after the first thinning (stand age approx. 62 years).
- The treatments had nominal stand densities of 5.5, 10.9, 16.4, and 22.4 m^2 ha^{-1} basal area under bark, and control plots of 28.5 m^2 ha^{-1}. Three more control plots added.
- Fertilised in 1987 and 1988 with 400 kg ha^{-1} N and 229 kg ha^{-1} P.
- Thinned from below i.e. the thinning removed the slower growing trees.
- Storm damage occurred after the thinning and fertilizer treatment, particularly in the heavily thinned and fertilized plots. There is a draft paper on this

1993

- Regeneration was poisoned in the first week of June 1993. Only the fertilized plots were treated. The fertilized plots are: 22, 15, 28, 20, 1, 19, 27, 6, 18, 21, 10, 9, 2, 26, 30.

Treatment summary

- Thinned from below.
- First thinned at 40 years old.
- Second thinning at 62 years old (i.e. + 22 years).
- Fertilised after second thinning.
- A third thinning now is possible at a stand age of 87 years (i.e. + 25 years).

Measurement history

The most regular measurements were of underbark diameters for all trees. Tree heights, crown depths and widths were also measured for all trees on two occasions. Individual tree leaf areas and leaf area index were determined for some plots. Various other data has also been collected on these plots including flower and seed production, litter-fall, and leaf nutrient status. All trees are numbered, tagged and mapped, and plot boundaries are clearly marked and mapped.

- Available measurements are listed in Appendix 1.
- Diameters of all trees were measured in 1965, then annually from 1984 to 1991, and then in 2010.
- Individual tree leaf areas were determined for all trees on 21 plots in 1987 and 1988.
- Leaf area index (LAI) was measured on 26 plots in 1988, 1989, 1990 and on all plots in 2010.
- Calculations of total plot standing biomass have been made for the various years presumably using Hingston's allometric equations.
- Seasonal growth monitored with dendrometer bands
- Stem flow
- Throughflow
- Midday and pre-dawn water potential
- Specific leaf areas

Future management and use of this trial

Extensive regrowth of new stems since the last thinning in 1986 has produced a cohort of small diameter stems, particularly on the more heavily thinned treatments (Fig. 1). These new stems are of a much smaller diameter than the original stems retained in 1964 and again in 1986. The basal areas of the treatments are now well above those prescribed in the original treatments in 1964 and 1986. The future of this study site now needs to be considered.

Fig.1. A thinned and fertilized plot showing the large number of small regrowth and ingrowth stems.

Thinning options

1. Do nothing. No thinning or removal of regrowth and ingrowth. Maintain plot and tree markings.
   - The second tier of small stems is very much younger than the stems remaining from the original and second thinnings, and these new stems are most common on the more heavily thinned plots – having little effect on the control and lighter thinnings (see Appendices 2 & 5). Consequently these small stems are an anomalous source of variation in measurements of tree and stand basal area growth.
   - However the regrowth are potentially useful for study water relations and long term responses to thinning.
   - Studies of the regrowth on a stand basis may have reduced value because of the uncertain history of interventions, (e.g. the poisoning of regrowth on the fertilized plots in 1993) and extensive foot traffic and machine tracks over parts of some plots.

2. Retain only the trees remaining from the 1964 and 1986 thinnings. Remove the ingrowth and the regrowth from stumps.
   - Basal area under bark (BAUB) across the treatments would then range from 10 to 35 m^2 ha^{-1} (2010 BAUB values in Appendix 2).
   - This action appears as the most efficient choice as it costs little and increases the scientific value of the treatments by removing the small ingrowth and regrowth stems which mainly add a source of variation to any measurements on the plots.

3. Remove ingrowth and regrowth and thin the plots a third time.
   - I suggest stand densities of 5, 12.4, 19.8, 27.2 and 34.6 m^2 ha^{-1} BAUB would be consistent with the previous thinning strategies.
   - Thinning to 20, 40, 60 and 80% of unthinned BA may be better and would be consistent with the 1986 treatment which I think was on that basis. However, as noted below 20% may be too low to be useful so maybe 30% instead as the low end and then spread evenly to 100%. A wider buffer may also be required for the T1 and T2 plots so that the influence of surrounding forest is reduced.
   - However there would then be too few trees on the most heavily thinned plots (5 m^2 ha^{-1}) to provide a good sample. I see no sensible way of achieving a 5 m^2 ha^{-1} treatment that is consistent with the previous thinning histories and has a reasonable number of stems.
   - A third thinning would have little relevance to operational silvicultural practice.
   - The plot buffers would also need to be thinned.
   - A third thinning is possibly useful as an example of maximizing tree growth in jarrah beyond the pole stage. Provides data on the ongoing effect of stand density as tree size increases beyond pole size.

4. Other more substantial or extensive treatments of the site, such as adding new thinning treatments, could be undertaken but would be more expensive and be driven by particular research questions.
   - One such possibility is thinning some of the existing plots, or creating new plots in the surrounding forest to examine the how stand age affects the response to thinning.

Value of this site for future studies

The study has significant value because of its sound replicated design and history of measurement since 1964.

The treatment plots provide a basis for studying the long-term effects of thinning and fertility on various stand and tree attributes and provide examples of varying stand density and varying tree size across similar tree ages. The existing experimental design is excellent for studying:

- Tree and stand growth
- Tree physiology
- Tree water relations (The earlier data provides a basis for comparison with tree water stress under a drying climate)
- Through fall, interception
- Stand LAI and tree leaf area
- Nutrient cycling
- Understorey diversity (may be impacted in the more heavily thinned and fertilized treatments by work done to control regeneration)
- Seed production
- Phenology
- Wood decay rates
- Litter fall
- Tree architecture

Long-term studies of jarrah growth are particularly valuable for studying the impact of rainfall decline over the last 34 years in SW WA. The Inglehope thinning experiment is one of a few thinning studies and is the best documented, measured and maintained of these long-term studies. The site has substantial value for studying the impact of rainfall decline because of this long record of measurement and should be maintained at least for this reason alone.

Appendices

Appendix 1. Measurement history. Tree and plot measurements available from the Inglehope thinning study.

Year	DBHOB [A]	DBHUB	Bark depth	Tree height	Height to top of crown	Crown break height	Height to bottom of crown	Crown width	Tree position (Dominance)	Tree leaf area[C]	Leaf area index[D]
1964	X										
1965	X	X	X	X					X		
1984	X	X	X	X		X					
1985				X	X		X	X			
1986	X	X	X								
1987[B]	X	X	X							X	
1988	X	X	X							X	X
1989		X									X
1990		X									X
1991		X									
2010	X	X	X	X	X	X					X
2016/17	X	X	X								

[A] These trees have had their bark scraped periodically. Consequently the overbark diameters are not representative of the wider forest.

[B] Plots 29, 30, and 31 (all in T5, i.e. controls) were not measured prior to 1987.

[C] Only the trees on twenty-one plots were measured.

[D] Only 26 plots were measured in 1988, 1989 and 1990.

Other available measurement data and studies at the site

- Seasonal growth monitored with dendrometer bands
- Stem flow
- Throughflow
- Midday and pre-dawn water potential
- Nutrient relations
- Rainfall
- Groundwater level
- Soil moisture (Kimber see Stoneman 1990)
- Seedfall
- Specific leaf area
- Leaf nutrients

- Litter nutrients
- Litter fall

Appendix 2. Treatment basal areas and stockings in 1964, 1987 and 2010.

Treatment	1964 BAUB (m^2 ha^{-1})	1987 Fertilized	1987 BAUB (m^2 ha^{-1})	2010 BAUB original stems (m^2 ha^{-1})	2010 BAUB ingrowth (m^2 ha^{-1})	2010 BAUB all stems (m^2 ha^{-1})	2010 % BAUB in ingrowth	Suggested target BAUB in 2010 (m^2 ha^{-1})
T1	6.9	N	5.7	10.2	4	14.2	39.4	5
T1	7.1	Y	5.6	9.8	3.7	13.5	37.3	5
T2	11.2	N	10.9	17.0	1.9	18.9	11.3	12.4
T2	10.9	Y	11.1	19.6	0.4	19.9	1.9	12.4
T3	15.4	N	16.6	22.1	0.5	22.7	2.4	19.8
T3	15.4	Y	16.5	25.7	0.1	25.8	0.4	19.8
T4	18.2	N	22.3	28.2	0.4	28.6	1.3	27.2
T4	18.5	Y	21.9	33.1	0.2	33.2	0.5	27.2
T5	22.0	N	29.1	34.2	0.2	34.5	0.7	34.5
T5	22.0	Y	27.3	35.0	1.2	36.3	3.5	36.3

Treatment	Fertilized 1987	1987 Stocking (stems ha^{-1})	1991 Mean diameter under bark (cm)	2010 Stocking original (stems ha^{-1})	2010 Stocking ingrowth (stems ha^{-1})	2010 Total stocking (stems ha^{-1})
T1	N	54	39.3	52	596	648
T1	Y	54	39.1	44	931	975
T2	N	181	28.5	179	165	344
T2	Y	150	33.2	133	121	254
T3	N	242	30.1	231	127	358
T3	Y	325	26.1	315	27	342
T4	N	579	21.5	573	58	631
T4	Y	554	22.5	546	6	552
T5	N	1100	16.7	1008	42	1050
T5	Y	1125	16.6	1033	125	1158

Appendix 3. Publications from the Inglehope thinning experiment.

Abbott, I., Loneragan, O., 1983. Response of jarrah (*Eucalyptus marginata*) regrowth to thinning. Australian Forest Research 13, 217-229.

Fitzgerald, B. (1996). Long term effects of thinning and fertiliser on tree and stand growth, leaf area index and water relations in Eucalyptus marginata (jarrah). School of Environmental Biology. Perth, Western Australia, Curtin University of Technology: 57.

Hingston, F.J., Galbraith, J.H., Dimmock, G.M., DeBoer, E.S., 1994. Effect of fertilizers on thinned and unthinned jarrah (*Eucalyptus marginata*) stands, Western Australia (I) growth rates. User Series no. 10, CSIRO Division of Forestry.

Hingston, F.J., Galbraith, J.H., Dimmock, G.M., 1994. Effect of fertilizers on thinned and unthinned jarrah (*Eucalyptus marginata*) stands, on gravelly lateritic soils in the Darling Range, Western Australia (II) Characteristics of leaves. User Series no. 11, CSIRO Division of Forestry.

Hingston, F.J., Galbraith, J.H., Dimmock, G.M., 1994. Effect of fertilizers on thinned and unthinned jarrah (*Eucalyptus marginata*) stands, Western Australia. (III) Physical characteristics and nutrient content of leaf litter. User Series, no. 12, CSIRO Division of Forestry.

Stoneman, G. L. (1990). Forest density reduction in a small catchment of the northern jarrah forest and the effect on water and wood production, University of Western Australia.

Stoneman, G. L. and N. J. Schofield (1989). "Silviculture for water production in jarrah forest of Western Australia: an evaluation." Forest Ecology and Management **27**: 273-293.

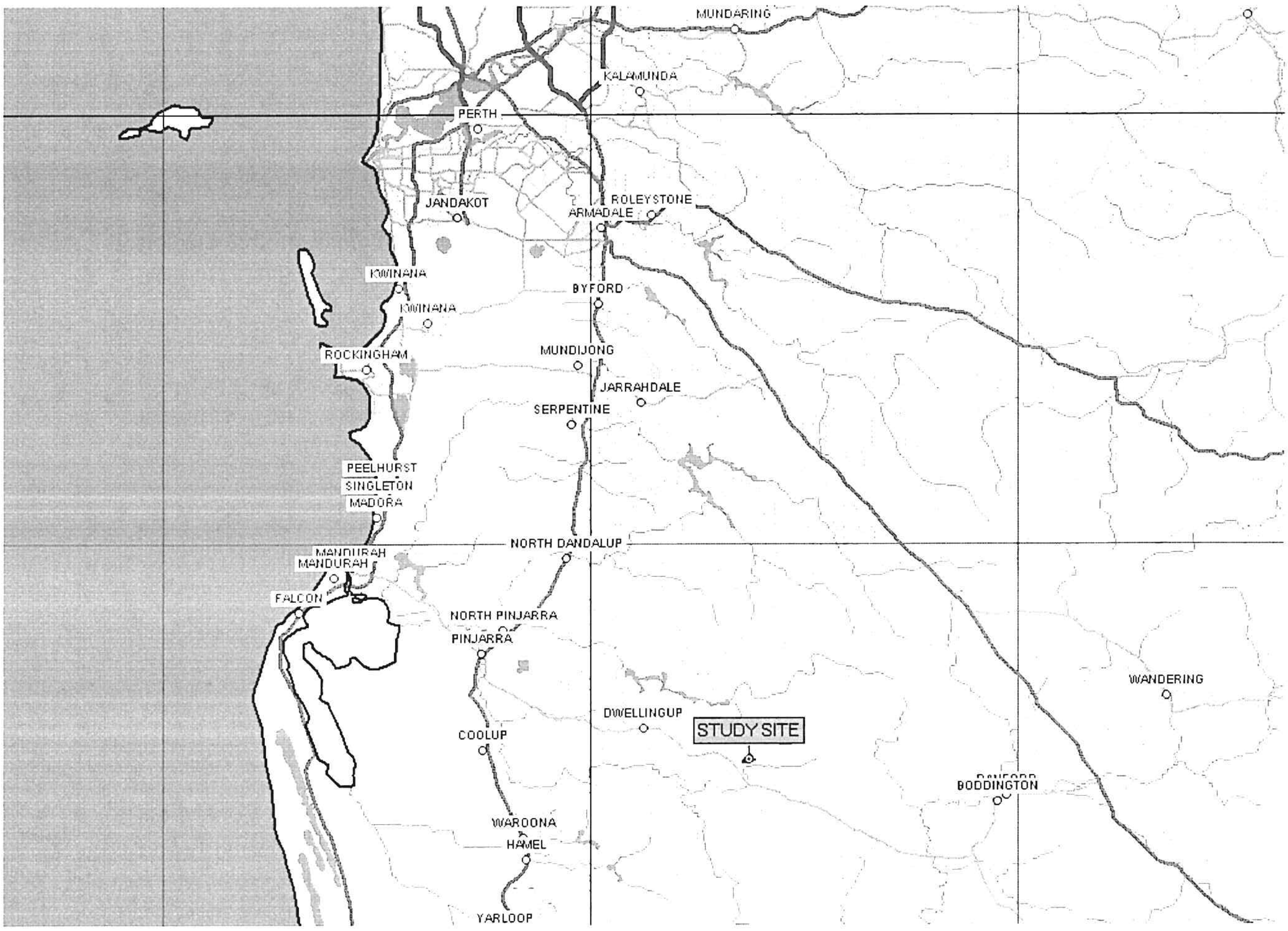
Stoneman, G. L., F. J. Bradshaw, et al. (1989). Silviculture. The Jarrah Forest. B. Dell, N. J. Malajzcuk and J. J. Havel. Dordrecht, Kluwer Academic Publishers: 335-355.

Stoneman, G.L., Whitford, K., 1995. Analysis of the concept of growth efficiency in Eucalyptus marginata (jarrah) in relation to thinning fertilising and tree characteristics. Forest Ecology and Management 76, 47-53.

Stoneman, G.L., Crombie, D.S., Whitford, K., Hingston, F.J., Giles, R., Portlock, C.C., Galbraith, J.H., Dimmock, G.M., 1997. Growth and water relations of Eucalyptus marginata (jarrah) stands in response to thinning and fertilization. Tree Physiology 17, 267-274.

Appendix 4. Study area

This study area is located in a high quality even-aged regrowth stand of *E. marginata* in Inglehope forest block 12 km south east of Dwellingup (see map below and Fig. 1). The overstorey trees on this site are predominantly jarrah (~1% marri). Long term average annual rainfall at the site is 1100 mm. Average monthly maximum temperature varies from about 30° C in January and February to 14° C in July. Average annual pan evaporation at Dwellingup is 1277mm.



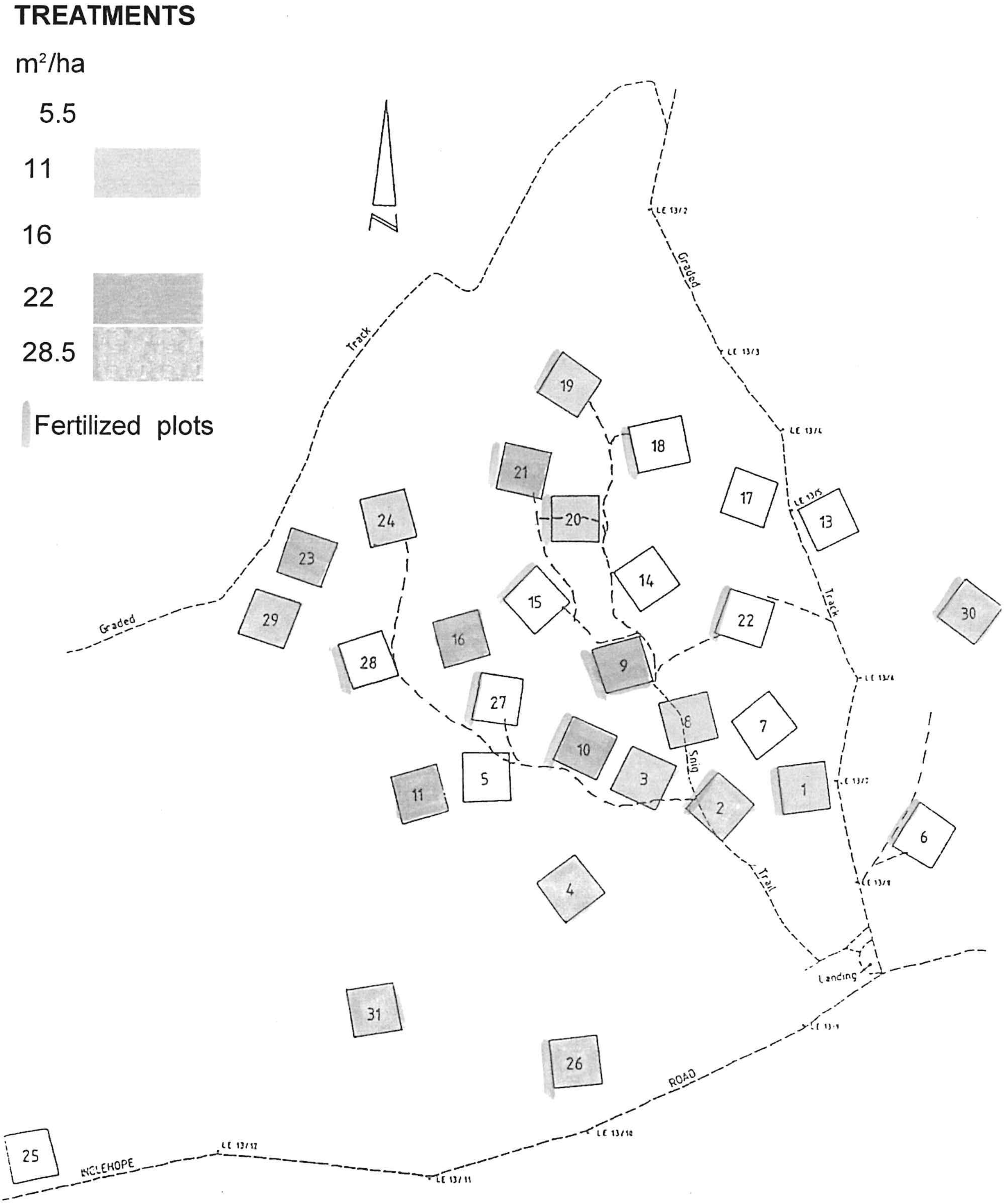
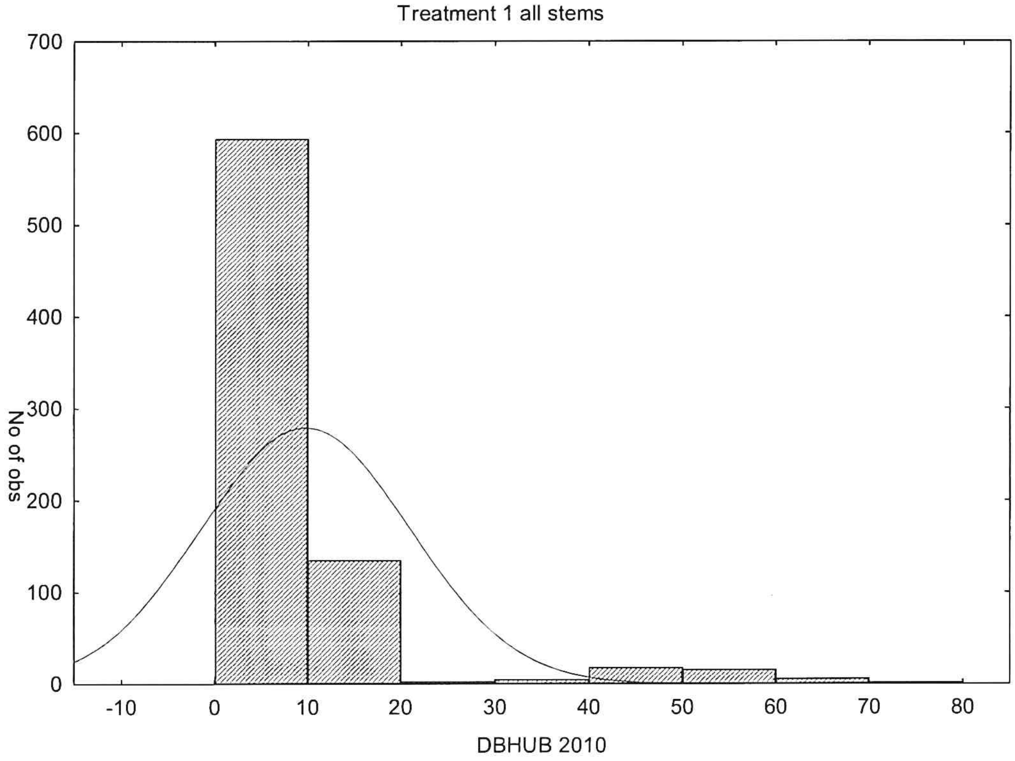
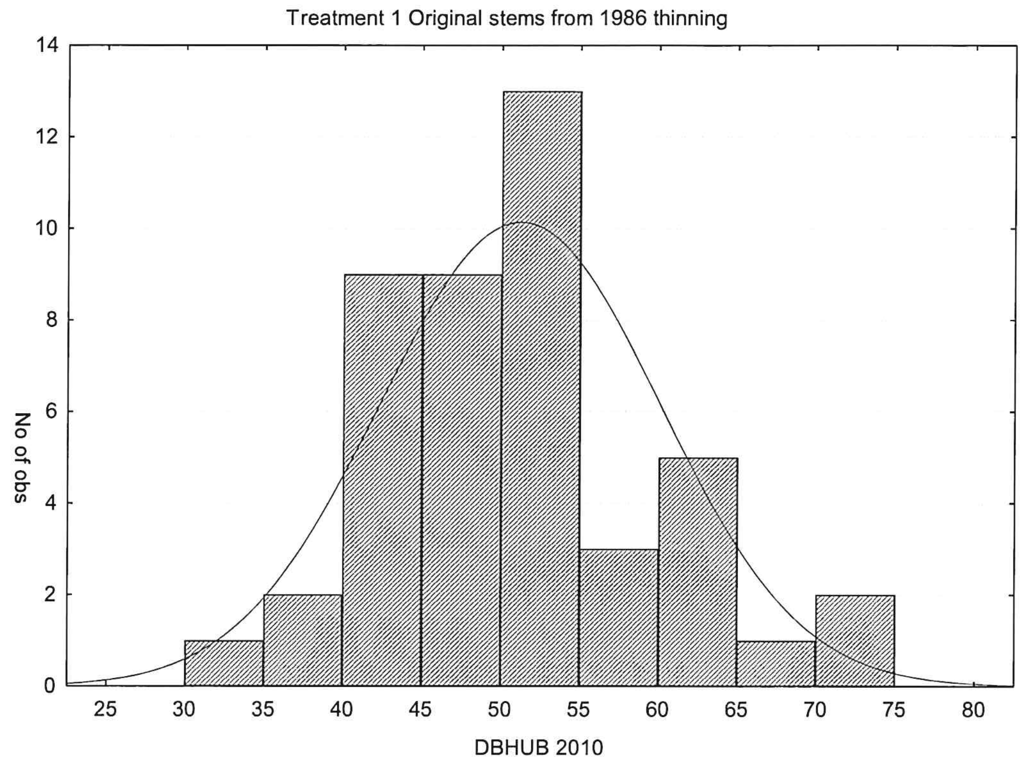


Fig. 1. The dispersion of the 30 plots (40 x 40 m) in the study of the effects of thinning and fertilizing on jarrah (*Eucalyptus marginata*) growth at Inglehope in the south west of Western Australia. The plots are labelled with their plot numbers.

Appendix 5. Diameter distributions in 2010 for all stems and for only those stems from the 1986 thinnings.

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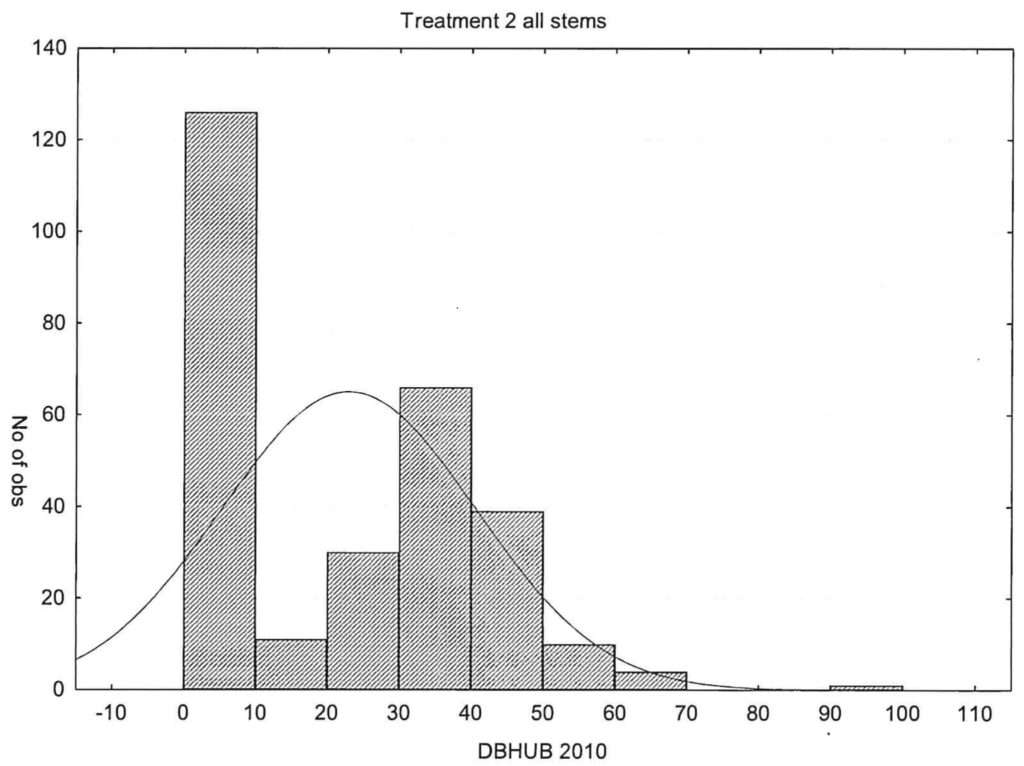
DBHUB 2010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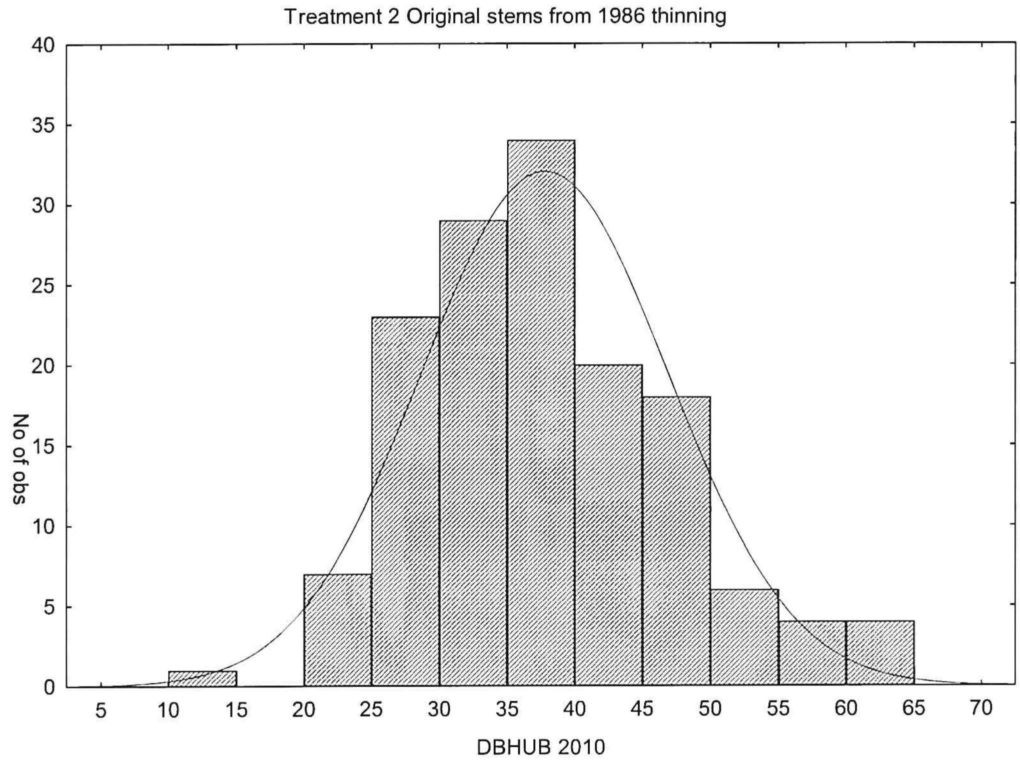
DBHUB 2010



Treatment 2 Original stems from 1986 thinning
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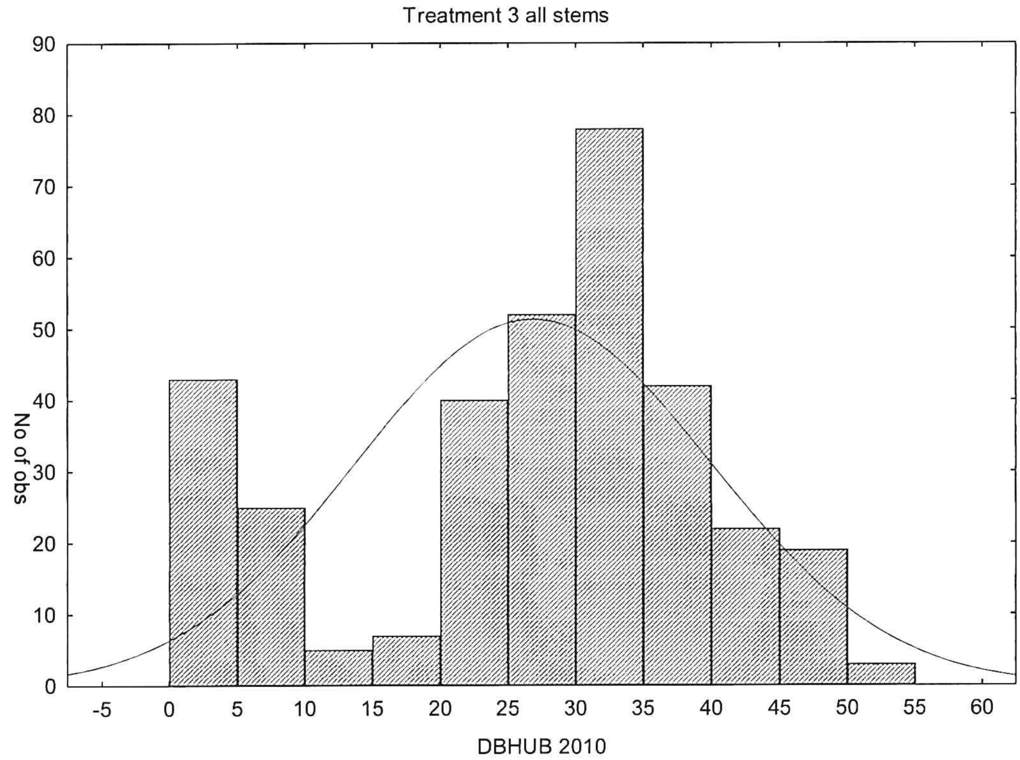

Treatment 3 all stems
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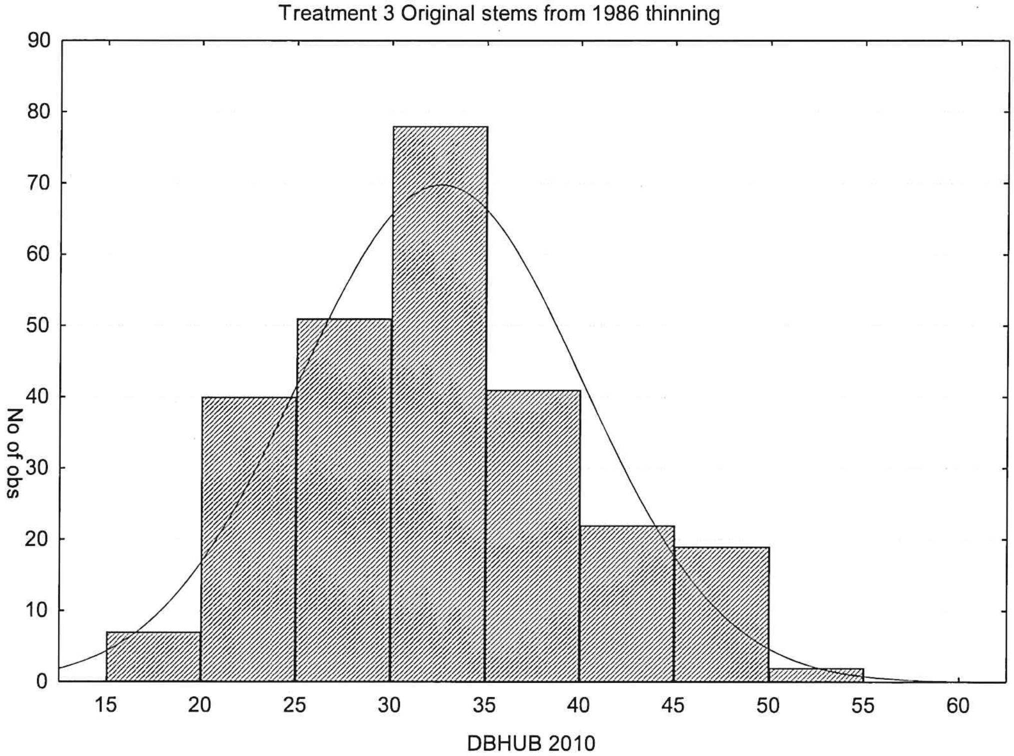
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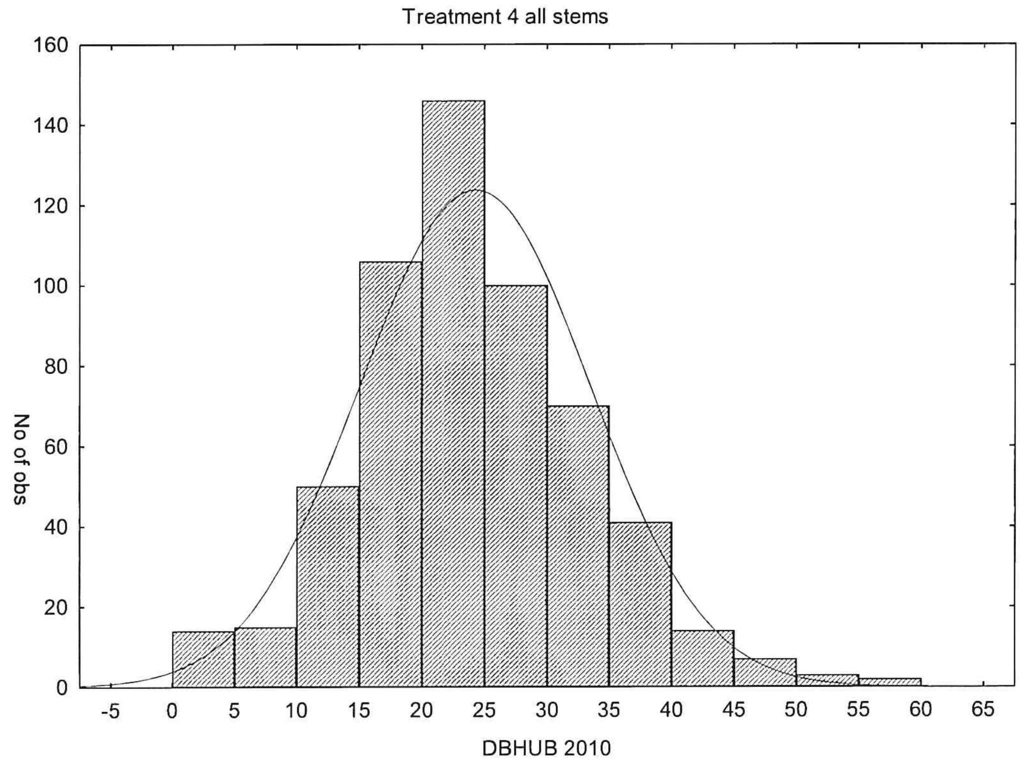
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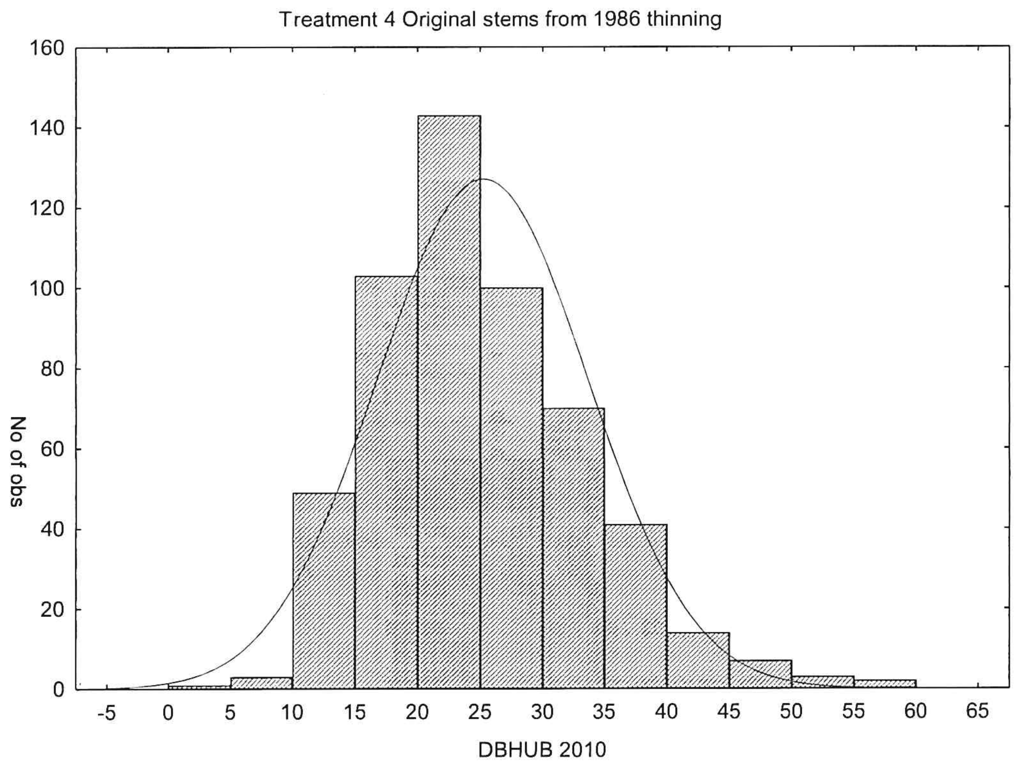
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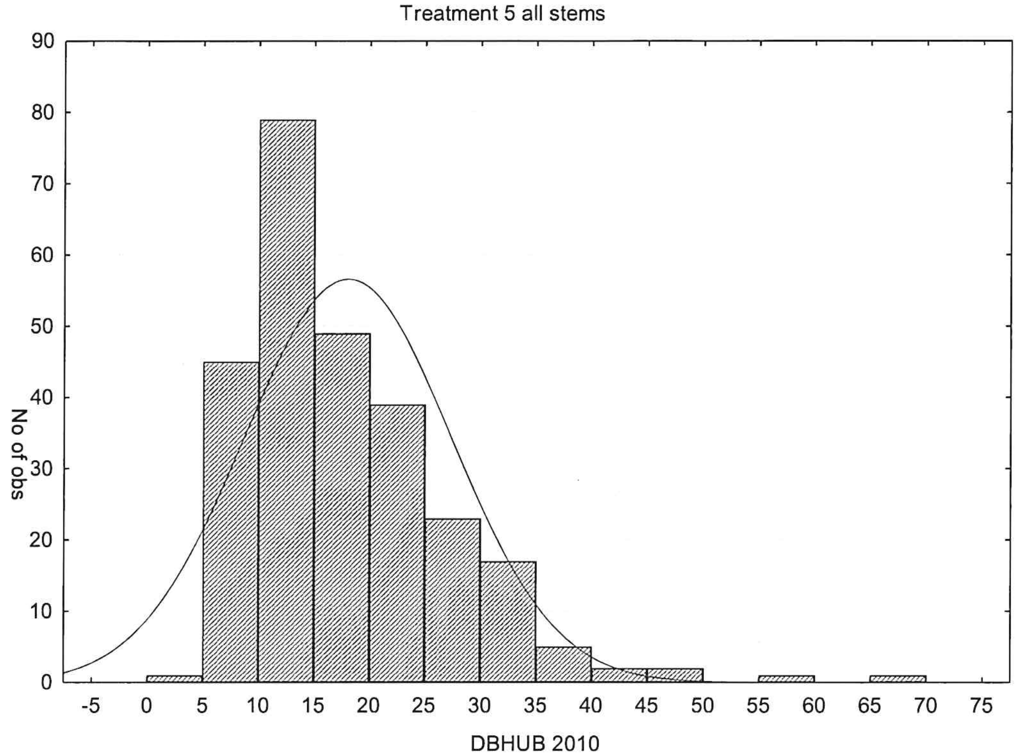
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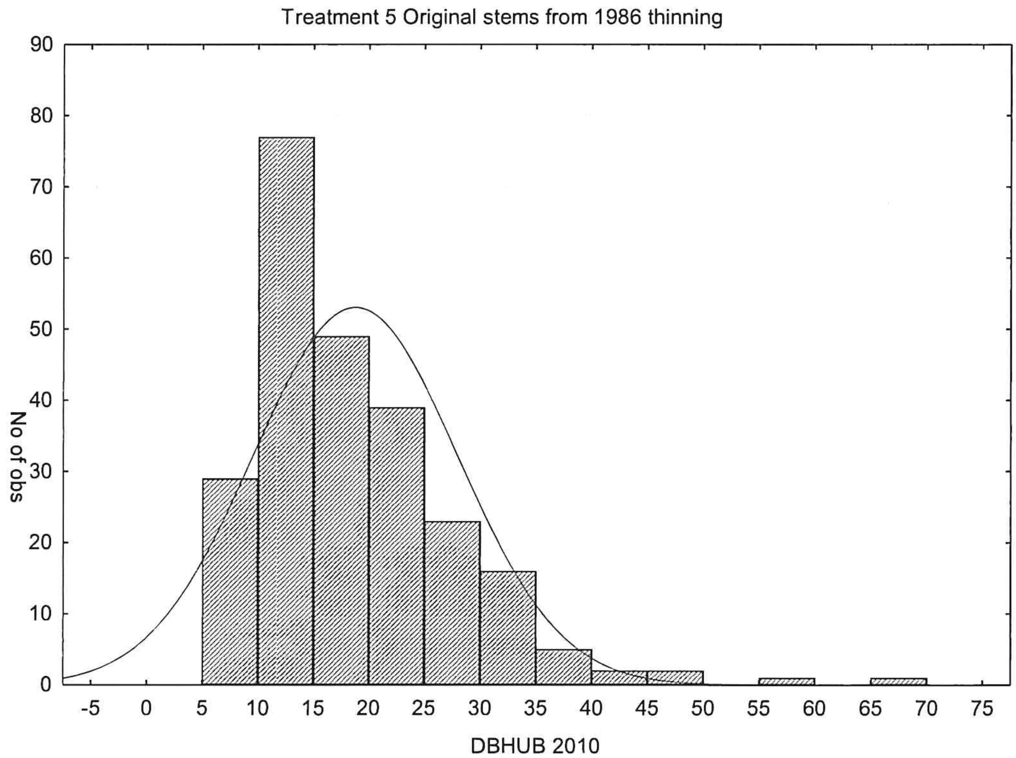
DBHUB 2010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DBHUB 2010