

**PORT ALICE SULFUR DIOXIDE
FOREST DAMAGE APPRAISAL
METHODS EVALUATION STUDY**

by

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FOREWORD

This report is one of a series of internal reports distributed by Forest Protection Branch, B.C. Ministry of Forests, to record accomplishments and interim or provisional results for the information of staff, colleagues, and others.

In the Canada-British Columbia Forest Resources Development Agreement (FRDA) 1985 to 1990, over 100 pest control projects were directly funded by the province and administered by protection staff. To facilitate application of the results, and development of improved forest health management strategies, the contractors reports have been edited and distributed as internal reports. Accordingly, any opinions and recommendations expressed are those of the contractor, and not necessarily those of the ministry or the FRDA management committee.

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The guidelines for internal reports outlined in the Protection Manual were adhered to as closely as possible. All manuscripts were altered to comply with a common format, but entire reports were not rewritten to conform to a standardized outline.

Most Executive Summaries were the work of Graham Hawkins of MoF Inventory Branch (formerly with Pacific Coast Forest Biology). All word processing was accomplished by Catriona Kaufman of Top Kat Services. Will Gordon of R. White Woods inc. prepared all maps and figures.

R. White, editor
R. White Woods inc.

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EXECUTIVE SUMMARY

From a study area located near the Port Alice pulp mill on northwestern Vancouver Island, tree cores were recovered from ground truthing plots and submitted for tree-ring analysis. Two cores were collected per tree from plots assessed as severely or moderately damaged and control (healthy), based on visible crown symptoms. Lightly damaged trees were assessed by other sensing means since this damage category was defined as consisting of trees without visible symptoms of stress. Thus, control plots did contain some damaged trees. Three control, two moderately and two severely damaged plots were measured and analyzed - a total of 155 western hemlock core pairs. Each plot contained between 25 and 30 sample trees.

Tree-ring measurements of the core samples were performed on a Digi-Mic (= digital micrometer) which was linked to a VAX mainframe. Analysis of growth patterns was performed using the TREERING, INDEX and SAS programs. Core pair data were averaged between core pairs. Unfortunately, 44 sample trees had to be removed from the data due to very high variability during the cross-dating procedure (non-resolvable age discrepancies between pairs).

High point to point variance was reduced by means of a cubic-spline function and the data set was truncated at 1940 due to excessive variance prior to this date. Data were sorted by plot and SAS MEANS, GLM, and GPLOT procedures were performed. The analysis of variance was used to test for significant effects of damage levels on the last 10 years of growth, as a measure of impact.

There was a significant decrease in growth over the last 10 years in core samples from moderate to severe damage plots relative to samples from control plots. There was no significant difference in the last 10 years' growth between the moderate and severe categories. Confidence intervals overlapped or were extremely close over a 35-year period for these categories, despite a very noticeable difference in the visible appearance of trees in these plots. This was probably the result of the growth characteristics of western hemlock under a prevailing mild and relatively steady climate. Other species, notably lodgepole pine and Douglas-fir, have much better defined growth but did not form a significant component in the area under investigation. It is interesting to note that MEIS-II and PIDAS could better differentiate between damage categories than could tree-ring analysis. In any case, radial increment is only one indication of tree health.

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1 INTRODUCTION

Sulfur dioxide is well documented as a damaging agent of forest stands (Hornstvedt 1970; Linzon 1971; Phillips *et al.* 1977; Scheffer & Hedgcock 1955; Stone & Skelly 1973). Crown injury and long-term reductions in growth have been recorded in numerous areas where this airborne pollutant has been present (Linzon 1972; Phillips *et al.* 1977; Smith 1981). However, visible damage symptoms are not always a reliable indicator of the degree of damage which may exist within a stand (Keller 1980; Phillips *et al.* 1977). If present in sufficient concentrations, sulfur dioxide inhibits CO₂ uptake, thus causing reduced radial increment (Fox *et al.* 1985; Keller 1980; Skelly *et al.* 1972). This effect is not always expressed in the form of crown symptoms that are readily apparent to the observer on the ground. In addition, subtle variations in impact often occur along a gradient due to atmospheric dispersion of the pollutant, making accurate damage assessment difficult. Detailed information is required for each location rather than extrapolating data from other sites (Smith 1968).

Damage assessment of abiotic factors such as sulfur dioxide is of concern to resource management and environmental agencies. However, these organizations must evaluate abiotic damage within the preceding constraints and within the context of the complex interactions of ecological systems with numerous abiotic and biotic factors. Thus, accurate and reliable detection methods are a necessity. The objective of this study was to evaluate three remote sensing techniques, in conjunction with dendrochronology (tree-ring analysis), for the detection and appraisal of sulfur dioxide damage. The remote sensing methods used were LANDSAT IV, MEIS-II and PIDAS. These aerial and ground-based assessment techniques were employed along a sulfur dioxide concentration gradient in order to determine if there was a correlated identifiable gradient of forest productivity and damage. For this purpose, the Port Alice area provided an almost ideal study situation. A single sulfur dioxide emission source has been present in this area since 1918, and is surrounded by a relatively non-complex forest ecosystem.

The remote sensing analyses are incomplete at this time. These will be reported in detail at a later date. The emphasis of the report is to briefly describe the study methods and results to date, with emphasis on the tree-ring analysis.

1.1 Site Description

The study area is located within the Windward Submontane Wetter Coastal Hemlock (CWH b1) biogeoclimatic subzone variant in the vicinity of the Port Alice sulfite pulp mill. The mill is located on the east side of Neroutsos Inlet on northwestern Vancouver Island at 127°27' longitude and 50°15' latitude (Figure 1). Sample plots are situated on both sides of the inlet, south of Rumble Beach.

Climate in this area is characterized by high annual precipitation and mild annual temperatures. The topography is relatively subdued, ranging from sea level to approximately 1 300m. Slopes are typically steep and have west or east aspects. Colluvial and

morainal materials predominate locally. Bedrock is sedimentary or volcanic in origin. Soils in the Port Alice area are classified as ferro-humic podzols. These soils typically have a forest litter surface horizon with an underlying red, acidic, iron and aluminum-rich subsurface horizon. Soils are well drained on the mid- and upper-slope locations; seepage may occur on lower-slope locations. The presence of an acid-tolerant S_1 "salal-moss" ecosystem reflects these conditions.

2 METHODS

2.1 Site Selection

Sample plots were established in pure western hemlock stands in the vicinity of Port Alice and Neroutsos Inlet (Figure 1). Initial stand and plot selection were made on the basis of site quality, stand species, age and ecological similarity. In addition, plot location was determined across a gradient of visible sulfur dioxide damage. Ecological descriptions and forest cover maps were used as a reference in the selection of similar stand types within the homogeneous ecosystem. The S₁ "salal-moss" ecosystem of the CWH b1 biogeoclimatic subzone variant and a pure western hemlock, medium site class, age 50-70 stand type were selected as the sample unit within which plots were placed.

Final sample plot locations were then determined by means of 1:20 000 air photos and aerial reconnaissance. Plots were established within three forest damage zones in order to provide a cross-section for both remote sensing and ground-based sampling. Damage zones were classified as severe, moderate and healthy. The severe damage zone contained stands which exhibited extensive visible crown damage and chlorosis, and frequent mortality. The moderate damage zone was defined as the area where crown damage, chlorosis and mortality were more irregular in occurrence. The healthy zone contained stands with no apparent damage. Two plots were established in each of the severe and moderate damage zones, and three plots were set up in the healthy zone (Figure 1).

2.2 Field Sampling

Square to rectangular 400m² plots were employed in order to minimize local variation due to microsite and genetic differences. Each plot contained approximately 25-30 trees. Both dominant and co-dominant crown classes were assessed. The following measurements were made in all plots:

- Two core samples were obtained from each tree with a power increment borer. Trees were bored on opposite radii between 60-80cm above the germination point, and parallel to the slope contour.
- All trees were visually evaluated for health class. Trees were considered to be severely damaged (code 3) if chlorosis, reduced leader or branch growth, and/or tip dieback could be seen. Trees were classified as being moderately damaged (code 2) if some chlorosis and crown thinning was evident, and were recorded as healthy (code 1) if no damage was apparent. Dead trees were also recorded (code 4).

- Stand composition and proportional damage ratings were estimated on a plot basis.
- Diameter at breast height (dbh) was measured in centimetres.
- Tree heights were estimated (from aerial photos).
- A description of ecological parameters was produced. This description included physiography, plants, and soils.
- Foliage samples were collected with a 12 gauge shotgun from the mid- to upper-crown of several representative trees. These samples were placed in dark bags for subsequent analysis with a PIDAS spectroradiometer, and later frozen and transported for chlorophyll a and b analysis.
- Tree cores were placed in tubes (straws), sealed, refrigerated and transported to the laboratory for tree-ring analysis.

2.3 Laboratory Analysis

All cores were stored below 10°C in sealed tubes (straws). Cores were measured on a Digi-Mic digital micrometer which was linked to a Digital Equipment Corp. 8650 VAX computer. Within core pairs, each sample was labelled with an individual tree number (n(n)1 or n(n)2). A saturated solution of phloroglucinol in 18% HCl was used to enhance the visibility of faint growth rings in some cores. Pairs were remeasured when discrepancies in age were found.

All measurements were entered into an R-file on the VAX-linked virtual using the TREERING program (FORTRAN). Data for each core sample included plot number, tree number, tree-ring width to 0.01mm, the number of rings (age), and the total core radius (mm). The R-file was transferred to an A-file (ASCII) in the VAX and three P-files (binary) were created using program TREERING. Subsequently, indices for all samples were produced using the INDEX program (FORTRAN) in order to perform core to core, tree to tree, and plot to plot cross-dating (Graybill *et al.* 1982). A computer-determined best-fit curve was applied to each set of raw data during this process. The computer defaults for these curves were exponential, linear or constant. Cross-dating proceeded based on this output.

The INDEX program was then used to remove high point to point variability. A cubic spine (smoothing factor 3) was applied to the actual tree-ring growth data in order to accomplish this (Cook & Peters 1981; Peters & Cook 1979). Pl- and PM-files were produced, and graphs of the actual smoothed tree-ring data were outputted with the preceding technique. Next, the data were transferred to an ASCII version of the PM-file for editing. Sample pairs were removed from the data set if they represented

species other than western hemlock, had an age discrepancy of greater than three years after 1940, had highly dissimilar curves, or were incomplete. The three corrected ASCII versions were merged to one PM-file and truncated at 1940. The smoothed data points of each core pair were then averaged, resulting in one set of data per tree.

This data file was statistically analyzed and graphed with the SAS Institute Inc. SAS MEANS, GLM and GPLOT procedures after data had been sorted by plot and by damage category (treatment)(SAS Institute Inc. 1985). The MEANS procedure produced the mean, standard deviation, variance, standard error of the mean, and coefficient of variance for each selected tree, per plot and per treatment (NEWVAR = 1 = severe; NEWVAR = 2 = moderate; NEWVAR = 3 = control). Due to the unbalanced condition of the data set, an analysis of covariance was conducted using the GLM procedure rather than through an ANOVA. This analysis of covariance was used to test for significant effects of the damage levels (treatments) on the last ten years of growth (1978-1988). The data were weighted to account for any differences in age and diameter in 1977. Tree age and diameter in 1977 were then used as covariates against growth during the last ten years. Sums of squares, mean growth over the last 10 years, standard error, F-value and P-value were calculated per treatment. Graphic output of plot and treatment averages was obtained with the GPLOT procedure (Figures 2, 3, 4, 5, 6, 7, 8 and 9).

3 RESULTS

3.1 Field Observations

Plots 3 and 6 were the severely damaged plots. Plot 3 contained 23% healthy, 45% moderately damaged, 32% severely damaged and 0% dead trees (Figure 10). Plot 6 had 8% healthy, 38% moderately damaged, 50% severely damaged and 4% dead trees. Plots 4 and 7 were the moderate damage plots. Plot 4 contained 97% apparently healthy and 3% dead trees. No moderately or severely damaged trees were noted. Plot 7 consisted of 45% apparently healthy, 44% moderately damaged and 11% dead trees. No severely damaged trees were found. Plots 8, 9 and 10 were the control (healthy) plots. Plot 8 had 77% healthy, 20% moderately damaged and 3% dead trees. Plot 9 contained 93% healthy, 7% moderately damaged and no dead trees. Plot 10 consisted of 100% healthy trees. No severely damaged trees were found in any of the control plots.

3.2 Laboratory Analysis

High variability was found during the cross-dating procedure. Cross-dating of key years for each decade from 1940 to the present revealed inconsistencies between core pairs and trees within the same plot. Application of the cubic spline curve reduced much of the variability (Figures 2, 3, 4, 5, 6, 7 and 8). A total of 44 sample trees were removed from the data set, mainly because of non-resolvable age discrepancies between core pairs. Subsequently, 155 trees were used for statistical analysis.

Analysis of covariance indicated a significant (F value = 10.76, $P < 0.001$) decreased in growth over the last 10 years in core samples from moderate and severe damage plots relative to samples from control plots (Tables 1 and 2, Figure 9). Growth during the 1978-88 period was also related to the diameter in 1978 ($P < 0.01$) and to the square of the diameter, but was not related to age in 1977 ($P > 0.05$). The mean growth in control plots was 19.3mm over the last 10 years (Table 3). The mean growth for the last 10 years in moderate and severe damage plots was 14.8mm and 12.2mm, respectively (Table 3). There was no significant difference ($P > 0.05$) in growth between moderate and severe damage sites (Figure 9, Table 3). Confidence intervals for these sites frequently overlapped or were extremely close from 1955 to the present (Table 2). Visual observations of damage symptoms were discovered to be somewhat inaccurate predictors of actual damage. In Plot 4 (moderate), growth over the last 10 years was still reduced relative to the control plots, despite the lack of visible damage symptoms. In addition, Plots 3 and 6 (severe) contained only 23% and 3% apparently healthy trees, respectively, while the figure for Plot 7 (moderate) was 45%. Despite these inequalities, no significant difference was found between the moderate and severe sites.

4 DISCUSSION

The high variability in age and ring width of the non-smoothed data was probably a result of the growth characteristics of coastal western hemlock. In this species, annual rings are formed in an asymmetric manner which is reflected in the irregular shape of the bole. Numerous cores did not pass directly through the pith, although non-resolvable discrepancies in age were still found in core pairs where both samples reached the pith. Season to season variations in climate are relatively slight and precipitation is high throughout the year in the Port Alice area. Subsequently, mean sensitivity and density of late wood may be reduced, thus reducing demarcation of some rings. This high variability within core pairs and between trees and plots led to limitations with the cross-dating technique. The sample size needed to be greatly reduced to 10 trees per plot, based upon the best samples for cross-dating from each plot, in order to construct an accurate chronology.

As this reduced sample size would be unacceptably small, variation in data was limited with the cubic smoothing spline. A smoothing factor of three was used since this produced curves which retained some sensitivity. Larger or smaller smoothing factors would have removed or left too much variability, respectively. The smoothing spline proved to be an excellent tree-ring standardization method due to its well-defined filtering characteristics and ability to range continuously from exponential, linear or constant fit curves (Cook & Peters 1981). In addition, the smoothing spline method was more applicable for measuring the overall effects of sulfur dioxide pollution than was employment of the index technique for analyses of chronologies. The latter method is most useful for detecting periodic growth fluctuations (insect outbreaks, drought years, etc.), but is not sensitive to long-term trends such as those produced by decades of continuous pollution (Alfaro personal communication; Phipps & Whiton 1988).

Despite the standardized data set, some sample trees were still rejected prior to statistical analysis mainly as a result of age or species discrepancies. Samples within core pairs were judged to be non-comparable if the difference in their ages was greater than three years after 1940. The incidence of spruce and Douglas-fir samples was too small for proper statistical representation of these species; thus, they were eliminated. Further, trees represented by a single core sample were removed in order to maintain consistency. All tree-ring data were truncated at 1940 because core to core and tree to tree variations in age and ring width increased dramatically prior to this date. Data from 1940 to the present were found to be much less variable in all plots, with the exception of Plot 8. Tree to tree variation in Plot 8 remains unexplained at present.

Continual exposure to airborne sulfur dioxide probably accounts for the difference in radial increment between healthy and damaged trees over the last 10 years. However, a gradient of pollution damage has not been firmly established because no significant difference in growth was found between moderately and severely damaged trees. The

similarity between moderate and severe plots is probably due to high variability of the data with respect to the more subtle gradient of pollution injury. Damage within the moderate plots may also be greater than is indicated by the observed lack of symptoms. This phenomenon has previously been noted by several researchers (Keller 1980; Phillips *et al.* 1977; Skelly *et al.* 1972). Sulfur dioxide pollution can reduce tree growth without inducing any visible symptoms, particularly in locations that are relatively distant from the pollution source. Separate analysis of data from each plot in conjunction with the remote sensing data may resolve these questions in the future.

5 CONCLUSIONS

Forest damage appraisal plots were established in the vicinity of the Port Alice sulphite mill in order to evaluate damage appraisal methods. Data were obtained from three control plots in healthy stands, two plots in the moderately damaged area and two plots in the severely damaged area. The appraisal methods employed were LANDSAT IV, MEIS-II, PIDAS, and analysis of tree-ring data from core samples.

Short-term variability of the tree-ring data was reduced with the cubic spline technique prior to statistical analysis. Analysis of covariance indicated a significant (F value = 10.76, $P < 0.001$) decrease in growth over the last 10 years in trees from moderate and severe damage plots relative to trees from control plots. This difference is probably attributable to chronic sulfur dioxide exposure. No significant difference in growth between trees from moderately and severely damaged sites has been detected to date.

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TABLE 1 ANALYSIS OF COVARIANCE

Source	Degrees of Freedom	Mean Square	F Value	Prob >F
Model	4	614.5	10.76	0.0001*
Pollution	2	692.9	12.13	0.0001*
Old Diameter	1	787.0	13.78	0.0003*
Old Diameter ²	1	622.2	10.90	0.0012*
Error	150	57.1	-	-

* Significant

TABLE 2 CONFIDENCE INTERVALS FOR TREATMENT AVERAGES

Year	Confidence Limits (Lower and Upper, mm)		
	<u>Severe Damage</u>	<u>Moderate</u>	<u>Healthy</u>
1940	(4.679, 4.870)	(3.782, 3.964)	(4.223, 4.385)
1945	(3.835, 4.015)	(3.170, 3.342)	(4.638, 4.800)
1950	(3.187, 3.366)	(2.808, 2.980)	(4.259, 4.406)
1955	(2.703, 2.882)*	(2.573, 2.745)*	(3.754, 3.900)
1960	(2.264, 2.443)*	(2.230, 2.401)*	(3.309, 3.455)
1965	(1.797, 1.976)*	(1.786, 1.957)*	(2.896, 3.042)
1970	(1.400, 1.580)*	(1.419, 1.590)*	(2.426, 2.572)
1975	(1.188, 1.367)*	(1.297, 1.469)*	(2.064, 2.210)
1980	(1.162, 1.342)	(1.356, 1.528)	(1.910, 2.056)
1985	(1.168, 1.347)	(1.393, 1.565)	(1.822, 1.968)

* Confidence intervals overlap

TABLE 3 MEAN GROWTH FOR THE LAST 10 YEARS (1978-88)

Treatment	N	Mean Growth (mm)*	Standard Error
Control (Healthy)	65	19.3 a	0.94
Moderate Damage	47	14.8 b	1.10
Severe Damage	43	12.2 b	1.16

* Means were adjusted by analysis of covariance to account for differences in tree diameter at the start of the measurement period (1978). Means followed by the same letter were not significantly different. Adjusted means were compared by orthogonal contrasts, $P < 0.01$.

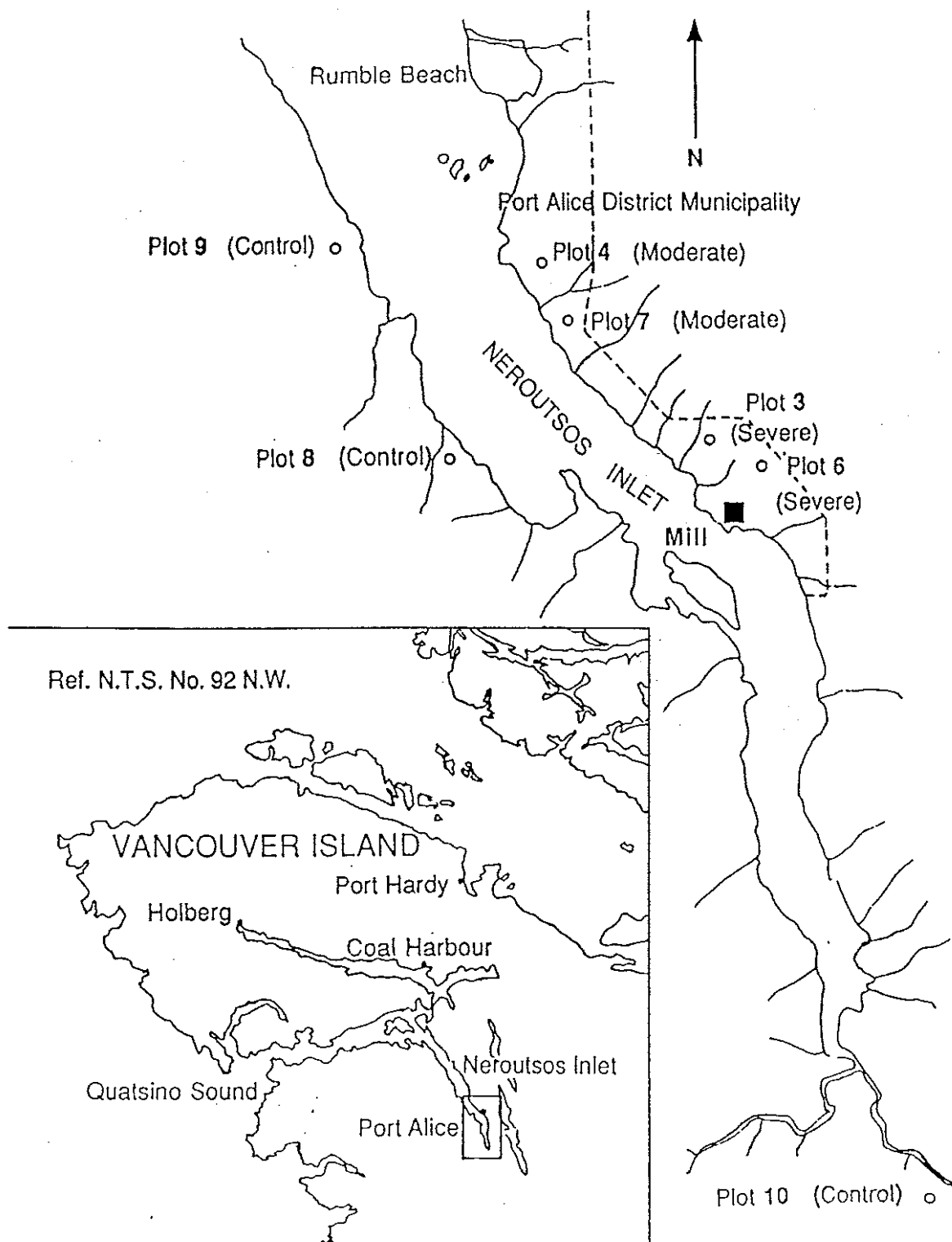
FIGURE 1 **PORT ALICE STUDY AREA**

FIGURE 2 PORT ALICE POLLUTION DAMAGE SURVEY: TOTAL MEAN RING WIDTH
BY PLOT (PLOT 3)

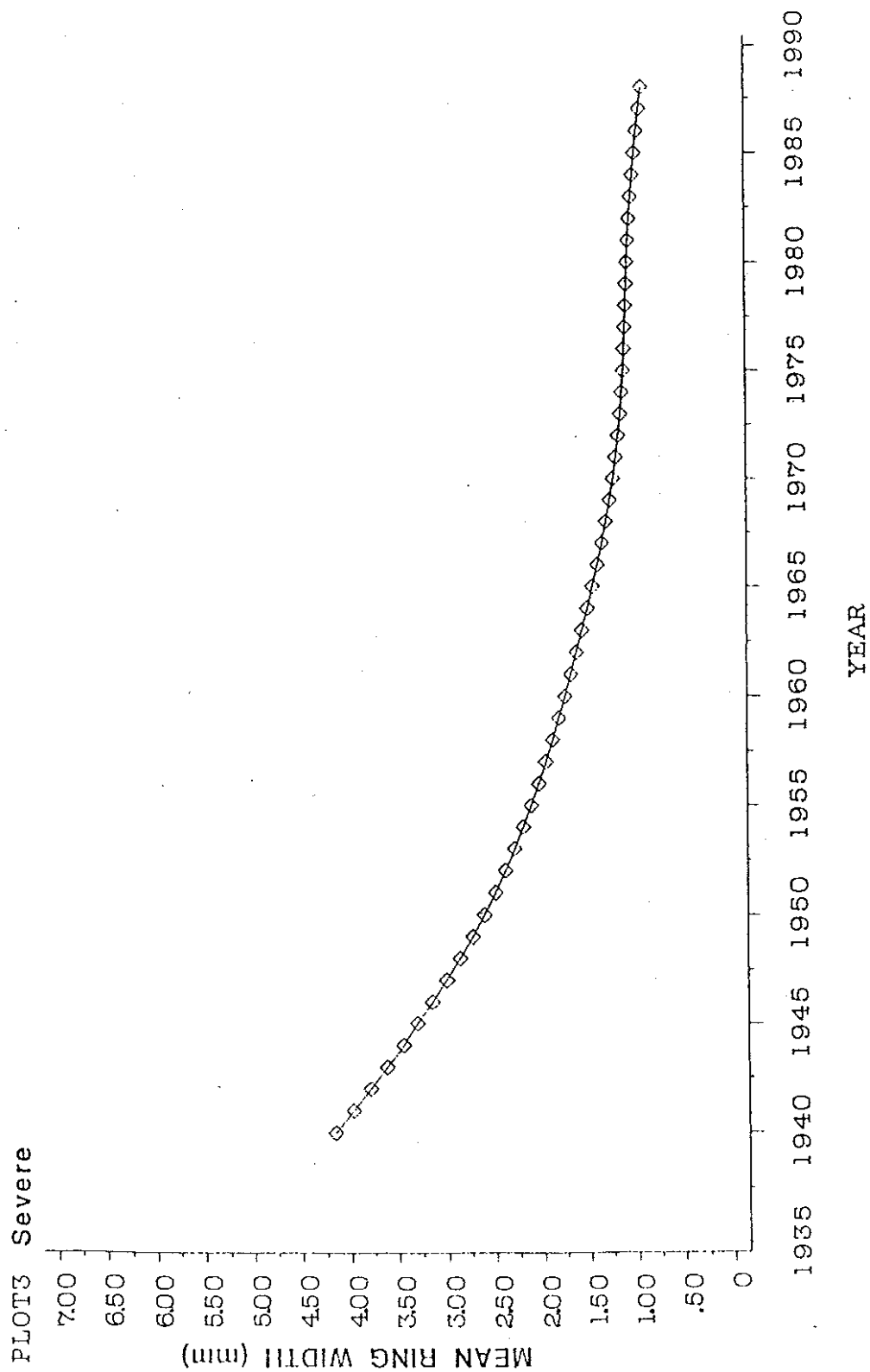


FIGURE 3 PORT ALICE POLLUTION DAMAGE SURVEY: TOTAL MEAN RING WIDTH
BY PLOT (PLOT 4)

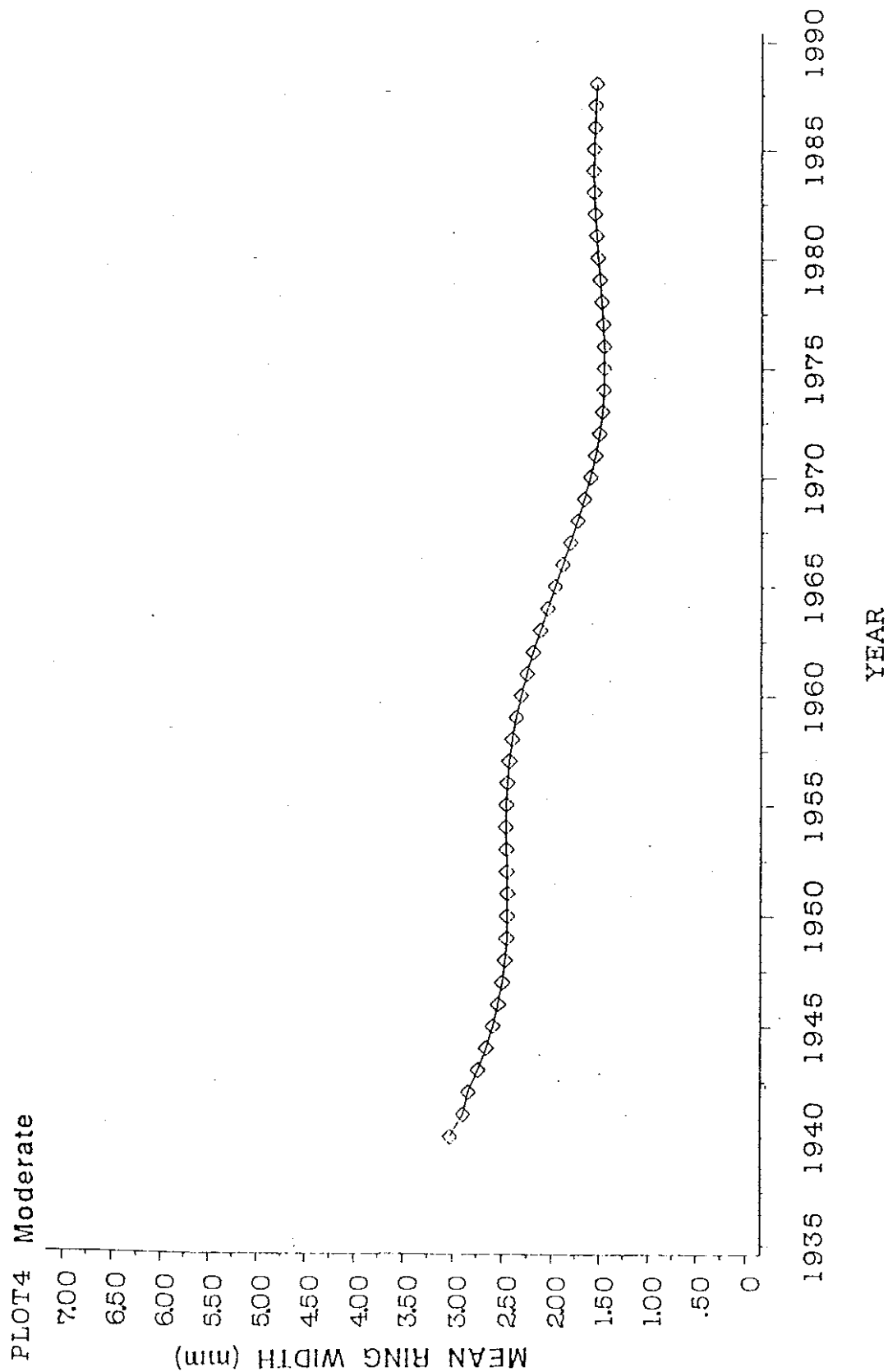


FIGURE 4 PORT ALICE POLLUTION DAMAGE SURVEY: TOTAL MEAN RING WIDTH
BY PLOT (PLOT 6)

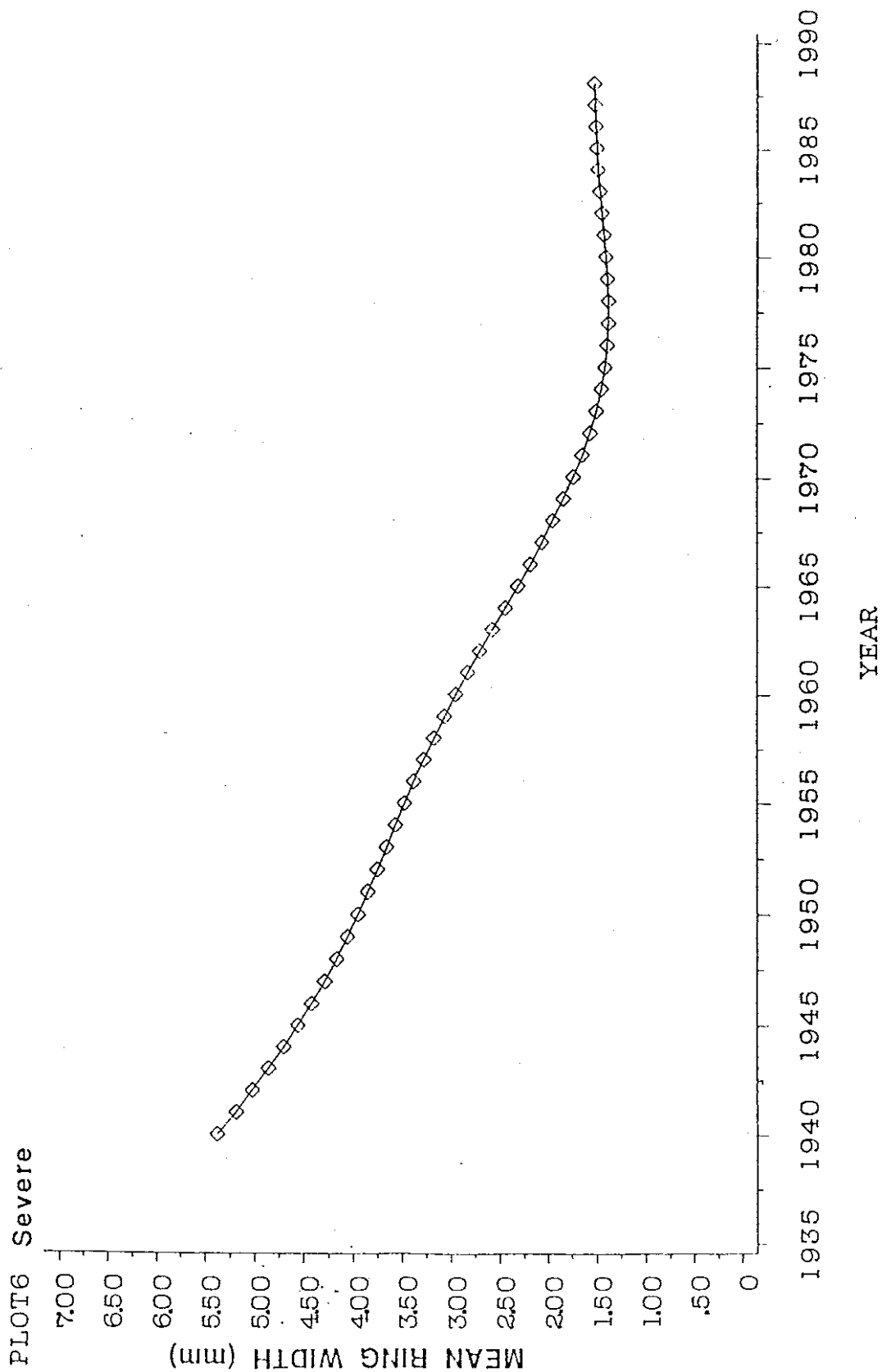


FIGURE 5 PORT ALICE POLLUTION DAMAGE SURVEY: TOTAL MEAN RING WIDTH
BY PLOT (PLOT 7)

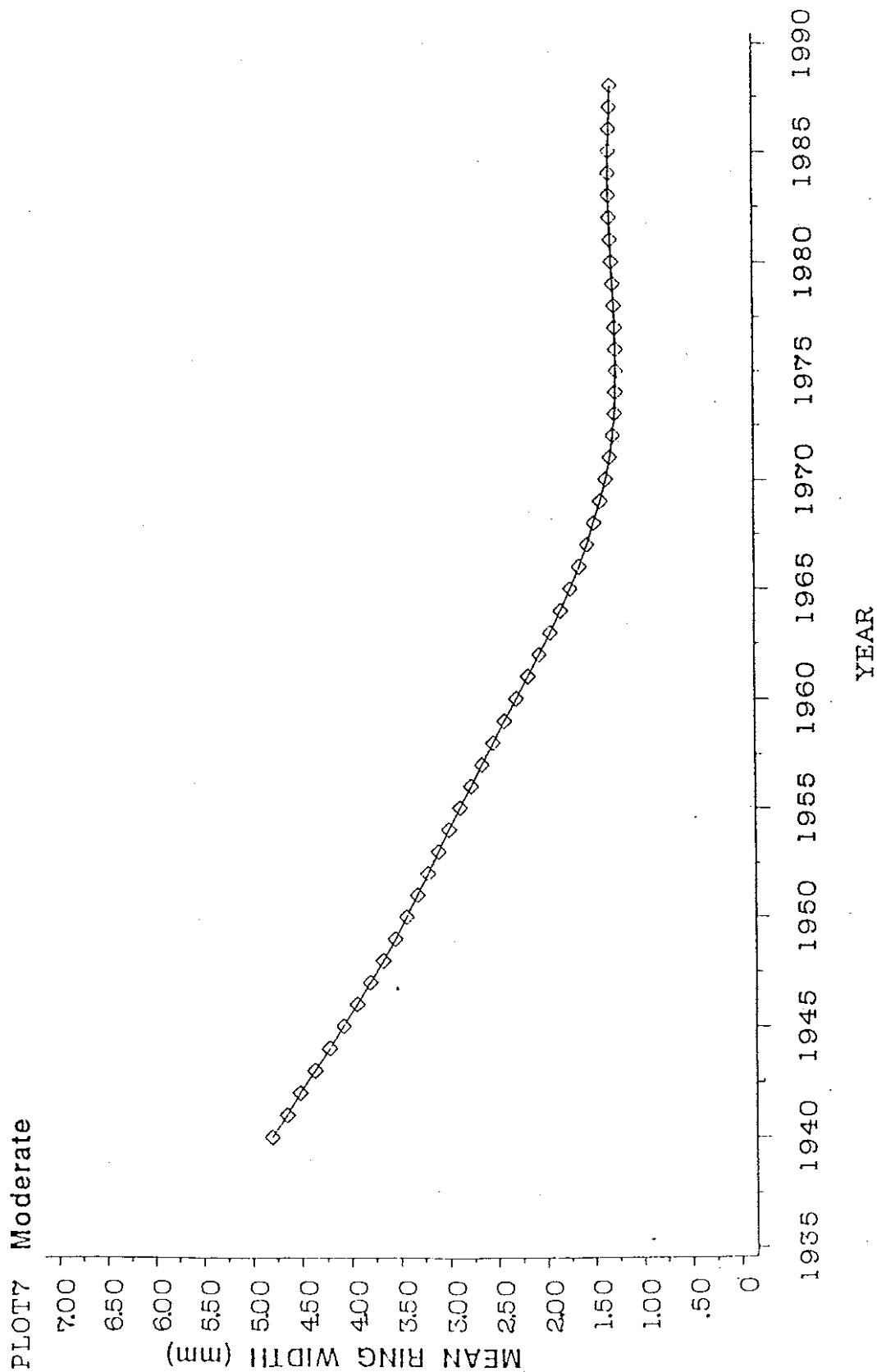


FIGURE 6 PORT ALICE POLLUTION DAMAGE SURVEY: TOTAL MEAN RING WIDTH
BY PLOT (PLOT 8)

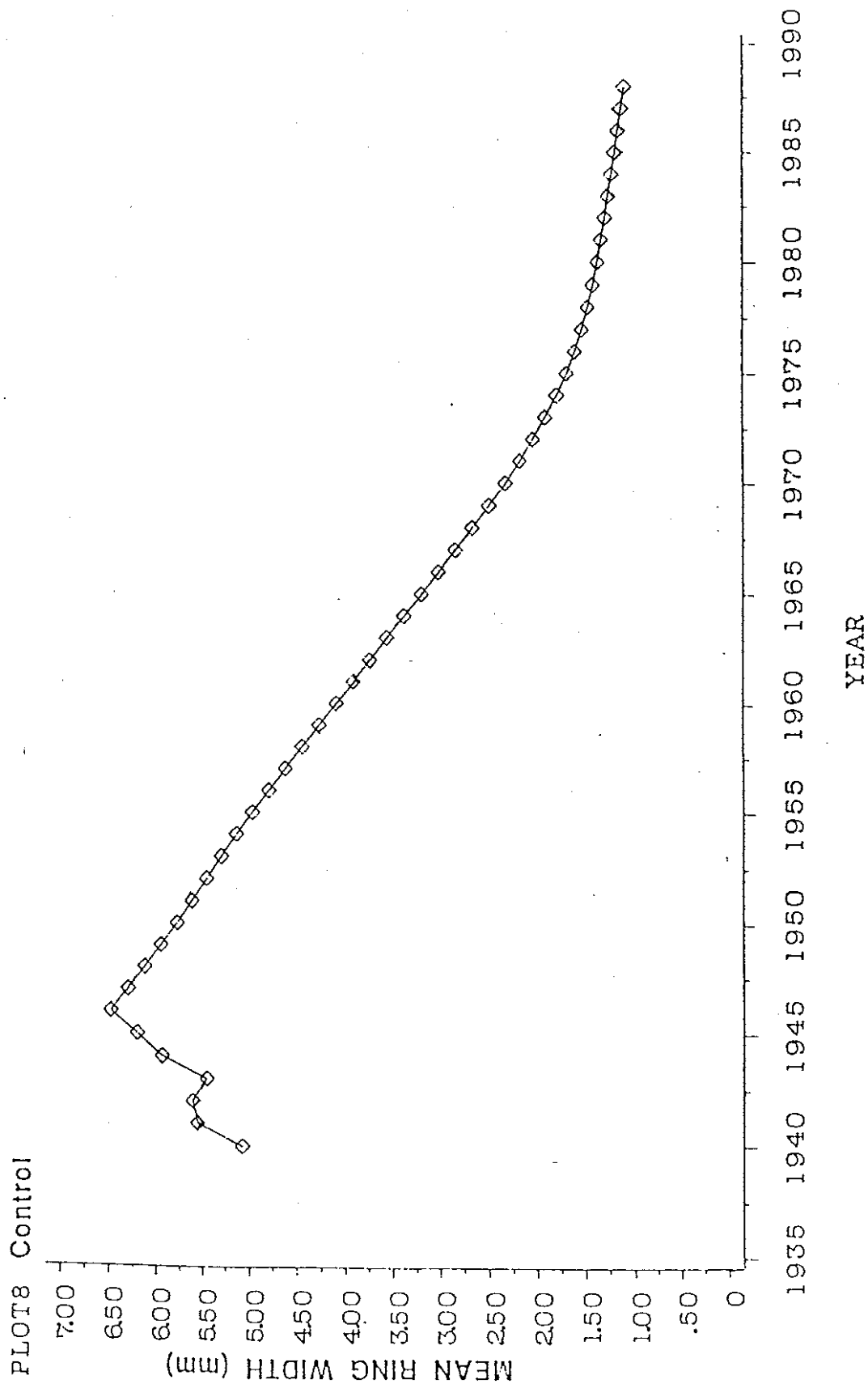


FIGURE 7 PORT ALICE POLLUTION DAMAGE SURVEY: TOTAL MEAN RING WIDTH
BY PLOT (PLOT 9)

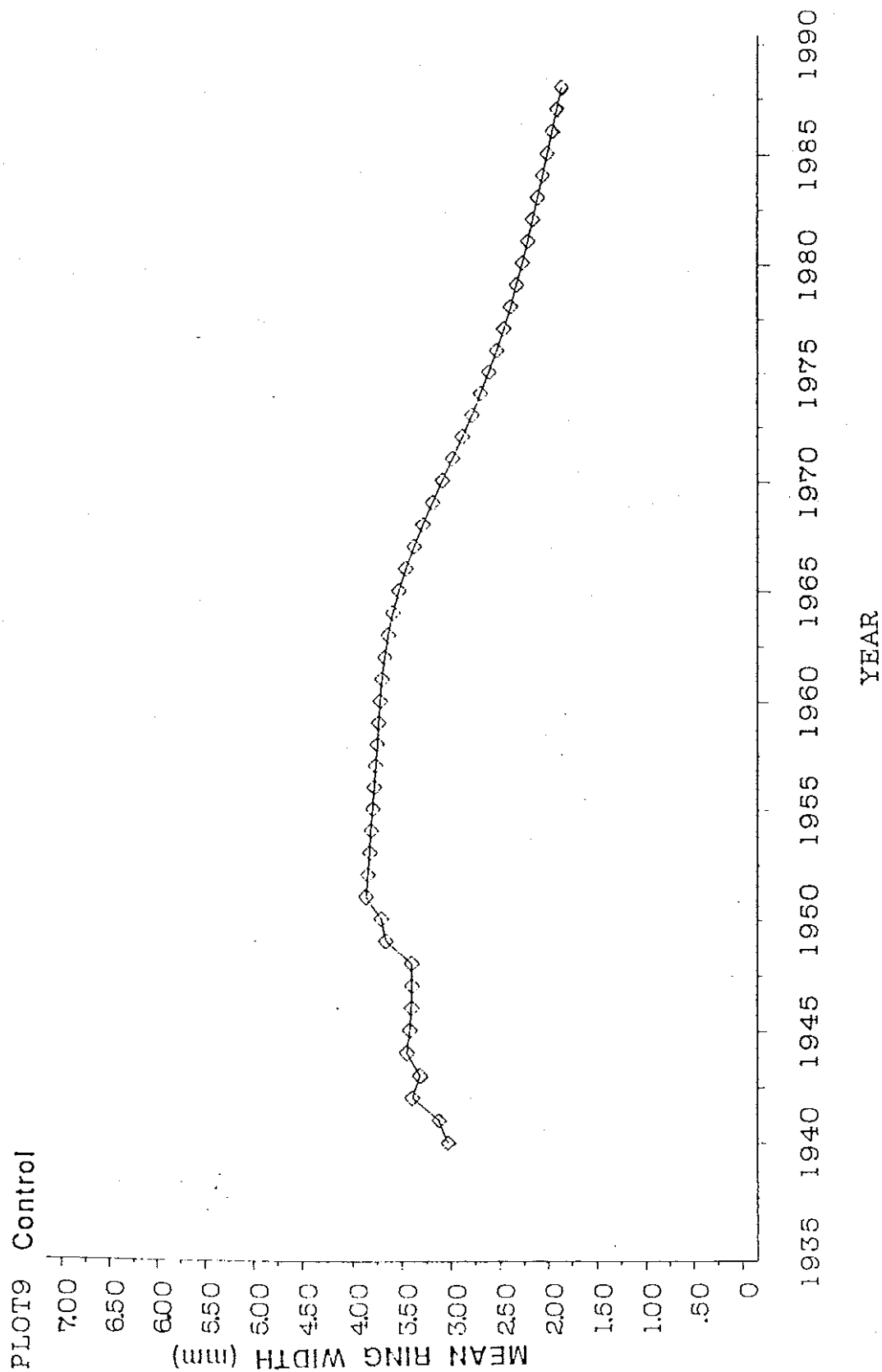


FIGURE 8 **PORT ALICE POLLUTION DAMAGE SURVEY: TOTAL MEAN RING WIDTH**
BY PLOT (PLOT 10)

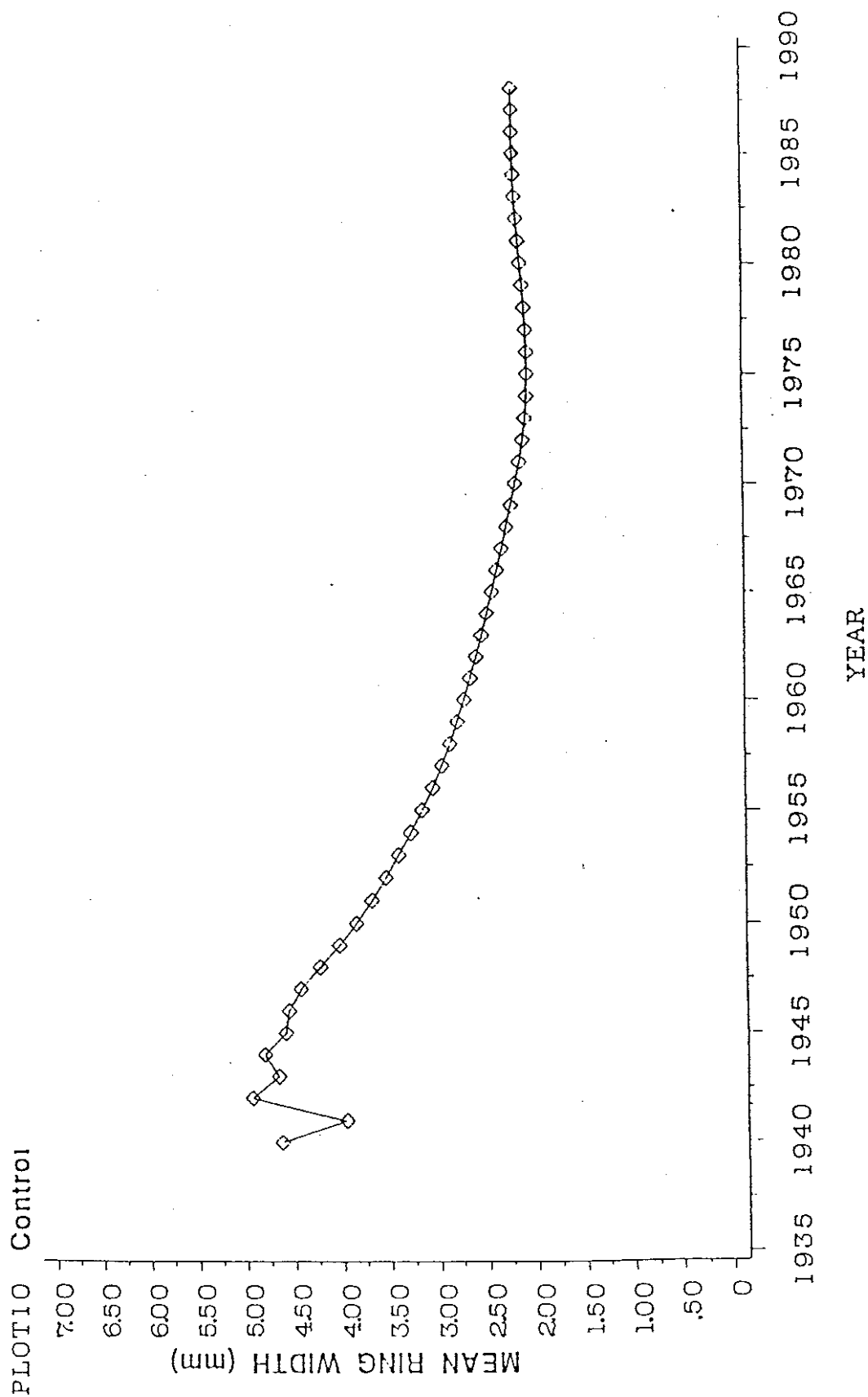


FIGURE 9 PORT ALICE POLLUTION DAMAGE SURVEY: TOTAL MEAN RING WIDTH BY TREATMENT

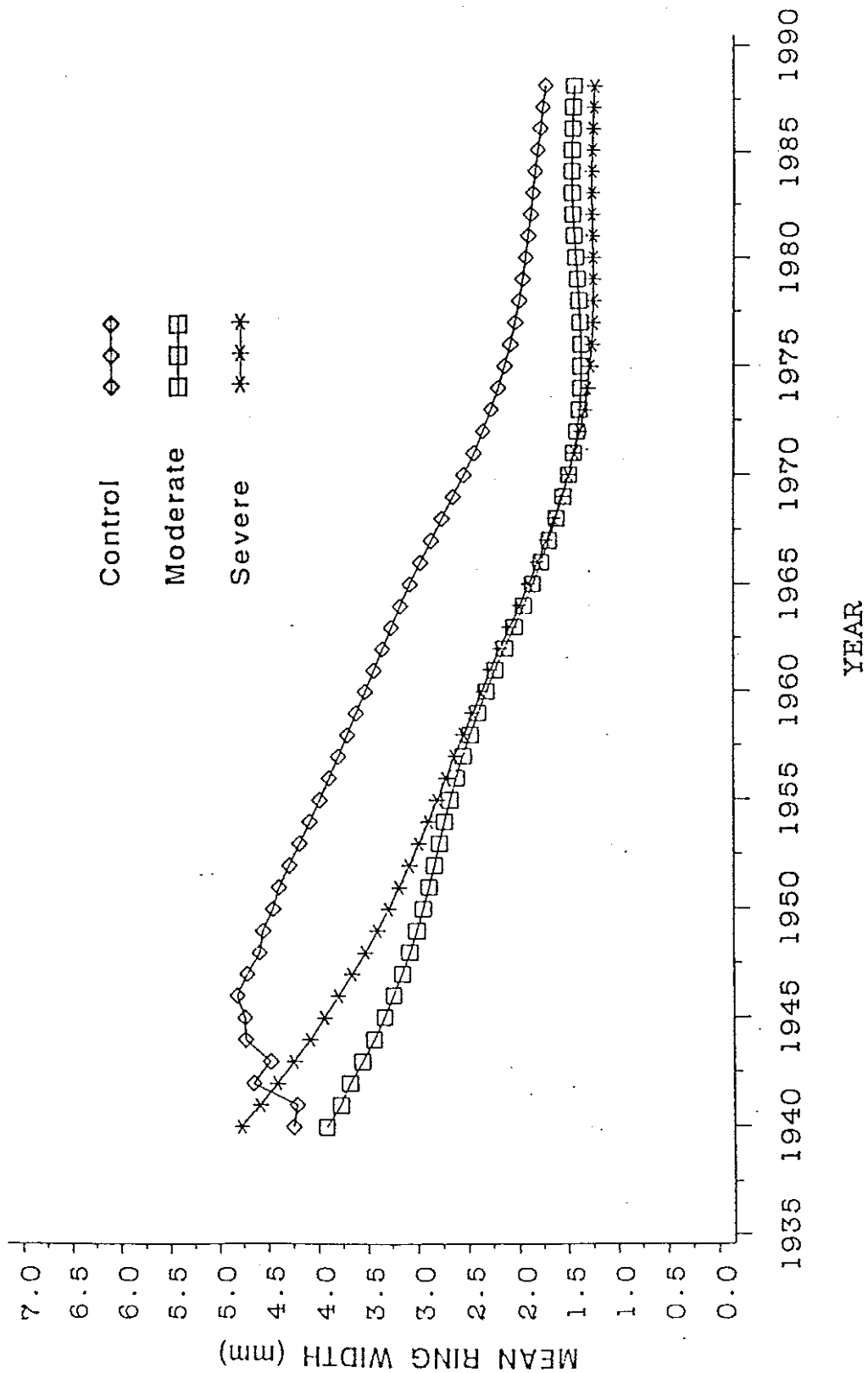


FIGURE 10 SUMMARY OF VISIBLE DAMAGE SYMPTOMS

