FRI Project Record

No. 5000

MODELLING STEM CONE OCCURRENCE, NUMBER of BRANCHES in a CLUSTER and CLUSTER DEPTH for RADIATA PINE: PROGRESS TO JANUARY 1996

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EXECUTIVE SUMMARY

Data on the branch and cone-whorls for twelve 26-year old trees from Kaingaroa forest were analysed.

A prototype model to predict occurrence of cones on the stem, the number of branches and cones in a cluster and the cluster depth was developed.

MODELLING STEM CONE OCCURENCE, NUMBER OF BRANCHES IN A CLUSTER AND CLUSTER DEPTH FOR RADIATA PINE PROGRESS TO JANUARY, 96

1. INTRODUCTION

The position and size of branches and stem cones affect the quality of timber obtained at the end of the rotation. It has been suggested that an improved estimation of stand log outturn could be achieved by developing a methodology for growing quality variables forward in time from a mid-rotation inventory (Rawley and Hayward, 1990). Grace (1992) suggested that two components of such a model should be equations to predict number of branch clusters formed per year and equations to predict the relative positions of these branch clusters within the annual shoot. The advantage of this approach is that these equations can be directly linked with the current suite of growth models used by the New Zealand forest industry. Other components of the model will need to be number of branches per cluster, number of cones per cluster and cluster depth.

The objective of the current study is to develop a prototype simulation model for the occurrence of stem cones on the tree and to develop predictive models for the number of branches formed per cluster and cluster depth.

2. DATA

Data was collected from twelve 26 year-old trees from a spacing experiment (RO696) in Kaingaroa forest. These were trees with a small, average and large DBH from plots at 200, 400, 600 and 800 stems per hectare. The trees were felled and the heights to the base and the top of each branch cluster were measured. The number of branches and cones in each cluster were counted and the branch diameters recorded. The number of growth rings were counted in the stem below the branch cluster. One branch per cluster was cut open and measured retrospectively for diameter growth. In some instances the ring count taken below the cluster did not agree with the ring count taken when the branch was measured for diameter growth. This happened more often with the trees with small DBH.

A data set containing only those annual shoots that were unlikely to have errors in the branch clusters formed per year was used. The trees with small DBH at 400, 600 and 800 stems per hectare were excluded as there were few shoots which were unlikely to have errors. In total 363 clusters distributed among 104 annual shoots were used.

3. Analysis and Results

3.1 Stem cones

A cluster can consist of branches only, be a combination of cones and branches, or contain only cones. Bannister (1962) found that clusters containing (or solely consisting of) stem cones very rarely occurred as the last cluster on the annual shoot. Clusters with cones were also less likely to occur in the second to last position on the annual shoot. Trees do not produce stem cones until they have reached reproductive maturity. For Bannister's data the age when the first stem cone was formed varied between 7 and 20 years.

In this data set five clusters consisted of cones only. These clusters have not been analysed separately, but has been treated as if they were clusters with a combination of branches and cones.

Stem cones and the age of the tree

The percentages of annual shoots with cones for the whole data set were plotted over the age of the tree (figure 1). This assumes no variation in coniness between trees.

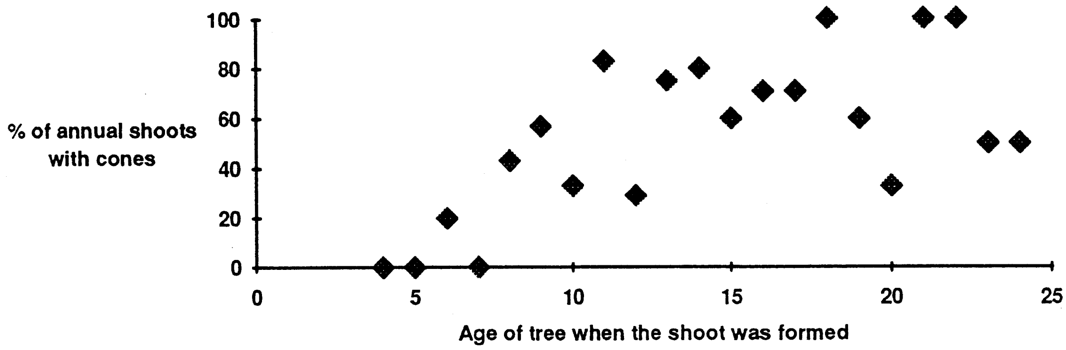


Figure 1. Percentage of annual shoots with cones against age of the tree when the shoot was formed.

The earliest reproductive maturity age for this data set appears to be around 6 years. When the trees are 8 years and older, there is no significant correlation between % of annual shoots with cones and the age of the tree when the shoot was formed.

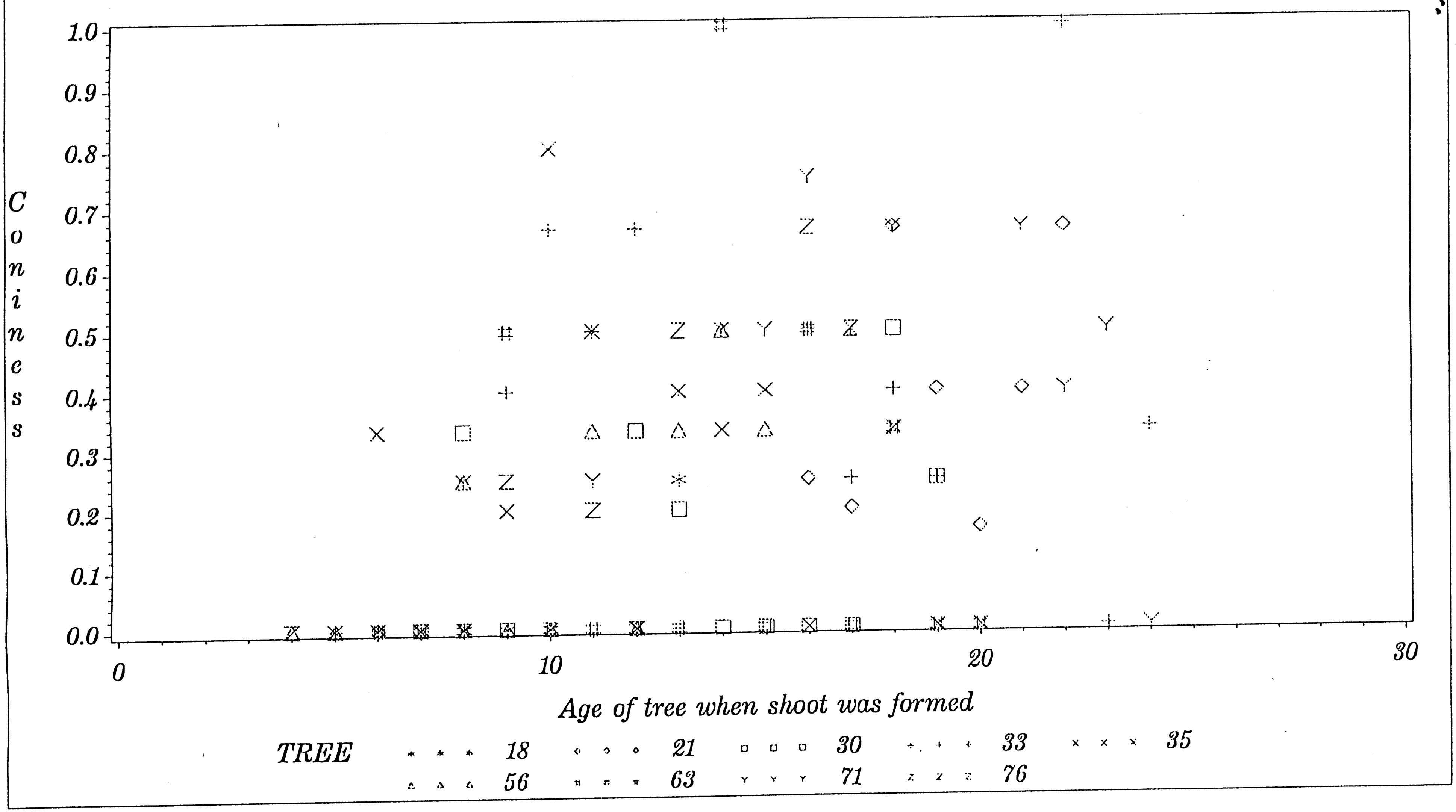
The following equation was fitted to describe the shape of the above curve.

$$Cness = a*(1-c*\exp(b*age)) \qquad 1.$$

Where	a= 0.746	(se. 0.1119)
	b= -0.207	(se. 0.1062)
	c= 2.627	(se. 1.5216)

The "coniness" of an annual shoot, that is the percentage of clusters with cones per annual shoot was calculated and plotted over the age when the shoot was formed for each tree (figure 2). When the trees are 8 years and older there is little trend in the coniness of the annual shoot. The correlation coefficient for 8 years and older was 0.23 ($p = 0.03$). This correlation is not considered to be of practical significance. Assuming that the coniness of a shoot does not depend on age, we then examined the location of cones on different types of annual shoots.

Figure 2. Coniness per annual shoot



Stem cones in different positions on the shoot

As an annual shoot consists of one to six clusters there are 21 possible cluster locations depending on the total number of clusters in the annual shoot and the cluster's position within the shoot (outlined in table 1). The percentages of clusters containing cones for all possible cluster positions were calculated for each individual tree. It was not possible to detect any patterns between trees so one table for all trees was produced (table 1). This also assumes that the presence of cones in one cluster does not affect the presence of cones in another cluster.

Table 1. Percentage of clusters with cones for all possible cluster positions .

Total number of clusters in annual shoot	**1** (6)	**2** (13)	**3** (32)	**4** (33)	**5** (17)	**6** (3)
Cluster number within annual shoot						
1	16.7	23.1	45.2	36.4	18.8	50.0 (2)
2		0	31.2	31.2	47.1	66.7
3			6.2	18.2	23.5	0
4				12.1	23.5	66.7
5					29.4	33.3
6						0

The total number of annual shoots of each type are given inside brackets at the top of the table. Number of observations are only shown in table where there were missing data.

For comparison with a study performed by Bannister (1962) a table showing the percentage of cone bearing clusters in relation to the total number of clusters on the annual shoot was produced (table 2).

Table 2. The percentage of cone bearing clusters for different number of clusters on shoot.

Total number of branch clusters on shoot	1		2		3		4		5		6	
cluster number within the annual shoot		*		*		*		*		*		*
6											0	0
5									6	0	6	33
4							3	0	5	2	11	33
3					2	0	5	19	5	48	0	33
2			0	0	10	14	8	54	9	34	11	0
1	17	0	12	24	16	67	9	23	5	8	11	0
0	83	100	88	76	72	19	75	5	71	8	61	0

* From Bannister's data.

In contrast to the results found by Bannister stem cones were present in the last cluster of the annual shoot but not as commonly as in other positions. Also stem cones appear to be less common in RO 696 than in Bannister's study area.

If we assume that the % of annual shoots with cones varies as per equation 1, and if we know an annual shoot has cones then we need to know the frequency of cones occuring in a given position on the annual shoot. These values are given in table 3.

Table 3. Frequency of clusters with cones on annual shoots with cones.

Total number of clusters in annual shoot	1	2	3	4	5	6
Cluster number within annual shoot						
1	1.0	1.0	0.82	0.60	0.31	0.67
2		0.0	0.59	0.55	0.62	0.67
3			0.12	0.30	0.31	0.0
4				0.20	0.31	0.67
5					0.38	0.33
6						0.0

Number of cones in a cluster

The average number of cones in the different cluster positions were calculated and are shown in table 4.

Table 4. Average number of cones in the cone clusters.

Total number of clusters in annual shoot	**1**	**2**	**3**	**4**	**5**	**6**
Cluster position within annual shoot						
1	4.0 (1)	3.3 (3)	4.1 (15)	4.2 (12)	4.0 (4)	3.0 (2)
2		(no obs)	2.7 (10)	4.0 (11)	3.3 (8)	1.0 (2)
3			4.0 (2)	2.7 (6)	3.3 (4)	(no obs)
4				2.3 (4)	2.5 (4)	4.0 (2)
5					2.2 (5)	1.0 (1)
6						(no obs)

Number of observations are inside brackets.

To test whether the number of cones varied significantly between cluster positions an analysis of variance of the number of cones in different cluster positions was performed for each type of annual shoot. The results are in table 5.

Table 5. Analysis of variance of the number of cones per cluster

Total number of clusters in shoot	Number of observations	P*
1	1	(only one group)
2	3	(values only available for one group)
3	27	0.32
4	33	0.08
5	25	0.53
6	7	0.22

* Probability of obtaining a F value under the hypothesis that one model is sufficient, that is there are no significant differences between number of cones in the different positions.

No differences were found to be significant hence the average number of cones in a cluster for each annual shoot type was calculated and shown in table 6.

Table 6. Average number of cones in a cluster for different number of clusters in the annual shoot.

Total number of clusters in shoot	Average number of cones in a cluster	Standard deviation
1	4.0	-
2	3.3	2.52
3	3.6	2.30
4	3.6	1.72
5	2.8	1.66
6	2.3	1.63

The distributions of the number of cones in cone clusters were tested for normality for each annual shoot type as shown in table 7.

Table 7. Test for normality.

Total number of clusters in shoot	Number of observations	P*
1	1	-
2	3	0.78
3	26	0.02
4	32	0.03
5	24	0.01
6	6	0.08

* The probability of obtaining a W value from a Shapiro - Wilk test for normality under the hypothesis that the distribution is normal.

This indicates that the distribution is not normal. In several instances low numbers of cones occur more frequently than high numbers. The frequencies are plotted by annual shoot type in appendix A. The relative frequencies for all shoot types combined are shown in table 8.

Table 8. Frequencies of different numbers of cones.

Number of cones in a cluster	Relative frequency	Cumulative frequency
1	0.23	0.23
2	0.16	0.39
3	0.17	0.56
4	0.15	0.71
5	0.14	0.85
6	0.10	0.95
7	0.02	0.97
8	0.01	0.98
9	0.01	0.99

3.2 Number of branches in a cluster

The number of branches in a cluster was plotted over number of rings in the stem below the cluster for each tree and for all trees together. The correlation between the number of branches in a cluster and the number of rings in the stem was calculated and was not significant for any individual tree or the whole data set.

The average number of branches per cluster for each tree was plotted over DBH and stocking but no patterns were detectable. This means we do not need to consider age, tree size or stocking when modelling number of branches per cluster.

The average numbers of branches per position within each annual shoot type was tabulated per tree as shown in table 9. This table was used to test whether there would be patterns between trees. As annual shoots with 3 or 4 branch clusters are the most common most data was available for those kind of shoots and they were therefore the ones used. The average number of branches for each possible position and annual shoot type were plotted over stocking and DBH. No useful trends could be distinguished in the plots.

Table 9. Average number of branches for all possible cluster positions.

Total number of clusters in annual shoot	**1**	**2**	**3**	**4**	**5**	**6**
Cluster number within annual shoot						
1	3.7 (5)	6.5 (10)	5.9 (17)	5.2 (21)	5.7 (13)	4.5 (1)
2		7.9 (13)	5.7 (22)	5.4 (22)	5.8 (9)	7.5 (1)
3			6.9 (30)	5.8 (27)	5.0 (13)	5.3 (3)
4				7.2 29)	5.6 (13)	5.7 (1)
5					6.3 12)	6.7 (2)
6						10.3 (3)

Number of observations are inside brackets.

To test whether the differences between positions that can be seen in table 9 are significant an analysis of variance of the number of branches in different cluster positions was performed for each type of annual shoot. The results are in table 10.

Table 10. Shoot type and number of branches per cluster.

Total number of clusters in shoot	Number of observations	P*
1	6	(only 1 group)
2	26	0.26
3	94	0.11
4	130	0.0006
5	81	0.49
6	16	0.13

* Probability of obtaining an F value under the hypothesis that one model is sufficient, that is there are no significant differences between number of branches in the different positions.

Significant differences between positions within an annual shoot were only detected for shoots with a total of four branch clusters. This type of shoot also has the highest number of observations. The average number of branches in a cluster for each annual shoot type were calculated as shown in table 11.

Table 11. Average numbers of branches in a cluster for different number of clusters in the annual shoot.

Total number of clusters in shoot	Average number of branches in a cluster	Standard deviation
1	3.7	2.42
2	7.2	1.76
3	6.2	3.33
4	5.9	2.33
5	5.7	2.75
6	6.6	3.54

The distributions of the number of branches in a cluster for each shoot type were tested for normality. The results are in table 12.

Table 12. Test for normality

Total number of clusters in shoot	Number of observations	P* (normal)
1	6	0.40
2	26	0.001
3	94	0.0001
4	130	0.002
5	81	0.001
6	16	0.16

* Probability of obtaining a W value from a Shapiro - Wilk test for normality under the hypothesis that the distribution is normal.

The distributions can be rejected as normal except for shoots with one or six clusters. However when the frequencies are plotted the distributions appear to be reasonably normal (Appendix B). The fact that the hypothesis needs to be rejected is probably caused by a few clusters with a very large number of branches. It is possible that the clusters with a large number of branches were in fact two clusters very close together.

3.3 Cluster depth

The cluster depth is the vertical distance between the base and the top of the cluster. Logically it should depend on the branch diameters, the angles of the branches and the number of growth rings at that point. As an initial step, we propose to see whether we can predict cluster depth without reference to branch angle. The correlations between cluster depth and largest diameter in cluster, number of rings in the stem, number of branches in the cluster and stocking were calculated and are shown in table 13.

Table 13. The correlations between cluster depth and some variables.

Variable	Correlation
largest branch	0.78 (p=0.0001)
number of rings in stem	0.52 (p=0.0001)
number of branches in cluster	0.29 (p=0.0001)
stems per hectare	0.15 (p=0.005)

The cluster depth was plotted against diameter of the largest branch per cluster (figure 3) and a linear regression equation that predicted cluster depth (m) as a function of largest branch diameter in the cluster was fitted:

Cluster depth = 0.06 + 0.0036 * largest branch (mm) (2.)

R^2=0.61

The residuals were plotted over number of rings in the stem (figure 4) and there appeared to be a correlation. A regression including the number of rings was therefore performed:

Cluster depth = 0.002+ 0.003* largest branch (mm)
+ 0.006* number of rings in stem (3.)

R^2 = 0.71

Figure 3. Cluster depth over largest branch

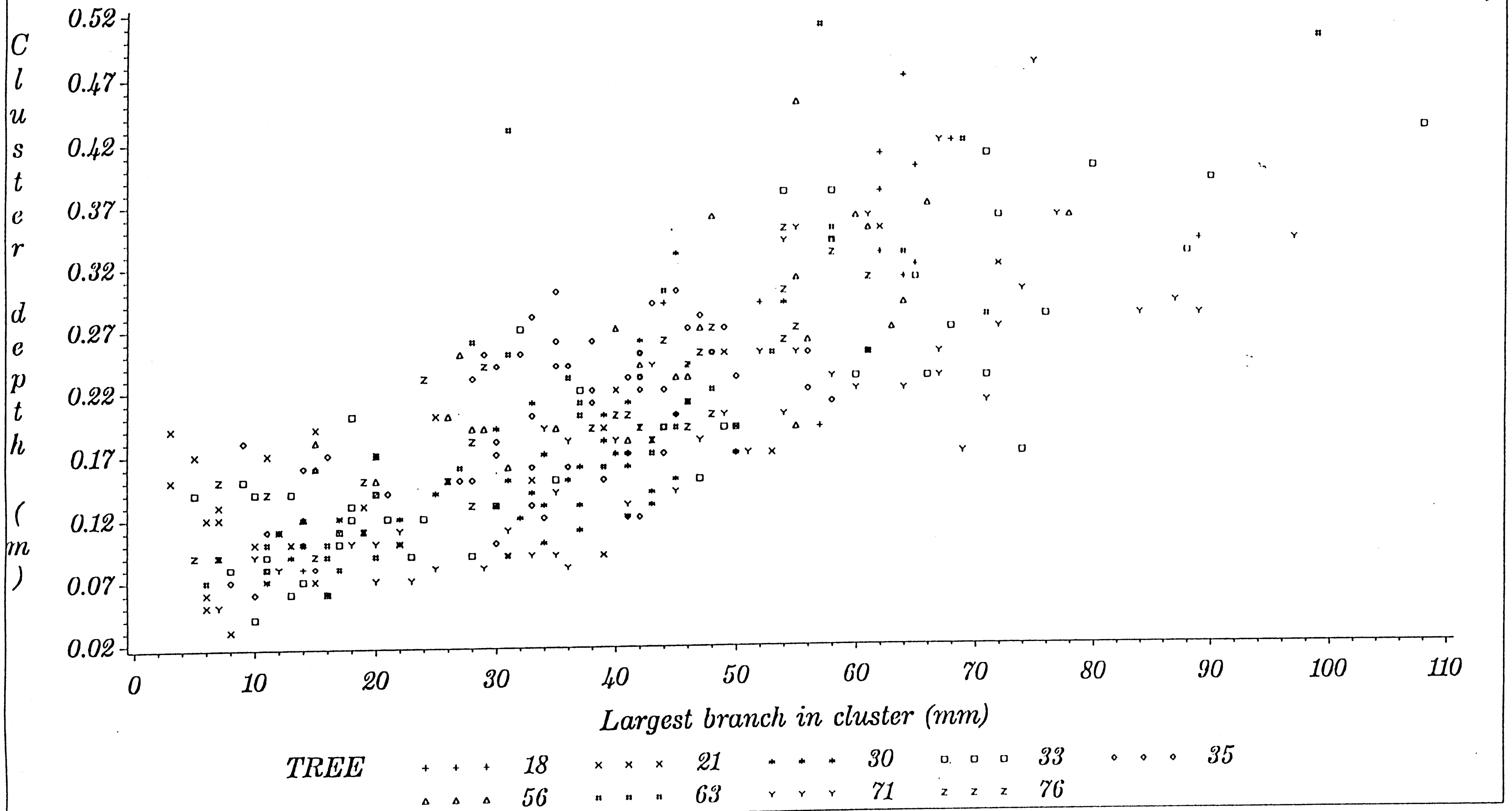
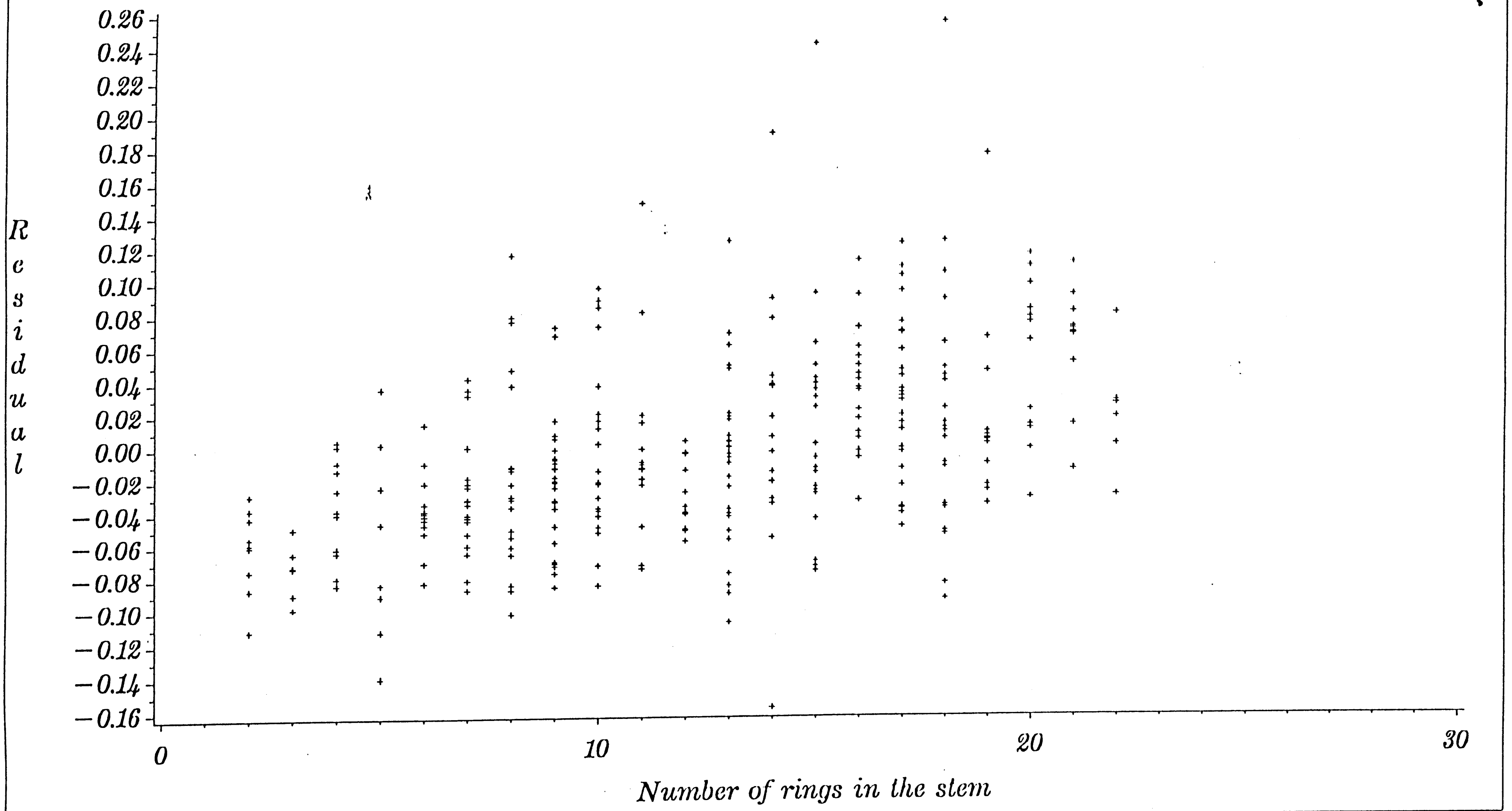


Figure 4. Residuals of cluster depth as a function of largest branch



The residuals from equation 1 were then plotted against number of branches in cluster (figure 5) and there appeared to be a correlation when the number of branches exceeded 12. The number of branches in cluster were included in the regression:

Cluster depth = -0.03+ 0.003* largest branch (mm)
+ 0.006* number of rings in stem (4.)
+ 0.006* number of branches in cluster

$R^2 = 0.73$

When the number of branches higher than 12 was excluded from the model the parameter was not significant. Given the small increase in R^2 equation 3 is probably best to use.

The residuals from equation 3 was also plotted against stocking (figure 6) but there did not seem to be a useful correlation and the variable was not significant when it was included in the regression.

Figure 5. Residuals of cluster depth as a function of largest branch

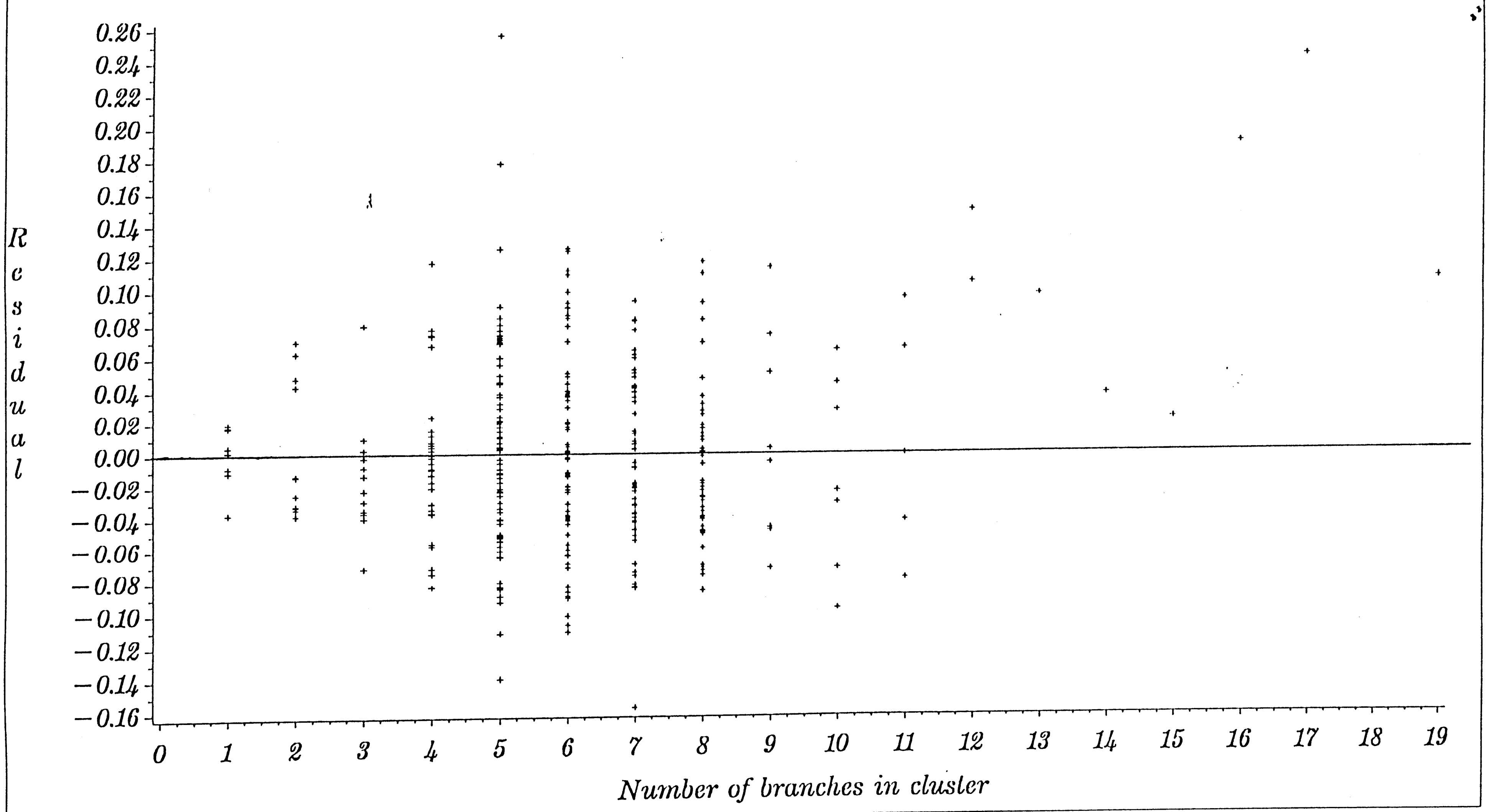
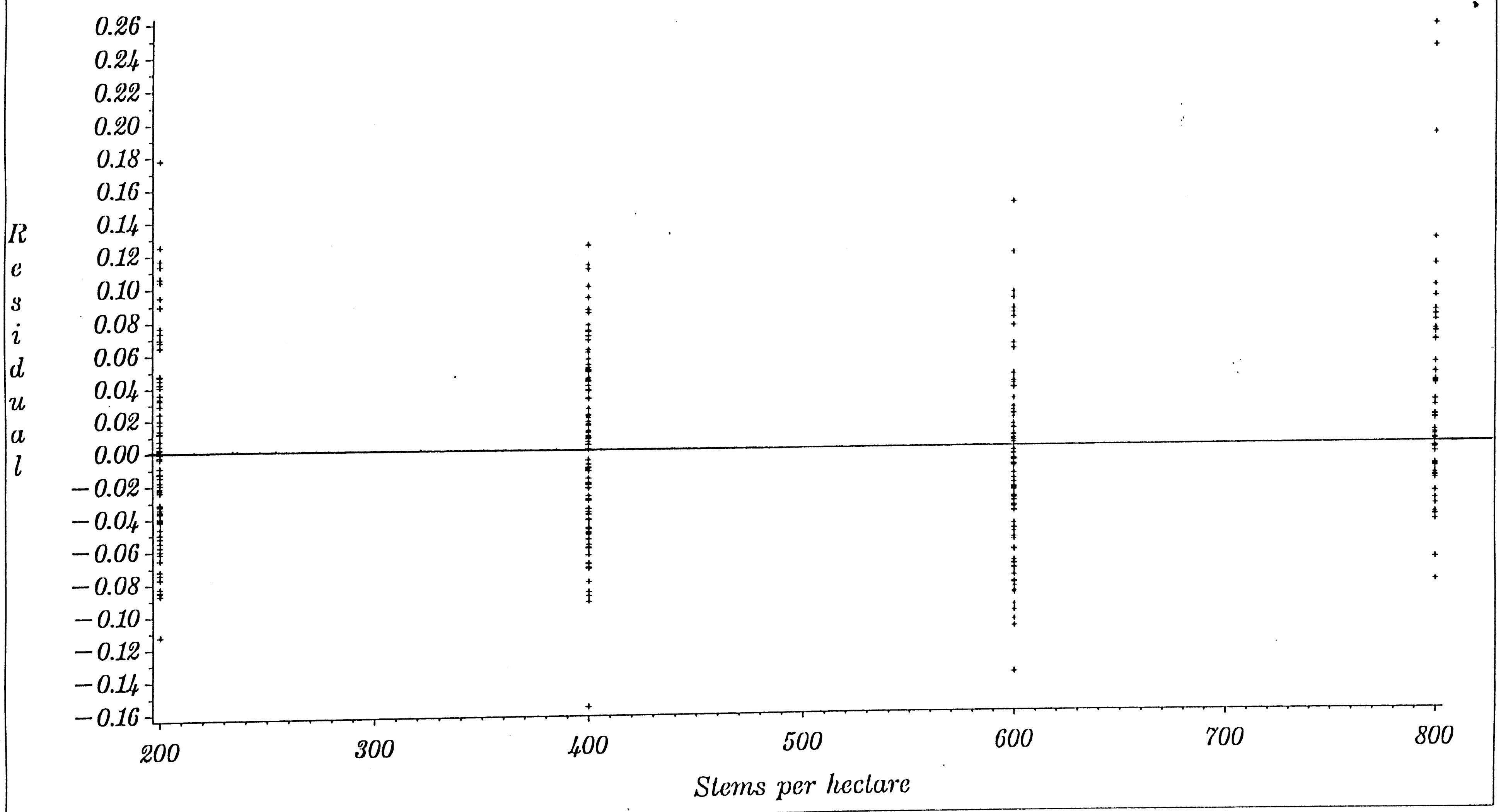


Figure 6. Residuals of cluster depth as a function of largest branch



4. PROTOTYPE MODEL

The following section is an addition to the prototype model described in Grace (1995) where the length of annual shoot, number of branch clusters and their relative position within the annual shoot are predicted for a specified age.

Stem cones

There are two possible options for modelling the position of stem cones:

A, Use a random number generator with equation 1 to determine if the annual shoot has cones. Then use table 3 to deteremine if the cluster has cones.

B, Assume no cones are formed until age 8 and use a random number generator with table 1 to determine whether a particular cluster has cones.

To predict number of cones in a cluster use a random number and the cumulative frequencies in table 8 as start and stop values to determine how many cones the cluster will have.

Number of branches in cluster

To predict the number of branches in a cluster, generate a random number from a normal distribution with mean and variance depending on number of clusters in annual shoot as given in table 11.

Cluster depth

Use equation 2 to calculate cluster depth with the predicted diameter of the largest branch in the whorl and the assumed number of rings in the stem as predicting variables. For this we need to develop an equation to predict a size of the largest branch in the clusters. This will be in a separate report.

5. References

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Fielding. J.M. 1967. Some characteristics of the crown and stem of *Pinus radiata. Forestry and Timber Bureau, Canberra, Bulletin No 36* 42pp.

Grace, J.C. 1992. Branch Dynamics in Radiata pine: Literature review. *Stand Growth Modelling Co-operative Report No. 28.*

Grace, J.C. 1995. Modelling the position of branch clusters in Radiata pine: Progress to end of June 1995. *Project Record 4724. NZ Forest Research Institute (unpublished).*

Lavery, P.B. 1986. Plantation Forestry with Pinus radiatia - *Review Papers. Paper No. 12. School of Forestry, University of Canterbury,* Christchurch. 255 pp.

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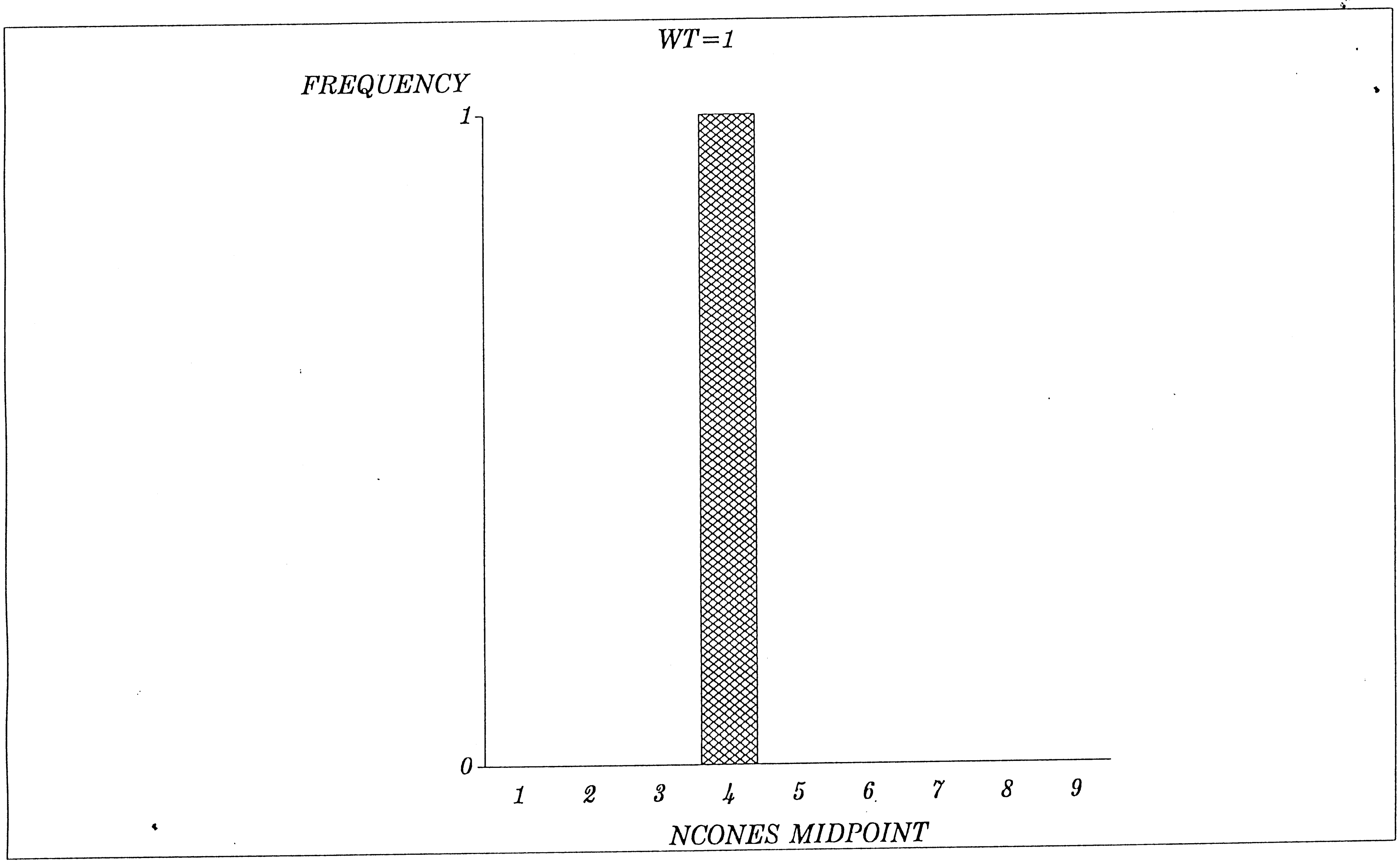
APPENDIX A. FREQUENCY TABLES OF NUMBER OF CONES BY NUMBER OF CLUSTERS ON THE ANNUAL SHOOT

Wt is the number of clusters in the annual shoot.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4
5
6
7
8
9
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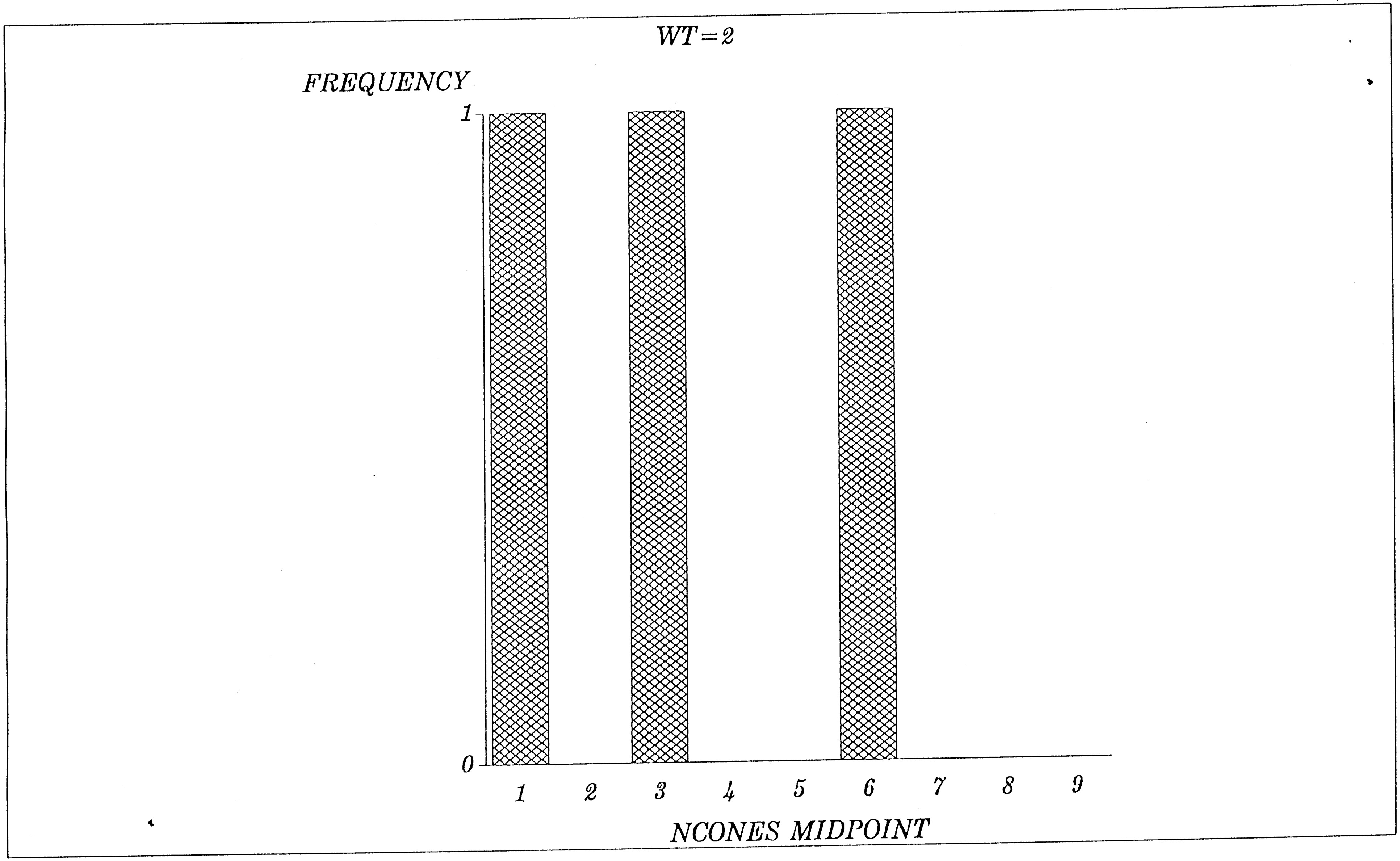
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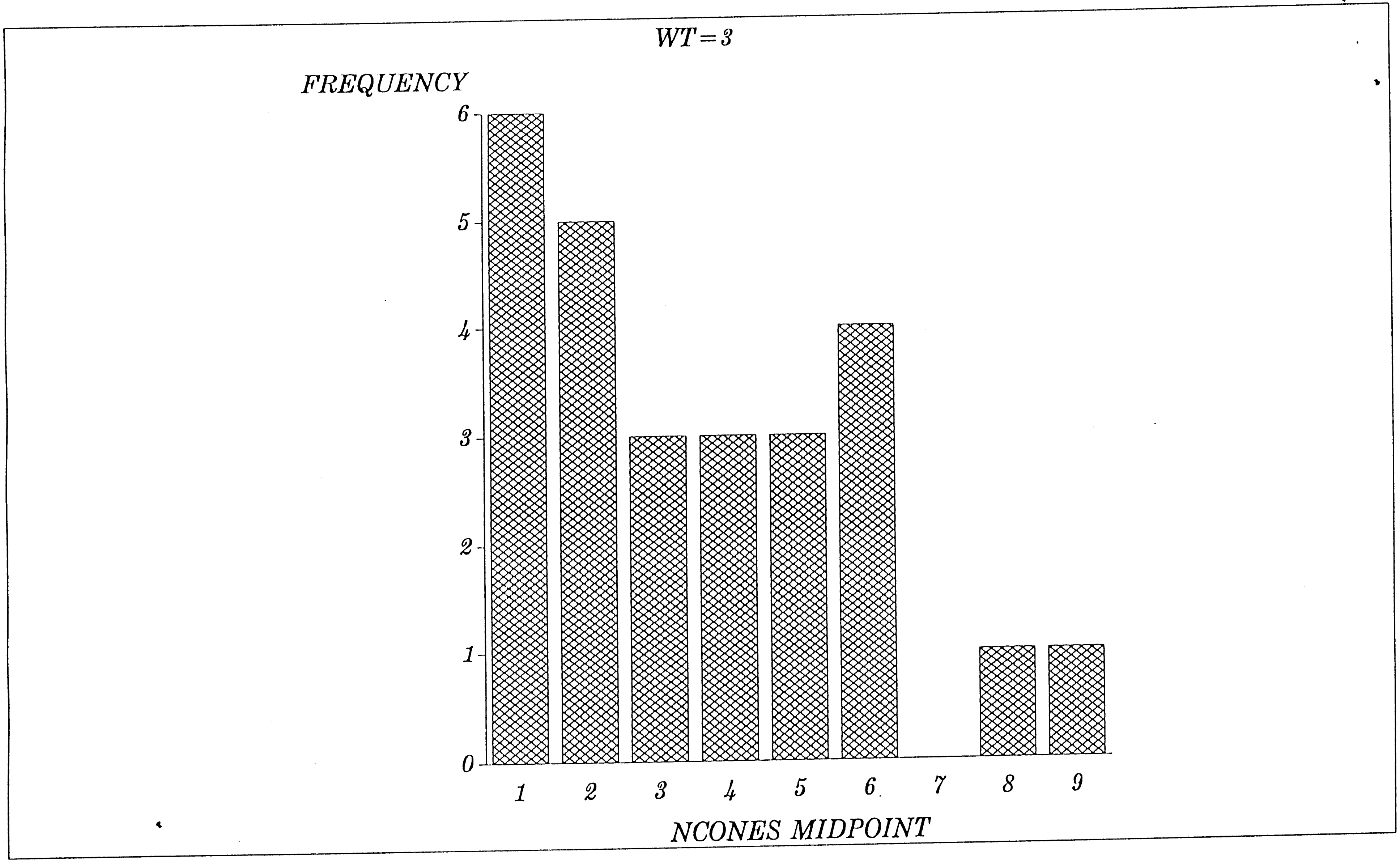
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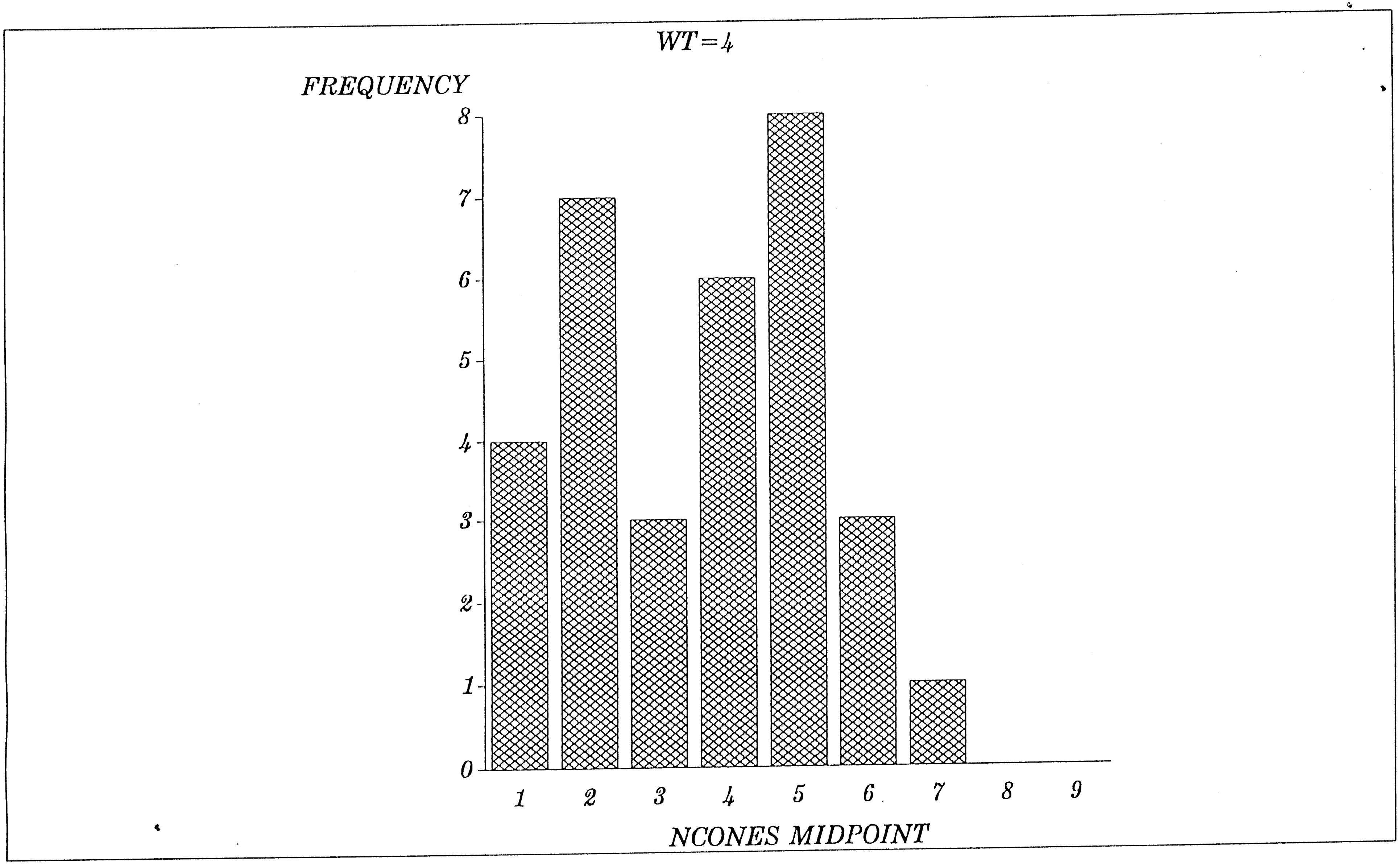
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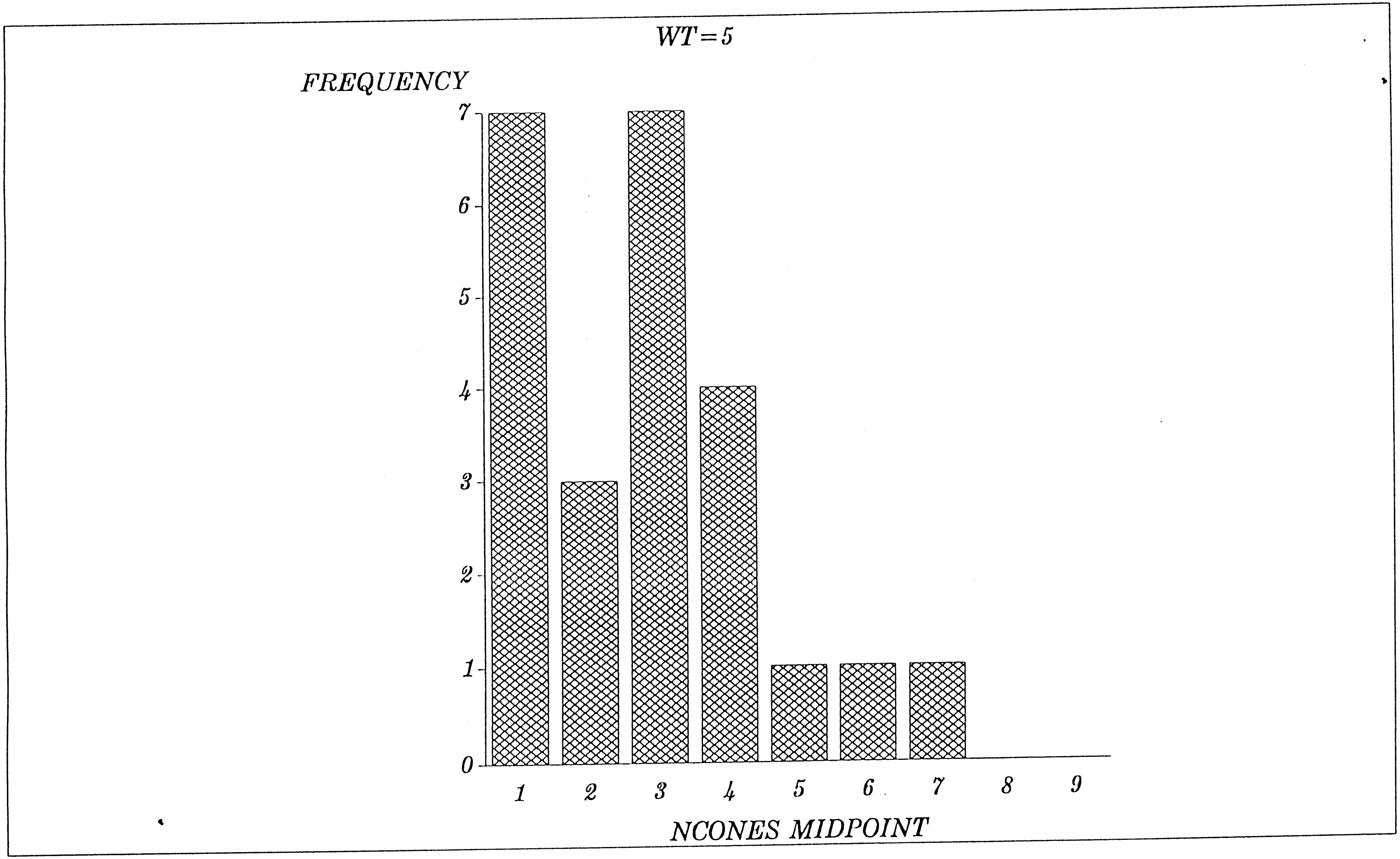
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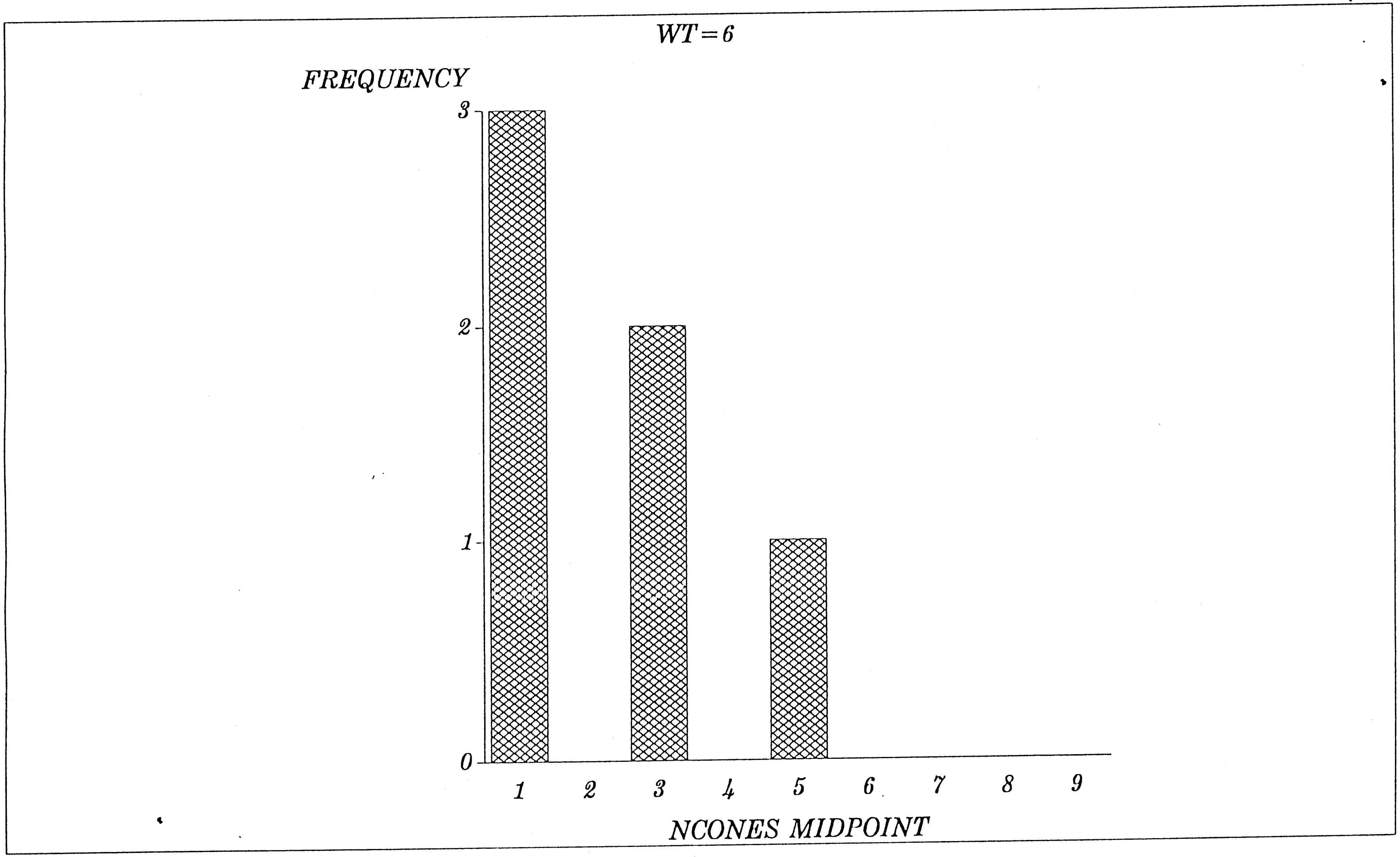
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1
2
3
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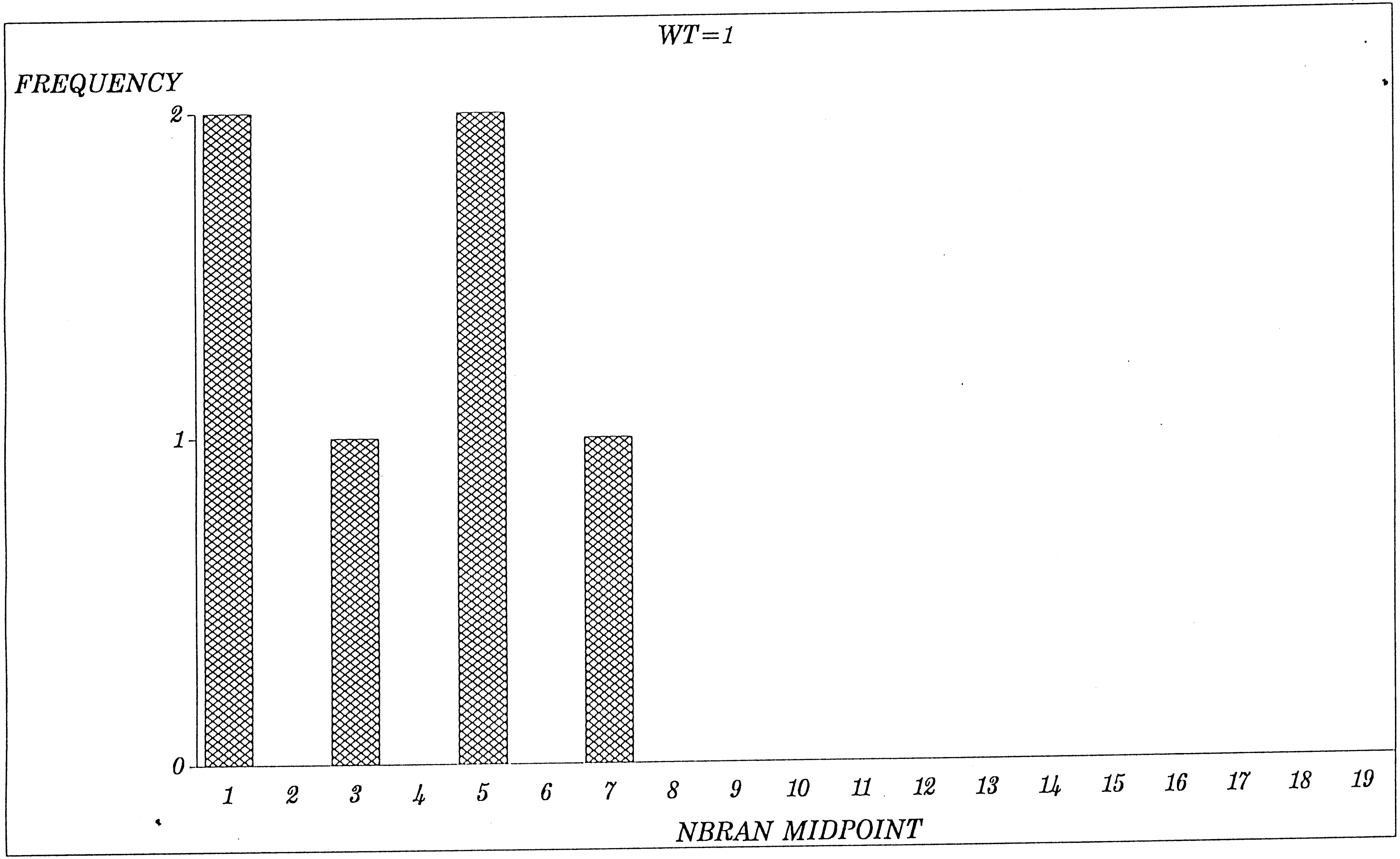
8
9
NCONES MIDPOINT

Appendix B. Frequency Tables of Number of Branches by Number of Clusters on the Annual Shoot

Wt is the number of clusters in the annual shoot.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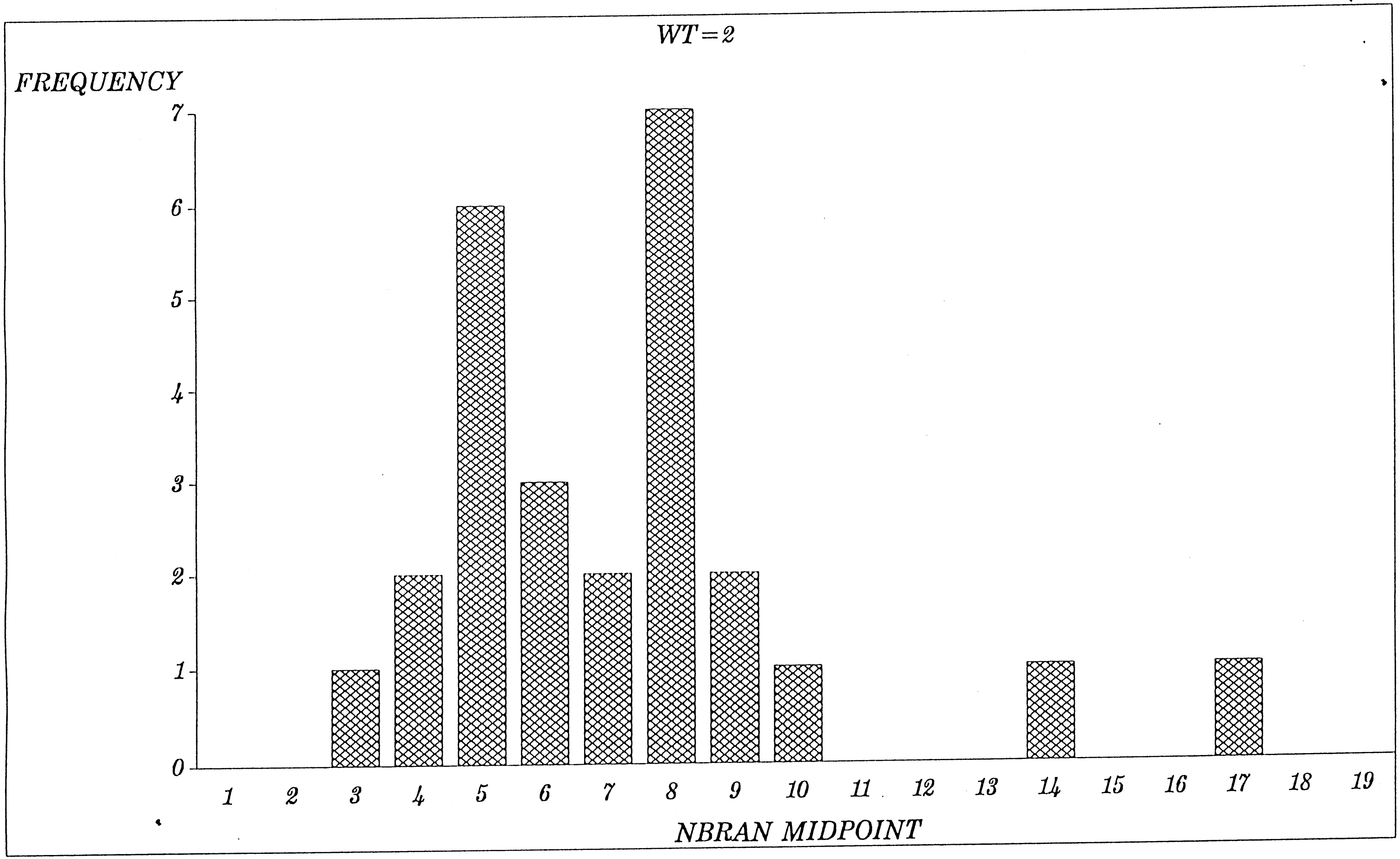
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14
15
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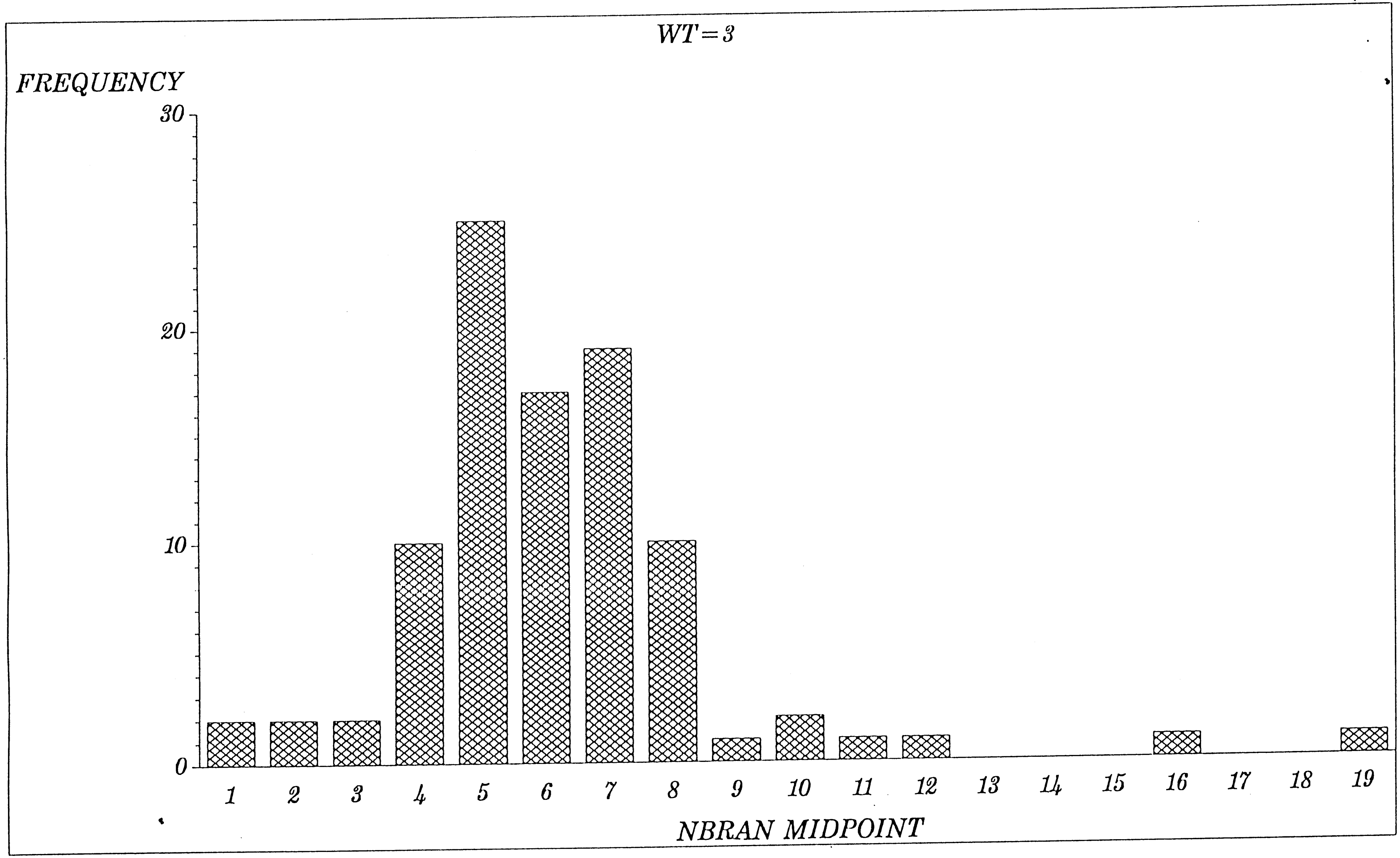
17
18
19
NBRAN MIDPOINT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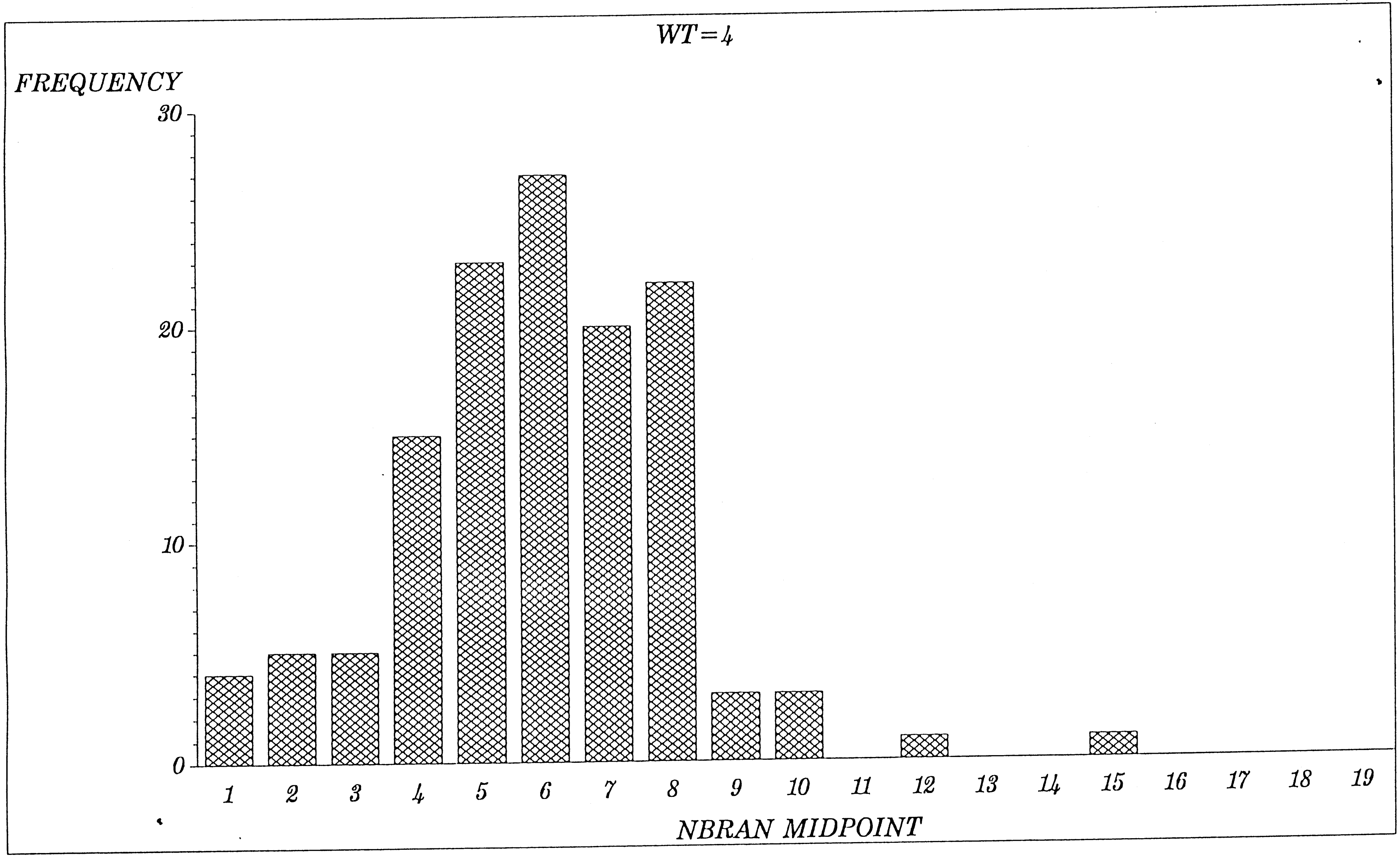
NBRAN MIDPOINT



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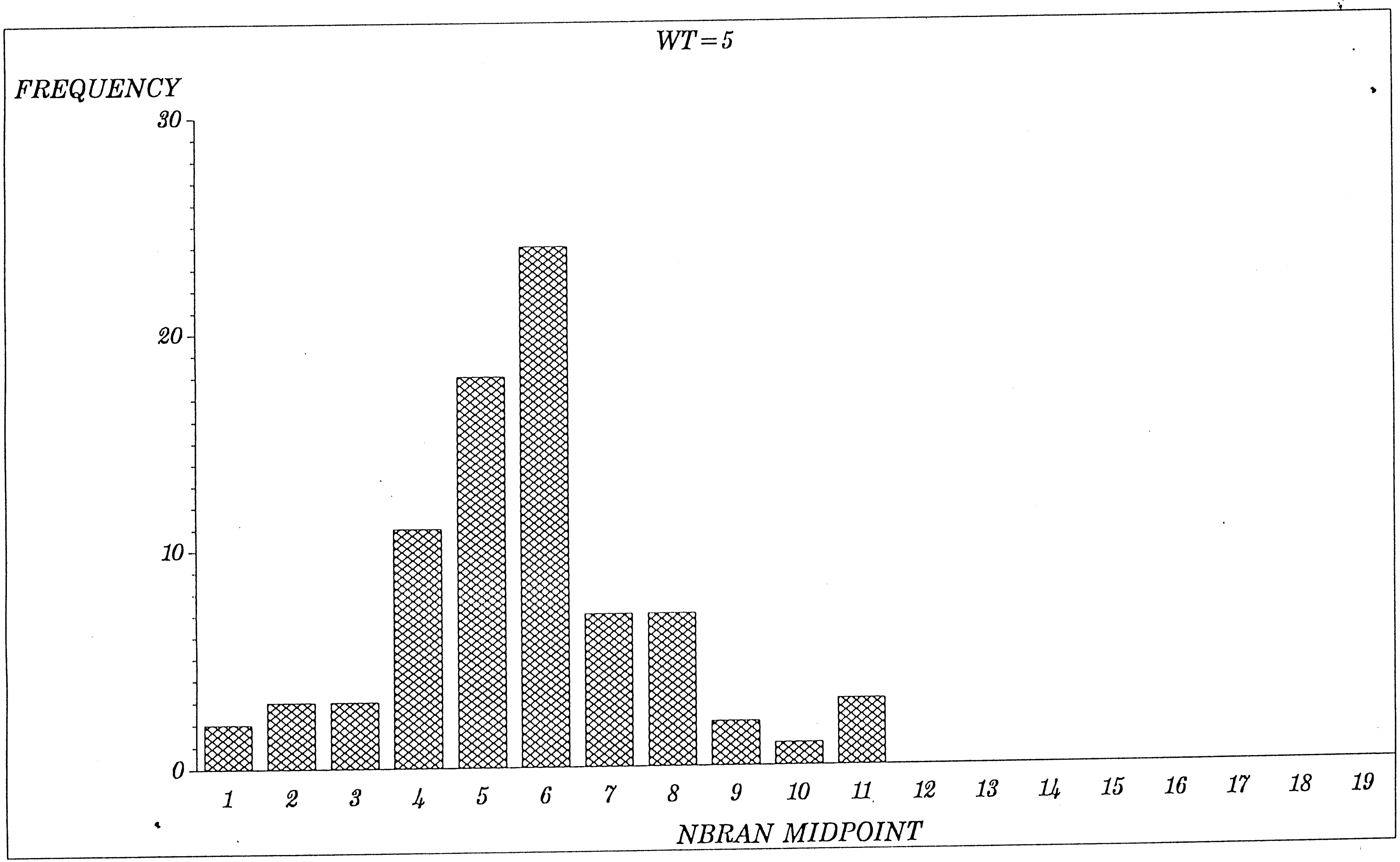
16
17
18
19
NBRAN MIDPOINT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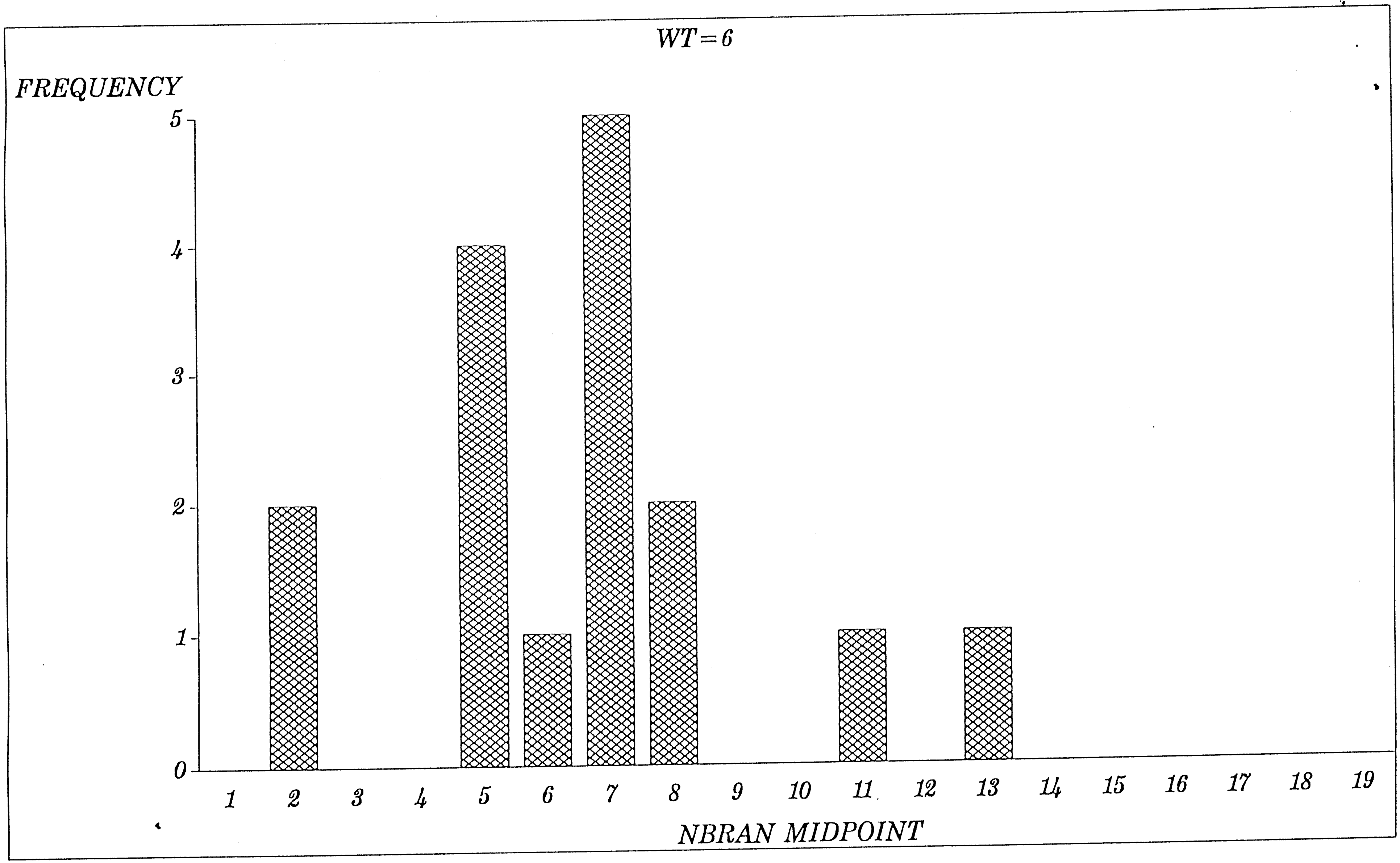
19
NBRAN MIDPOINT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FREQUENCY
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4
3
2
1
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1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
NBRAN MIDPOINT