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THE RESPONSE OF NORTHERN RED OAK TO ENVIRONMENTAL CHANGE IN THE ST. CLAIR RIVER DELTA

by

Walter Roberts Skinner

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ABSTRACT

THE RESPONSE OF NORTHERN RED OAK TO ENVIRONMENTAL CHANGE IN THE ST. CLAIR RIVER DELTA

by

Walter Roberts Skinner

The growth response of one deciduous species growing in the public bush area of Walpole Island in the St. Clair River delta, northern red oak (Quercus rubra), to a broad range of environmental variables was analyzed. Two separate dependent variables were initially considered, annual tree-ring width and annual tree-ring area. Statistical response functions were developed to describe the response of the growth indexes to environmental variables.

Response functions were developed on the basis of 48 climatic variables, mean monthly temperatures, total monthly precipitation, total monthly bright sunshine hours and mean monthly Lake St. Clair levels for the period April 1 to September 30 of both the previous and current growing seasons. A weak relationship over a 60 year period of analysis from 1925 to 1948 was found. Shorter 30 year periods, 1925-54 and 1955-84, were analyzed. A wholesale change was seen from the early period to the later period in the effects of the important environmental variables. The most notable changes in the environmental variables were in mean lake levels, from a number of consecutive years of extremely low levels during the early period to a number of consecutive years of extremely high levels during the later period.

Two short periods of extremely low and high lake levels were further analyzed. Water availability, through the input of precipitation and fluctuations of the Walpole Island water table, in conjunction with fluctuations in river and lake levels, appears to be the primary limiting factor in the growth of the red oak trees. Moisture stress and environmental shock relating to low and high water table levels, respectively, can have negative effects on tree growth. Favorable growth can occur during a period of low water table providing the precipitation, temperature and sunshine inputs are appropriate to meet the growth demands of the tree. Favorable growth can also occur during a period of high water table providing the evaporative demands are high and the precipitation inputs are low to moderate. Air pollution, in combination with other factors such as the availability of water, might also have been responsible for the observed changing relationships and reduction in tree growth in recent years.

ACKNOWLEDGEMENTS

I would like to thank my committee Chairman, Dr. J. D. Jacobs, for his advice, guidance and patience during the preparation of this thesis. I would also like to thank Dr. I. M. Weis for his continuing advice and his instruction on the procedure for extracting core samples from trees. I would also like to extend a special thanks to Laurie Montour from the Walpole Island Research Centre for assisting me in the field work. I am grateful to the Atmospheric Environment Service of Canada for providing the climatological data for this investigation. I would also like to gratefully acknowledge the financial support given me by the Canadian Environmental Assessment Research Council.

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CHAPTER I

OBJECTIVES AND BACKROUND THEORY

1.1 Introduction

The analysis of annual growth-rings of trees from a selected site in the St. Clair River delta provides a unique opportunity to study the vegetational responses which have occurred in the past due to environmental change on both local and regional scales. The natural vegetation of Walpole Island, which is situated in the eastern portion of the delta, consists of a rare and relatively large Carolinian forest. It is presently being managed through an on-going program in conjunction with the University of Windsor, but has been preserved in its natural setting. Future energy supplies from the forest biomass offer a realistic alternative energy source to the people of the Island. Tree-ring samples, representing up to 90 years in growth, provide an uninterrupted proxy record of past vegetational responses to environmental change. In order to speculate on future changes, there must exist a thorough knowledge of those changes which have occurred in the past, coupled with an understanding of those processes which are responsible for such changes.

All factors that influence variation in tree growth can be broadly catagorized by variation in the bio-physical environment. Climate and climatically related events represent the most important environmental processes behind the bio-physical environment. The variation in the growth of natural vegetation can be directly related to the variation of temperature and precipitation (Fritts, 1976). In addition, fluctuations in river, lake and groundwater levels can be directly related to both variations in climate and to the human occupancy of the land. The past one hundred years spans a period of both extremely high, and low levels of lake, river and groundwater. It also includes the recent construction of the St. Lawrence Seaway which has resulted in the wholesale modification of river channels. Standardized tree-ring chronologies can be calibrated with regional climatic records. Such information can have both local and regional significance.

A detailed reconstruction of changing environmental conditions can provide both locally and regionally significant information. Information pertaining to the effect of a changing bio-physical environment on the local natural vegetation can be derived. In addition, an improvement in the understanding of even local environmental change could provide practical input into future environmental impact statements. On the other hand, it can also yield information on a much broader scale. The St. Clair River delta is located on the northeastern shores of Lake St. Clair opposite the large industrial complex of Detroit, Michigan and Windsor, Ontario. The delta represents an important location with respect to changing environmental conditions. Such a reconstruction could eventually be incorporated into a regionally based estimate of the frequency and geographic extent of environmental change.

1.2 Theoretical Formulation

This investigation is formulated on the basis of previous studies in dendroclimatology. The hypothesis states that inferences can be drawn from the manner in which the growth of the local natural vegetation of Walpole Island in the St. Clair River delta is related to environmental variables. Since the main objective of dendroclimatology is to statistically describe past climate by analyzing the structure of the annual growth-rings of trees, the general approach, or rationale, of that discipline is adhered to in this investigation. This general rationale is to express the nature of a complex system in such a manner that it may be subjected to hypothesis testing and conceptual development. It thus becomes necessary to simplify the system and to describe it with the use of a model or a series of models. The internal workings of the system can then be visualized as a process-network model where there is a network of linkages between conditions, or states, in the climate-plant system.

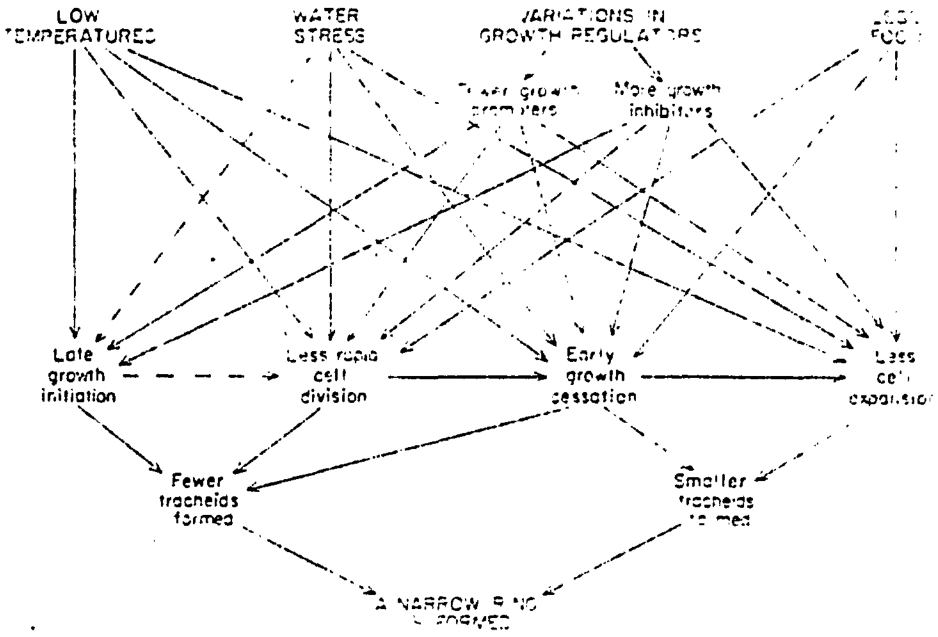
It is best to begin with a general and flexible a priori model and then to proceed to apply statistics in a posteriori manner with the intention of shaping the a priori model to the specific annual tree-ring responses (Fritts, 1976). A good a priori model should describe the important relationships between climate and tree growth. The most important plant processes which affect ring-width growth are light, temperature, water, atmospheric components and physiological factors which affect photosynthesis and respiration. The most important site factors which can alter the energy and water balances of a tree and thus affect ring-width are topography, soils, elevation and orographic factors. Careful sampling and site selection can reduce the influence of the site factors. However, many of the factors which limit the plant processes can be linked to climatic conditions through the energy and water balances. All of these factors which provide linkages between climatic factors and tree growth are part of a complex and interrelated ecological system. Because of the extreme difficulties in modelling the specific biochemical reactions and the physical linkages in the system it has become more practical to generalize the processes by stressing the major pathways in the system (Fritts, 1976). This includes the range of but not all of the possible physiological components. However, these generalizations should be consistent with the experimental evidence into both biochemical and physiological processes.

The climate of a given year affects the growth of trees in that same year as well as in the subsequent year. Here the response to climate can be seen to lag one year behind the occurrence of climate. The effects of heat, wind, carbon dioxide and water can be seen on tree growth in year (t) and also in year (t+1) through the effects on buds, sugar, hormones and roots. Because of these year to year linkages the growth of a tree in year (t-1) is statistically related to the growth in year (t). This effect is modelled as autocorrelation in ring width.

Figure (1.1) describes the four major factors causing a reduction in the size of an annual ring-width. Cause and effect are indicated by the arrows which include various types of interrelations among the processes and variables. Here it is implied that if the temperature and precipitation conditions were opposite then the ring-width would increase. The four major limiting conditions which are depicted are the temperature of the growing tissues, water stress in the tissue, concentrations of growth regulators and the amounts of building materials which includes both foods and mineral salts. If any of these factors is present in limiting amounts the rates of cell

FIGURE (1.1)

Model describing the four major factors causing a reduction in size of an annual ring-width. Figure implies that an increase in ring-width will occur due to an effect of the opposite extreme. (Source: Fritts, 1976, p. 227)



division and expansion and the start and end of the growing period will be altered with an accompanying reduction in the size of the annual ring-width. This model shows the direct relationship of temperature and ring-width. It also implies the indirect relationships between ring-width and precipitation, humidity, temperature, wind and light when dealing with water stress. In addition, the limitation of stored foods, which eventually become building materials, is quite dependent on a number of climatically related processes such as photosynthesis, respiration and food manufacture.

1.3 Present Objectives

Initially, in research such as this, the hypotheses to be tested may involve the model itself. This incorporates the identification of all variables which are part of the model but are not relevant to it and searching for variables that should be included in the model but have been omitted. It also includes the identification of any sources of error or inaccuracies that might be present in the model, any feasible alternatives to the model structure and the awareness of any constraints that may be incorrectly formulated. The model should then become more and more useful for the testing of inferences and hypotheses about the system. The effects of unusual conditions and situations can then be better understood and anticipated.

The connection between tree-growth and climate is best visualized as a process-network system with different variables entering into the relationship. There is variation in limiting factors. Therefore, the most appropriate approach is to design a general and flexible _a priori_ model that includes many variables as predictors of growth, then proceed to make use of statistical techniques in order to determine which variables are most important.

CHAPTER II

REVIEW OF RESEARCH

2.1 Introduction

The science of dendrochronology, or tree-ring analysis, is based upon the study of the annual growth-rings of trees. Dendroclimatology is the science of reconstructing past climate with the use of tree-rings. Tree-ring chronologies have a very precise time resolution because they can be dated to the exact year in which a change in climate occurred. In general, a new growth-ring is formed each year but the width of the ring is a function of various limiting factors. Ring thicknesses tend to become narrower as the tree becomes older. In addition to this normal variation is variation caused by changes in climate and by human influences. For example, a series of years with low moisture availability will show a series of narrow rings. Until recently, most tree-ring analyses in North America have been conducted in climatically sensitive areas such as the American southwest and at alpine and sub-alpine sites. In more humid temperate regions, such as the Great Lakes area, ring-widths are related to a complex interaction of precipitation, temperature and other variables (Fritts, 1976).

2.2 Current Status of Dendroclimatology

In dealing with 1000 to 8000 year records from bristlecone pines from the southwestern United States, La Marche (1974) summarized the state of research in which tree-rings have been used to estimate past climates. His concern was based on the exclusive use of one single variable, the width of the annual ring. Until that time there had been little use made of other statistics besides the mean value. He called for more research into the study of variation of ring-width statistics through time, the investigation of the physical and chemical properties of wood and the combined multivariate analysis of data for a number of climatic indicators.

Terasmae (1975) summarized the methods used in tree-ring research and their significance in current attempts to resolve the food supply, water resource and energy problems of mankind. He stressed the close relationships between climate, tree-rings and changes in our natural environment.

Fritts (1976) outlined the current status of the interdisciplinary field of dendroclimatology. He presented a compilation of the new approaches developed at the University of Arizona. The subject matter is presented in a series of graded chapters beginning with the basic biological facts and principles of tree growth followed by the development of important quantitative methods then by examples of past climatic reconstructions. He presented, as follows, the most widely used and basic principles and concepts in the field of dendroclimatology.

The uniformitarian principle states that the same biological and physical processes which cause variations in tree growth today must have been in operation in the past. The principle of limiting factors states that a biological process cannot proceed at a faster rate than is allowed by the most limiting factor. In dendroclimatology, this principle implies that narrower growth-rings provide the most precise information on limiting climatic conditions. A series of wide growth-rings indicates the relaxation of limiting factors. The concept of ecological amplitude states that, depending on hereditary factors which determine phenotype, each species may reproduce and grow only over a certain range of habitats. Climate often becomes limiting to the physiological processes of species growing near the margins of their natural range.

In order to obtain the best possible information, the law of limiting factors and the concept of ecological amplitude must be applied when dealing with site selection. The sampling design is deliberately stratified in order to obtain the maximum amount of information from the population of ring-widths. Also, in order to retain a more or less constant genetic response, the sampling design is restricted to one or two particular species. A tree which exhibits a high degree of variability in ring-width has a high sensitivity while one which has a lack of ring variability exhibits complacency. A sensitive chronology is more desired for it more clearly exhibits the law of limiting factors. The most important principle of dendroclimatology is crossdating. All annual ring-widths must be crossdated among all radii within a given stem, and among selected trees within a given stand. The mere fact that crossdating is obtainable is evidence that there is some environmental or climatic information common to the sampled trees.

There must also be repetition or replication in sampling. This applies to sampling more than one stem radius per tree as well as from more than one tree. This allows for statistical comparisons of variability within the same tree as well as between trees and between groups of trees. If climate is limiting to growth then the same ring-width variations will be evident in the samples and the rings will be easy to crossdate. If climate is not highly limiting then there may be distinct differences in ring-widths between trees and possibly even differences in growth on two sides of the same tree. Here a larger sample size would be necessary in order to obtain a reliable chronology.

The procedure of standardization is basic to dendroclimatology. Systematic changes in ring-width that are associated with age are removed from the measurements and the transformed values are called ring-width indices. Indices generally have no linear trend, with a mean value of one. The large variability in ring-width of young fast-growing portions of a tree are comparable to the lower variability in the ring-width of the older and slower-growing portions of the tree. Standardized indices from individual trees are then averaged to yield a mean chronology for a sampled site.

Models of growth-environment relationships are based upon some idea of how the environment affects growth. Various types of models serve as hypotheses which can be checked by comparison with information obtained from observation. A mathematical model, or response function, which describes tree growth serves as a linkage between the inputs and outputs of the system. Models must often be revised when new information contradicts the model relationships. The model may be accepted when there is a close resemblence with actual relationships.

2.3 Applications in Dry and Cold Environments

A small number of researchers have applied the principles, concepts and methodologies of Fritts (1976).

Fritts, Lofgren and Gorden (1979) have calibrated spatial anomalies of western North American tree-ring records with those in North American meteorological records. They have developed multivariate transfer functions to scale and convert spatial variation in tree-ring records since the early 17th century into estimates of past variation in seasonal temperature, precipitation and sea-level pressure over the North American and North Pacific sectors.

Stockton and Fritts (1973) have reconstructed long-term water level changes for Lake Athabasca through an analysis of white spruce tree-rings growing on natural levees of the channels of the delta region of the lake. The 33 year record of lake level changes was found to correlate well with water levels in the channels. The record of lake levels was extended to 158 years for late May, early July and late September.

Jacoby, Cook and Ulan (1985) have reconstruted June and July degree-days in central Alaska and northwestern Canada from 1524. Their samples were taken from the long-lived white spruce species, a species which often exhibits temperature sensitive ring-width variations.

Fritts (1962), Schulman and Bryson (1965) and Estes (1970) have shown the growth of oak trees in the midwest to be affected by climatic variables.

Duvick and Blasing (1981) sampled white oak trees from three sites in central Iowa and found the ring-width indices to be good indicators of precipitation over a 300 year period. They found that individual growth-rings were strongly influenced by precipitation over a period of about one year prior to the stoppage in radial growth. This period began in July or August of one year and extended to the next June or July.

Stockton and Meko (1983) have, through tree-ring analysis, reconstructed a history of drought from 1700 to present in four regions flanking the Great Plains; Iowa, Oklahoma, Eastern Montana and eastern Wyoming.

2.4 Other Applications

In a more humid environment, Cook and Jacoby (1977) have shown the relationship between tree-ring indices and a drought index in the Hudson Valley, New York while Cook and Jacoby (1983) have reconstructed Potomac River streamflow by using tree-ring chronologies from sites in or near the river basin. Each of these investigations used the same general principles, concepts and methodologies as outlined by Fritts (1976).

Ashby and Fritts (1972) employed principal components analysis and stepwise multiple regression analysis to determine the relationship of white oak growth to climate in northern Illinois-Indiana. Monthly temperature and precipitation variables were found to account for 59% of the growth variance in the 55 year ring-width chronology while prior growth accounted for an additional 2% . Their study indicated that a reduction in growth in the LaPorte area during the 1940's may have been related to high levels of smoke haze reported in Chicago during that decade.

La Marche et al. (1984) have considered the possibility of accelerated natural vegetation growth due to increased atmospheric carbon dioxide concentrations. They feel they may have detected this in the annual growth-rings of subalpine conifers growing in the western United States. They have observed greatly increased tree growth since the mid-19th century to be consistent in magnitude with increases in global carbon dioxide, especially in recent decades. Also, laboratory experiments have shown that carbon dioxide can be an important limiting factor in the growth of C3 plants (Carter and Peterson, 1983; Kramer, 1981).

Puckett (1982) utilized tree-ring indices from white pine, eastern hemlock, pitch pine and chestnut oak in order to determine the relationship of tree growth to climate in southeastern New York state. Changes in the derived relationship through three specified time intervals corresponded with suspected increases in acid rain and air pollution in the area in the early 1950's. He suggested that the change might be the result of physiological stress due to increased pollutants which in turn cause climatic conditions to be more limiting to tree growth.

Phipps (1982) and Cook, Conkey and Phipps (1982) disussed the problems in developing climatically sensitive tree-ring chronologies from eastern North America. Problems are discussed with site and species selection as well as those involved in the removal of growth and competition trends through standardization of individual chronologies and merging of several chronologies, respectively. Because tree-ring collections from eastern forests are not as sensitive as those from western collections they conclude that the greatest potential for dendroclimatological studies in eastern deciduous forests lies in the better resolution of local climatic conditions, in estimating hydrologic variables such as streamflow and in examining climatically related variables such as air pollution and acid rain.

This study offers an opportunity to increase the present knowledge of both local and regional environmental change. Information derived from such an analysis could prove to be valuable in many respects. There is no documented history of the responses of natural vegetation to either natural or human change in the entire area. Also, derived changes in microclimatic and mesoclimatic regimes might be incorporated into both local and regional models of environmental change.

CHAPTER III

THE ST. CLAIR RIVER DELTA

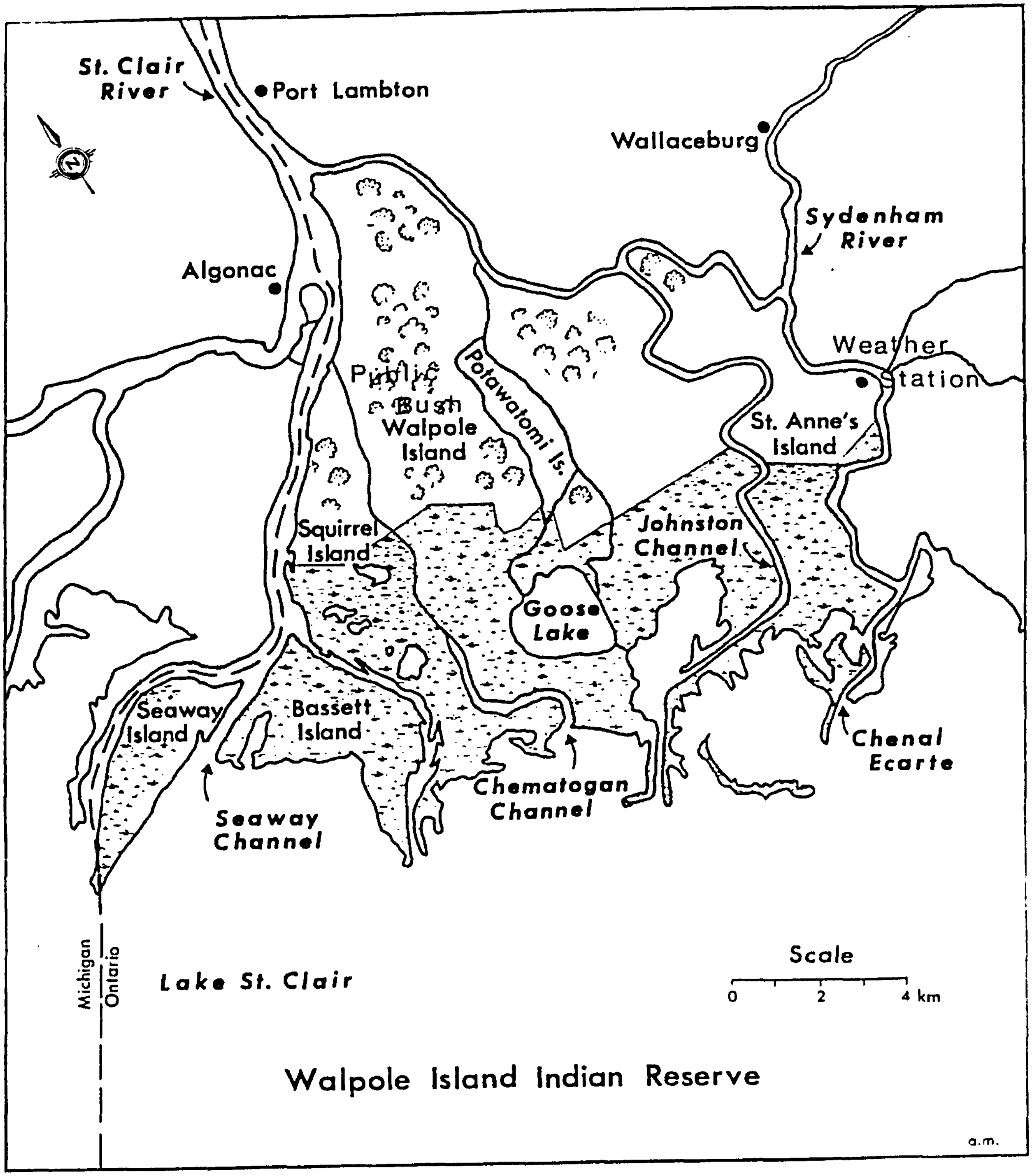
3.1 Introduction

The St. Clair River delta represents an important location with respect to changing local and regional environmental conditions. The rare and naturally preserved Carolinian forest of Walpole Island, located in the eastern portion of the delta, has been designated as a portion of an environmentally sensitive area. It has also been targeted as a realistic alternative energy source for the people of the Island. A more thorough knowledge of human-forest-climate interactions would improve conservation and management techniques aimed at maximizing the economic, social, aesthetic and ecological value of the resource.

The Walpole Island Indian Reserve and individuals from the Reserve own and provide administration for approximately 16,000 hectares of land on the Canadian side of the St. Clair River delta. As can be seen in Figure (3.1), the Reserve consists of five large delta islands situated at the mouth of the St. Clair River . They are Walpole, Squirrel, Bassett, Seaway and St. Anne's islands.

FIGURE (3.1)

Walpole Island and the St. Clair River Delta



3.2 Physical Geography

The following descriptions of the St. Clair River delta are outlined in Wightman (1962). The delta is a large sand depositional feature built out onto Lake St. Clair from the mouth of the St. Clair River and lies in a large clay basin which is bordered in Michigan and Ontario by much older moraines. Water flowing from the Huron to Erie basins during the Lake Algonquin stage about 8000 years ago built a delta at the mouth of the St. Clair River. This delta was subsequently destroyed by waterfalls in the basin during the Lake Stanley low period. During the Lake Nipissing stage, about 4000 years ago, a second delta was formed. The present delta incorporates this and remnants of the first delta in its head. Today, it receives little or no material from the St. Clair River although the fall in lake level due to the downcutting of the Detroit and St. Clair Rivers gives it an appearance of continued growth. The islands of Walpole and St. Anne's have not shown any signs of activity for some period of time. Both of these islands are slightly higher and drier than Bassett and Squirrel Islands.

Walpole Island can be divided into subaerial and subaqueous deltas. The subaerial delta can be further subdivided into dry and wet portions. The dry delta is any portion of the delta which slopes gradually from the high head towards the lake level. The wet delta begins where the sloping surface is so close to the water table or lake surface that it is saturated but not submerged. The average gradient for the delta is 0.27 meters per kilometer.

These minor differences in elevation are of major importance in the effect on the distributions of both soils and vegetation. There are three classes of soils on the delta formed from the same basic materials, sand and silt. The dry delta has a fine sandy loam while the wet and subaqueous portions of the delta have progressively sandier soils. On high delta land, where the water table is a few meters below the surface, a hardwood Carolinian forest of primarily oak, ash, maple and elm has developed. The limits of this forest, where cutting has not taken place, are distinct. As soil moisture content increases the forest yields to areas of grass and sedges. At the water's edge this changes rapidly to cat-tails and reeds.

The channels on the delta are in constant competition for dominance. This has resulted in numerous abandoned distributaries, which are now classified as wet delta, within the dry delta area. The rate of growth, size and activity of the delta channels generally increases from the Ontario eastern portion to the Michigan western portion. However, the artificial deepening of the South Channel, which delimits the western boundary of Walpole

Island, and the St. Clair River for the St. Lawrence Seaway has somewhat reduced this west-east gradient in channel activity. The connection between soils, vegetation and moisture availability on Walpole Island is quite distinct. Any alterations in moisture availabilty through time should be evident on the growth patterns of the local natural vegetation.

3.3 The Walpole Island Reserve

Extensive rural and residential development has occurred on the Reserve. Much of the land area is under cultivation for corn and there has been extensive drainage diking and channel improvements. The forested area of the Reserve is divided into both private and public ownership. The public bush area is located in the north-central area of Walpole Island as can be seen in Figure (2). Fire breaks were recently cut as a safety measure and drainage ditches were dug to alleviate flooding problems.

Carolinian Canada, a conservation program initiated in 1984 under the Ontario Heritage Foundation, has included the sensitive complexes of Walpole Island as one of the 36 outstanding natural areas in the Carolinian life zone of Canada, a small area in the extreme southwestern portion of Ontario. Its prime objectives are for the protection and management of these significant and natural areas of Ontario. Non-purchase methods, or cooperation with the people of the Reserve, are felt to be necessary in order to meet their goals.

The Band Office is now conducting a variety of programs and studies to develop energy, agro-forestry and recreational opportunities. The newly established NIN-DA-WAAB-JIB or "those who seek to find" cooperative research program engages personnel from the Walpole Island Band Community, the University of Windsor and the Ontario Ministry of Natural Resources. A forest management and job creation program has been initiated through both private and public funding.

Andresen (1984) provides details of a 1983 study concerned with a Walpole Island energy profile. The major energy demand on the Island is for space heating. The forest bimass provides an accessible energy source and appears to be the best energy resource to satisfy expected increases in demand. The current forest management program and improved silvicultural practices should improve forest productivity and regeneration.

CHAPTER IV

METHODS AND PROCEDURES

4.1 Introduction

The data required in this analysis were tree growth measurements and climatic and climatically related environmental variables. Each data set was then averaged and transformed for the purposes of the analysis. It was extremely important to strictly adhere to procedures which ensured the correct collection and processing of the tree ring and climatic data. This began with a clear definition of the pertinent study variables, an effective sampling design and field plan and a justifiable mode of analysis to assess the hypothesis.

4.2 Dependent Variables

Two separate dependent variables were considered in this investigation. They were annual tree-ring width and annual tree-ring area. This was done in order to test the similarity between the derived indexes and also to determine if a ring-area index might be more sensitive to the selected environmental variables.

The public bush area of Walpole Island was felt to be the most climatically sensitive available area of the delta from which to sample trees. Phipps (1982) stresses that the most important factor in sample site selection is the degree to which growth is limited by environmental factors, not whether the site is normally wet or dry. There has been success in deriving climatically sensitive collections in temperate subhumid areas by using sites of soil water discharge such as swamps and wetlands. Phipps et. al. (1979) found a direct correlation between precipitation and growth of selected trees in swamps. Although the public bush area of Walpole Island is relatively one of the driest sites on the delta, it can still be classed as a seasonally wet site. Even with the construction of drainage ditches in 1982-83, the drainage of surface water during the spring and summer months is slow. Phipps (1982) claims that wet site tree species are relatively more sensitive to dry conditions than are dry site tree species. During drought the root systems may be left high and dry. Also, during very wet conditions there is reduced root growth through lower respiratory gas exchange and accompanying negative effects on above ground growth.

A total of forty core samples were removed from twenty trees of three different species growing in the public bush of Walpole Island in October, 1985. These three species were northern red oak (Quercus rubra), white oak (Quercus alba) and sugar maple (Acer saccharum). In order to retain a more or less constant genetic response only one particular species, red oak (Quercus rubra), was further analyzed.

Spurr and Barnes (1973) describe the physiology and ecology of the oak genus in general and red oak in particular. The oaks are a widely distributed Northern Hemisphere species. They normally occupy dry sites from the southern edge of the boreal forest and extend well into the tropics. Oak bark is thick and quite fire-resistant. The oaks show a wide diversity in morphology and thus a wide tolerance of ecological conditions. They are primarily deep-rooted xerophytes but some species have become adapted to mesic and even hydric conditions. Red oak has adapted to a wide range of sites and conditions but attains its maximum development under mesic conditions. Kramer and Kozlowski (1960) state that this species has an intermediate tolerance to endure shade. Northern red oaks also have a high tolerance to various air pollutants. Davis and Wilhour (1976) and Smith (1981) report that this species shows tolerance to acute damage by sulfur dioxide, ozone and PAN (peroxyacetylnitrate) exposure under laboratory conditions.

It was felt that the red oaks were the most climatically sensitive of the species sampled from the public bush. A tree of this species growing on the northern limits of its range on a semi-hydric site but in relatively well-drained sandy loam soil, such as Walpole Island, should be more susceptible to changing environmental conditions than the same tree growing on a more mesic site well within its range. In addition, the tolerance of the species to both shade and air pollutants should dampen the non-climatic noise apparent in many species (Fritts, 1976).

The sampling design was deliberately stratified in order to maximize the climatic information from the population. Overstory, rather than understory, trees were sampled since the public bush is a closed canopy site with a moderate degree of crown crowding. This method of sampling gave preference to older trees where effects of competition with nearby trees was minimal. A Swedish increment borer was used to remove two core samples at breast height from opposing radii of each tree. This replication in sampling, from a north and a south exposure, was done to allow for statistical comparisons of variability in the same tree. If climate is a limiting factor then the same ring-width variations should be evident in each core.

A number of fire breaks were cut in the public bush during the winter of 1983-84 as part of the forest management program. A large number of tree slabs cut from the tops of tree stumps of a variety of tree species were saved for various interests. Ten of the best red oak slabs were selected in order to compare and to possibly supplement the red oak cores taken for this study. The replication principle was adhered to by marking opposite radii on each slab to be measured. This was done in the absence of any knowledge of a north or south exposure.

Each core or slab was dried, mounted and sanded and the rings were crossdated from the outermost ring at 1985 for the cores and 1983 for the slabs to the innermost ring which was formed a variety of years earlier. The distinct nature of the growth rings and the consistent occurrence of wide or narrow rings provided the initial check for the crossdating technique. For example, rings for 1980, 1966 and 1942 were consistently wide while rings for 1954, 1950, and 1934 were consistently narrow. After each ring was dated the widths were measured to the nearest 0.025 mm with a binocular microscope. Both earlywood and latewood widths for a given growth year were measured and all data were entered on microcomputer disk. The original ring-width measurements and mean tree calculations for the 17 red oak trees are provided in Appendix A. Table (4.1) shows tree ages and correlation coefficients between corresponding ring-widths from opposing radii for each red oak tree measured. Distinct differences in growth on opposite sides of the same tree were expected if climate were not highly limiting to growth. Tree sixteen was

TABLE (4.1)

Tree Age and Correlation Coefficients Between Corresponding Ring-Widths from Opposing Radii for each Red Oak Tree Measured

Tree Number	Tree Age (Years)	Correlation Coefficient
1	56	0.633
2	79	0.901
3	88	0.532
4	55	0.491
5	51	0.765
6	90	0.492
7	63	0.861
8	68	0.607
9	49	0.810
10	60	0.750
11	60	0.682
12	68	0.913
13	72	0.469
14	61	0.857
15	49	0.928
16	36	0.425
17	54	0.639

All correlations highly significant at $P < 0.01$ with the exception of Tree # 16 at $P < 0.025$.

deleted from further analysis due to a combination of low correlation and young age.

4.2.1 Ring-Width Chronology

The two sets of ring-widths were then averaged for each of the remaining trees to yield a set of mean ring-widths for each tree. The keypunching and dating were checked by overlaying graphs from different trees and observing the consistent occurence of wide and narrow rings.

The ring-widths from each tree were then converted to ring-width indices by the process of standardization (Fritts, 1976). This was done in order to remove systematic changes in ring-width, or the growth trend, due to the increasing age of the tree. The resultant standardized ring-width chronologies can then be examined with the trend removed and a mean and variance that is more homogeneous with respect to time. This was accomplished by applying the best-fit exponential or quadratic curve to the data. For example, Figure (4.1) and Figure (4.2) show the ring-width series' and the best-fit quadratic curve for red oak trees two and three, respectively. Once the appropriate curve equation was developed it was solved for the expected yearly growth (Yt). Measured ring-widths were then converted to ring-

FIGURE (4.1)
RING-WIDTH SERIES WITH EXPECTED
GROWTH FROM QUADRATIC SMOOTHING
FOR RED OAK TREE TWO

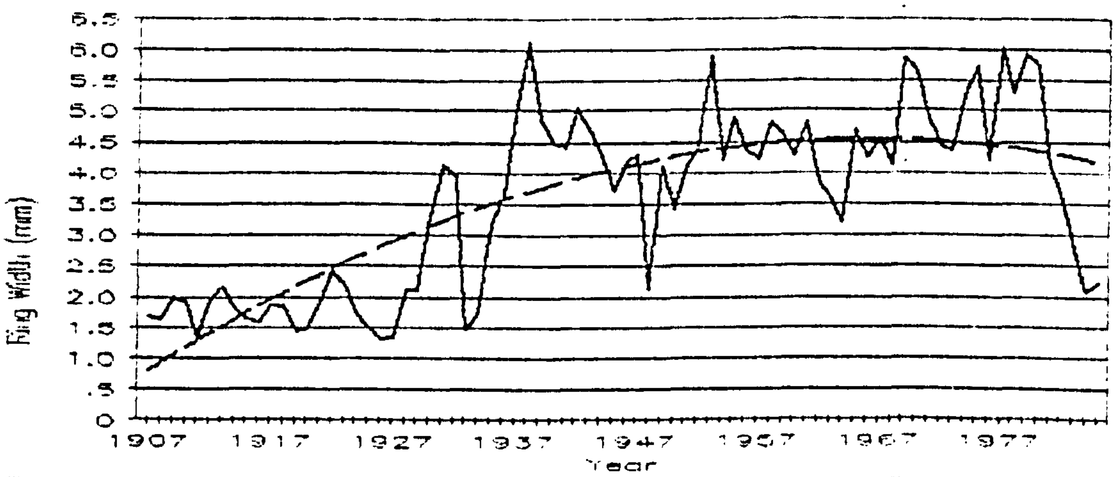
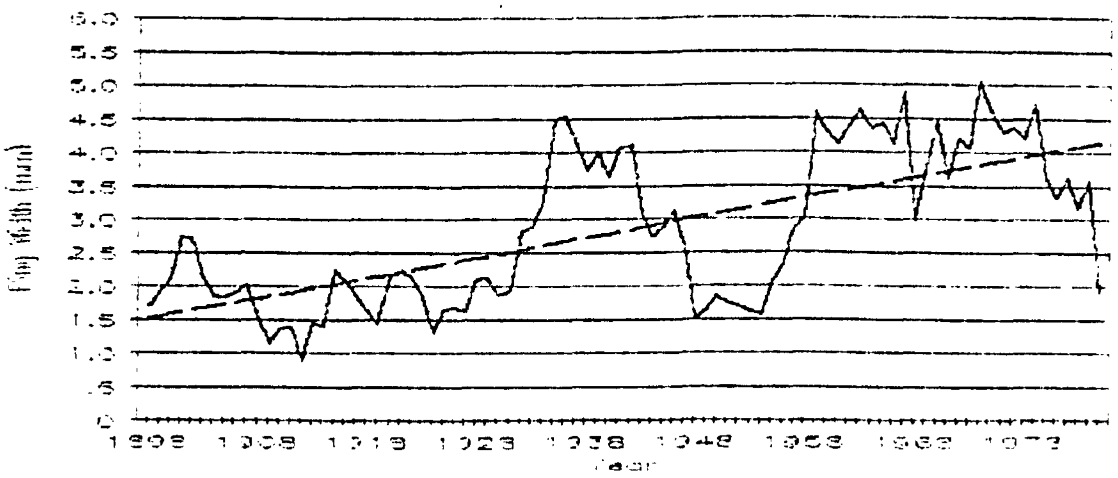


FIGURE (4.2)
RING-WIDTH SERIES WITH EXPECTED
GROWTH FROM QUADRATIC SMOOTHING
FOR RED OAK TREE THREE



width indices (It) by dividing each width for each year t (Wt) by the expected yearly growth from the growth curve.

Figures (B1-B16) in Appendix B show actual ring-widths and expected growth from the best-fit curve for the 16 remaining trees. Table (4.2) shows the correlation matrix between the standardized ring-width indices for each tree for the period 1935 to 1983. Trees 1-7 represent core samples while trees 8-17 represent slab samples. Some measure of intercorrelation was expected in order to retain a given sample. As a result tree 15 was deleted from further study due to the persistence of negative correlations.

Table (4.3) shows the statistics of the remaining 15 ring-width series and their indices. The mean sensitivity statistic measures the relative difference in width from one ring to the next. Average mean sensitivity for a series is calculated as

$$ms_x = \frac{1}{n-1} \sum_{t=1}^{t=n-1} \left| \frac{2(x_{t+1} - x_t)}{x_{t+1} + x_t} \right|$$

where x_t is each datum and the vertical line is the absolute value of the enclosed term. Values range from zero where there is no difference to a value of two where there is maximum difference. Mean sensitivity values for

TABLE (4.2)

Correlation Matrix of Standardized Ring-Width Indices for each Red Oak Tree for the Period 1935 to 1983

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	17
1	1	.40	.65	.22	.65	.23	.61	.20	.27	.50	.47	.45	.50	.32	-.39	.30
2	-	1	.31	.65	.36	.36	.59	.46	-.02	.17	.31	.68	.27	.45	-.23	.21
3	-	-	1	.22	.55	.24	.59	.38	.13	.62	.22	.47	.24	.16	-.12	.03
4	-	-	-	1	.40	.23	.58	.61	-.20	.10	.30	.56	.22	.30	-.11	.39
5	-	-	-	-	1	.33	.53	.26	.11	.56	.48	.43	.28	.40	-.45	.24
6	-	-	-	-	-	1	.37	.05	.31	.33	.35	.40	.32	.39	-.12	.13
7	-	-	-	-	-	-	1	.45	-.10	.25	.40	.79	.50	.35	-.27	.33
8	-	-	-	-	-	-	-	1	-.20	.19	.22	.46	.02	.24	.01	.33
9	-	-	-	-	-	-	-	-	1	.25	.18	.22	.32	.20	.27	-.33
10	-	-	-	-	-	-	-	-	-	1	1	.16	.17	.42	-.24	.06
11	-	-	-	-	-	-	-	-	-	-	1	.40	.36	.82	-.19	.10
12	-	-	-	-	-	-	-	-	-	-	-	1	.17	.43	-.31	.17
13	-	-	-	-	-	-	-	-	-	-	-	-	1	.24	-.12	.02
14	-	-	-	-	-	-	-	-	-	-	-	-		1	.02	.02
15	-	-	-	-	-	-	-	-	-	-	-	-		-	1	-.32
17	-	-	-	-	-	-	-	-	-	-	-	-		-	-	1

TABLE (4.3)

Ring-Width and Index Statistics for Remaining 15 Trees

Tree	Mean Width		Std. Deviation		First Order Autocorrelation		Mean Sensitivity	
	Actual (mm)	Index (mm)	Actual (mm)	Index (mm)	Actual	Index	Actual	Index
1	2.94	1.00	1.14	0.33	0.86	0.77	0.17	0.16
2	3.55	1.02	1.44	0.32	0.84	0.72	0.18	0.19
3	2.83	1.00	1.16	0.31	0.89	0.81	0.15	0.15
4	2.61	1.00	0.63	0.23	0.49	0.40	0.21	0.21
5	3.16	1.04	0.81	0.27	0.54	0.55	0.18	0.18
6	2.77	1.01	0.88	0.27	0.68	0.61	0.19	0.19
7	3.02	1.01	1.21	0.31	0.82	0.62	0.22	0.22
8	2.50	1.00	0.91	0.28	0.82	0.63	0.17	0.17
9	2.71	1.13	1.41	0.56	0.61	0.50	0.39	0.39
10	4.44	0.99	2.24	0.30	0.82	0.54	0.24	0.23
11	3.37	1.00	1.22	0.18	0.85	0.46	0.16	0.16
12	2.71	1.08	1.92	0.43	0.89	0.66	0.24	0.24
13	3.77	1.00	1.43	0.33	0.78	0.73	0.19	0.19
14	3.44	1.01	1.29	0.21	0.85	0.60	0.16	0.16
17	1.50	1.01	0.62	0.33	0.58	0.33	0.27	0.27
15 Tree Mean	3.02	1.02	1.22	0.31	0.75	0.60	0.21	0.21

ring-width measurements of Walpole Island red oak trees are slightly lower than those for western North America conifers (Fritts, 1976) but are slightly higher than those for eastern North America _Quercus_ _stellata_ (Phipps, 1982).

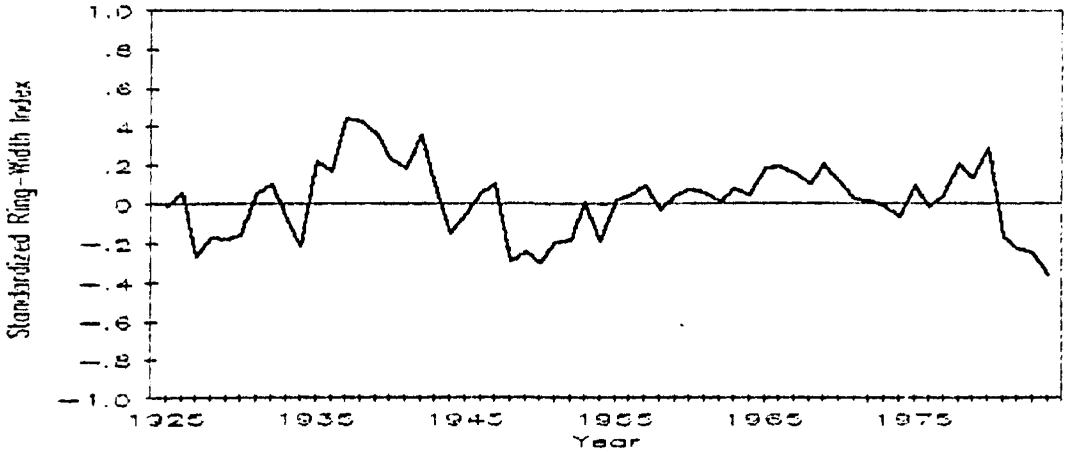
The remaining 15 trees were comprised of seven core samples (tree one to tree seven) and eight slab samples (tree eight to tree fourteen and tree seventeen). The youngest tree was 49 years old while the oldest tree was 90 years old. The mean tree age was 65.6 years old. Each ring-width series was next analyzed for a period of change from low growth to more rapid growth early in its life. The years prior to this change in growth pattern were subjectively deleted under the assumption that an individual tree was more under the influence of local competition factors than regional environmental conditions during this early stage of its growth. For example, indices for tree two were retained from 1930 and those for tree three were retained from 1932. Table (4.4) shows the years retained after the exclusion of the years prior to accelerated growth for all of the remaining chronologies. The derived indices were then averaged to yield a single mean red oak ring-width chronology for the public bush of Walpole Island. This merging technique eliminates much of the competition trend present in individual trees (Phipps, 1982). Figure (4.3) shows the mean ring-width chronology for the period 1925 to 1984.

TABLE (4.4)

Years Retained After Exclusion of Years Prior to Accelerated Growth for Both the Ring-Width and Ring-Area Chronologies

Tree Number	Tree Age (Years)	No. of Years Retained	Period
1	56	50	1936-85
2	79	56	1930-85
3	88	54	1932-85
4	55	51	1935-85
5	51	51	1935-85
6	90	64	1921-85
7	63	54	1931-85
8	68	65	1919-83
9	49	28	1956-83
10	60	52	1932-83
11	60	49	1935-83
12	68	54	1930-83
13	72	67	1917-83
14	61	47	1937-83
17	54	46	1938-83

FIGURE (4.3)
MEAN RING-WIDTH CHRONOLOGY FOR 15 WALPOLE ISLAND RED OAK TREES FOR THE PERIOD 1925 TO 1984



4.2.2 Ring-Area Chronology

The mean area of each annulus was calculated for each tree. This was accomplished by applying the following formula to the mean set of ring-widths for each tree,

$$A_x = \pi(r_x^2 - r_{x-1}^2)$$

where A_x is the mean area of each annulus, $\pi = 3.14159$ and r_x is the radius from the centre of the tree to the desired annulus and r_{x-1} is the radius from the centre of the tree to the previous annulus.

The growth patterns of the ring-area chronologies were similar to their corresponding ring-width chronologies but characterized by more year-to-year variations. The individual growth patterns did approximate a logistic-type growth curve. However, the nature and magnitude of the oscillations present made standardization by either logistic curve or simple exponential or quadratic curve difficult. Repeated attempts at standardization by these methods did not significantly reduce the autocorrelation due to the growth trend which was present in each individual series. Warren (1980) experimented with an incremental polynomial function to account for accelerated growth as a result of release at various times in the tree's history. Cook and Peters (1981) described a technique to remove non-climatic variance in a trees growth using the smoothing spline. They argued that the method was superior to orthogonal polynomial functions because no preliminary assumptions were made as to the shape of the curve which eventually was to be used for standardization. Aubanel and Oldham (1985) outlined a method for fitting a curve to a series of data by employing Fourier smoothing without the fast Fourier transform. This method of smoothing data is not a fast fourier transform but shares many of its advantages. It uses the sine and cosine functions and replaces the high number of multiplications required with additions. It is readily applicable to regularly spaced data and provides a better degree of fit to the end points of a data series. It is designed to eliminate the high frequency portion of the spectrum, or the noise in a data series, while accentuating the signal or the low frequency portion of the spectrum.

The Fourier smoothing method was employed to approximate the growth trend in individual trees. The algorithm outlined by Aubunal and Oldham (1985) allows for user input pertaining to the degree of smoothing required. This provided an attractive alternative to the above mentioned techniques. Standardization by dividing the actual ring-area by the area expected from the growth curve accentuated variations not related to tree growth. For example, Figure (4.4) and Figure (4.5) show the actual area of annulus series' with expected growth from Fourier smoothing for red oak trees two and three, respectively. Figures (B17-B32) in Appendix B show actual ring-areas and their accompanying growth curves as generated by the Fourier smoothing routine. Table (4.5) shows the correlation matrix between the standardized ring-area indices derived for each tree for the period 1935 to 1983. Tree 15 was again deleted from further study due to the persistence of negative correlations. The same 15 trees were retained to develop the ring-area chronology that were used to develop the ring-width chronology. Table (4.6) shows the statistics of the remaining 15 ring-area chronologies and their indices. The mean sensitivity values for the ring-area measurements are higher than those found for the ring-widths and are comparable to those found for western North America conifers (Fritts, 1976). The times of accelerated growth are much more pronounced in most of the ring-area chronologies but occurred at the same time as in the ring-width chronologies. As a result, the same years were retained, as seen in Table (4.1), for further analysis. Figure (4.6) shows the mean ring-area chronology for the period 1925 to 1984.

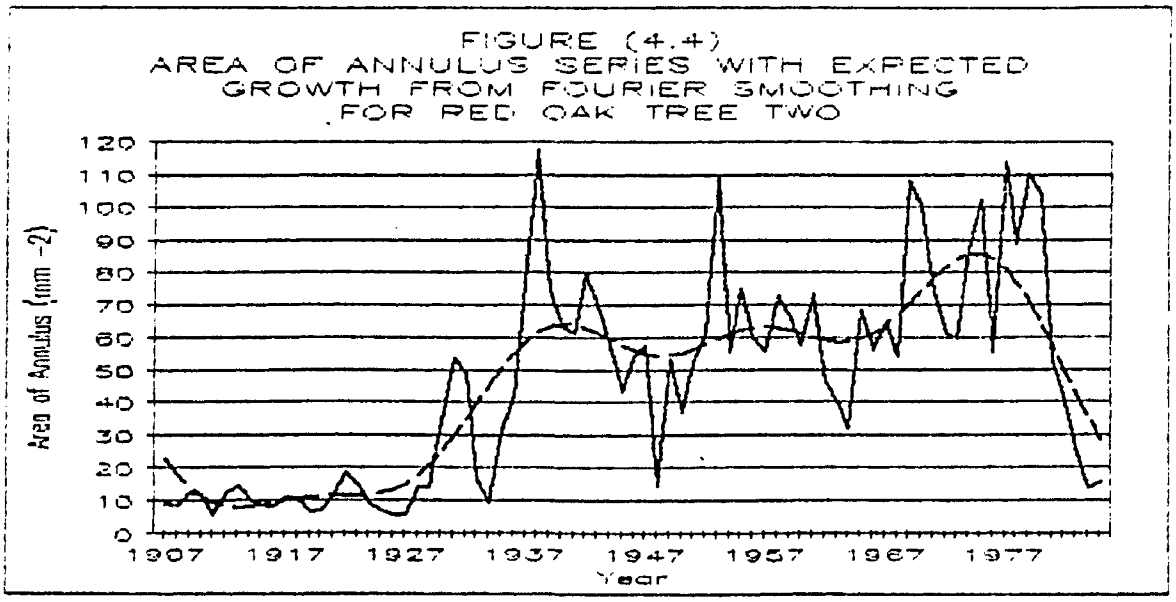


FIGURE (4.4)
AREA OF ANNULUS SERIES WITH EXPECTED GROWTH FROM FOURIER SMOOTHING FOR RED OAK TREE TWO

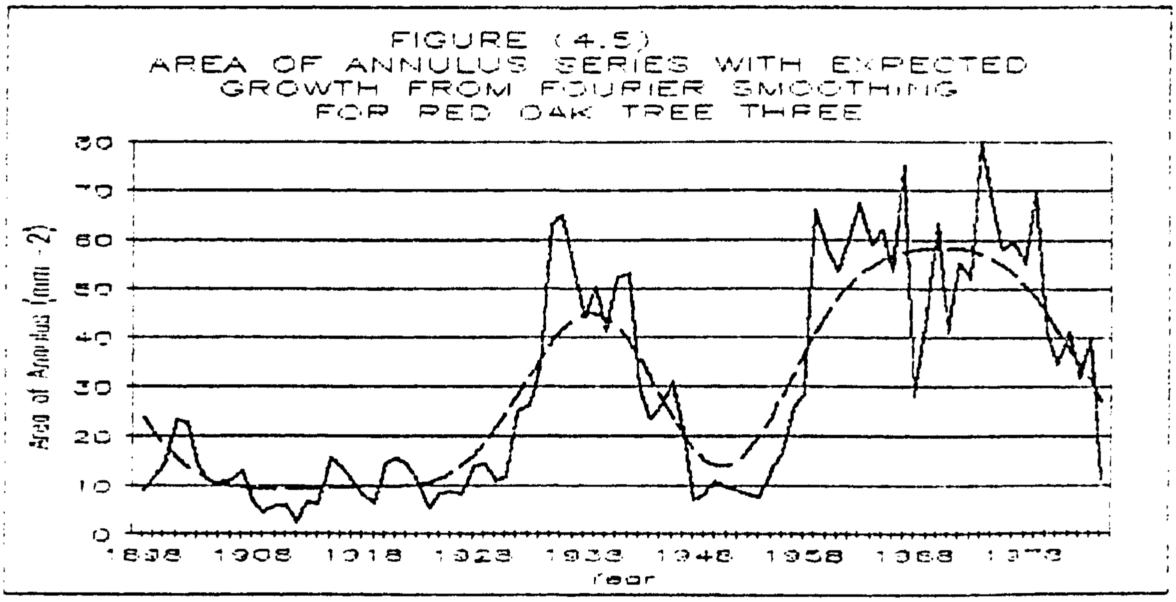


FIGURE (4.5)
AREA OF ANNULUS SERIES WITH EXPECTED GROWTH FROM FOURIER SMOOTHING FOR RED OAK TREE THREE

TABLE (4.5)

Correlation Matrix of Standardized Ring-Area Indices for each Red Oak Tree for the Period 1935 to 1983

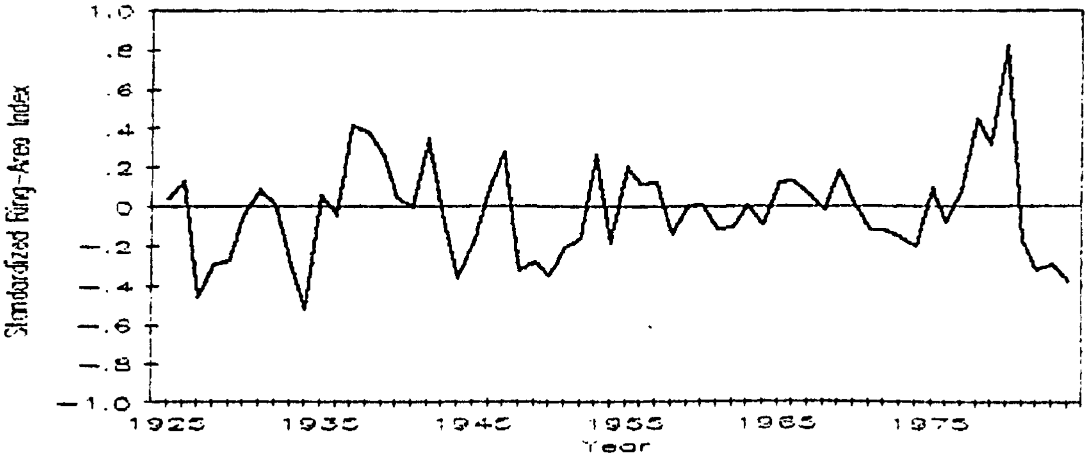
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	17
1	1	.49	.16	.29	.29	.25	.35	.25	.42	.14	.48	.37	.50	.42	.11	.20
2	-	1	.04	.55	.33	.41	.56	.46	.03	.12	.30	.53	.48	.49	.03	.42
3	-	-	1	.07	.23	.17	.00	.02	.04	.41	.04	-.03	-.01	.09	-.29	-.16
4	-	-	-	1	.47	.36	.62	.61	-.07	.03	.33	.44	.51	.32	-.15	.60
5	-	-	-	-	1	.53	.37	.28	.17	.40	.45	.24	.25	.47	-.14	.30
6	-	-	-	-	-	1	.35	.38	.09	.35	.41	.38	.34	.42	-.21	.27
7	-	-	-	-	-	-	1	.57	-.20	.01	.39	.66	.53	.41	-.15	.39
8	-	-	-	-	-	-	-	1	-.16	-.03	.46	.51	.48	.45	-.34	.56
9	-	-	-	-	-	-	-	-	1	.09	.17	-.17	-.01	.10	.46	-.13
10	-	-	-	-	-	-	-	-	-	1	.34	.02	.11	.41	-.13	-.04
11	-	-	-	-	-	-	-	-	-	-	1	.47	.27	.81	.00	.33
12	-	-	-	-	-	-	-	-	-	-	-	1	.42	.53	-.18	.25
13	-	-	-	-	-	-	-	-	-	-	-	-	1	.28	-.22	.26
14	-	-	-	-	-	-	-	-	-	-	-	-		1	.00	.22
15	-	-	-	-	-	-	-	-	-	-	-	-		-	1	.08
17	-	-	-	-	-	-	-	-	-	-	-	-		-	-	1

TABLE (4.6)

Ring-Area and Index Statistics for Remaining 15 Trees

Tree	Mean Area		Std. Deviation		First Order Autocorrelation		Mean Sensitivity	
	Actual (mm^2)	Index (mm^2)	Actual (mm^2)	Index (mm^2)	Actual	Index	Actual	Index
1	31.17	0.94	22.45	0.33	0.81	0.32	0.32	0.30
2	46.11	0.97	32.23	0.38	0.77	0.38	0.35	0.36
3	29.32	0.95	21.96	0.35	0.86	0.53	0.29	0.29
4	22.58	0.99	10.55	0.41	0.47	0.31	0.40	0.40
5	33.39	0.98	15.47	0.38	0.51	0.20	0.35	0.35
6	26.54	0.99	16.53	0.41	0.62	0.34	0.36	0.36
7	33.18	0.95	23.94	0.41	0.82	0.40	0.41	0.41
8	22.21	0.98	16.17	0.36	0.79	0.00	0.33	0.32
9	29.16	0.98	30.25	0.73	0.47	0.38	0.71	0.70
10	77.42	0.92	77.22	0.44	0.78	0.32	0.46	0.42
11	40.21	0.97	25.13	0.33	0.81	0.27	0.31	0.31
12	34.51	0.95	48.11	0.68	0.83	0.51	0.44	0.47
13	50.93	0.94	36.49	0.41	0.72	0.39	0.37	0.35
14	42.26	0.96	25.56	0.35	0.79	0.36	0.31	0.32
17	8.27	0.99	6.55	0.69	0.43	0.23	0.50	0.51
15 Tree Mean	35.15	0.98	27.24	0.44	0.70	0.33	0.40	0.39

FIGURE (4.6)
MEAN RING-AREA CHRONOLOGY FOR 15 WALPOLE ISLAND RED OAK TREES FOR THE PERIOD 1925 TO 1984



4.3 Independent Variables

The independent variables considered were the important climatic and climatically related environmental variables in the climate-plant system, temperature, precipitation, sunshine, lake levels and prior growth. Data describing temperature, precipitation and sunshine for a number of stations surrounding the St. Clair River delta were obtained from Atmospheric Environment Service in Toronto. A limited number of temperature and precipitation measurements from a farm location on St. Anne's Island, situated in the eastern portion of the delta, as can be seen in Figure (3.1), were used in order to compare and adjust the regional record to that of the delta. Mean monthly temperatures, and total monthly precipitation were used for each growing season. One year of prior growth was used to account for autocorrelation in the ring-width and ring-area mean chronologies.

Stations used for a regional temperature and precipitation analysis were St. Anne's, Sarnia, Wallaceburg, Chatham, Courtright, Petrolia, Ridgetown, Windsor and Woodslee. The shortest of these records was St. Anne's with 13 complete months of daily temperature values and 22 complete total monthly precipitation values for various months from 1982 to 1984. The longest records were from Wallaceburg and Ridgetown, beginning in the

1920's. Longer records were available from Chatham and Wallaceburg but many missing values and changes in observation sites made these records unreliable. The Ridgetown observation site, the Western Ontario School of Agriculture situated about 1.5 km east of the town, had few missing values and was felt to be the most reliable of the longer term records. On the other hand, the Wallaceburg observation site, at a factory in an industrial area near the town centre, had a number of missing values especially during the 1960's. The instruments at this location have a relatively poor exposure today.

All missing monthly values for all stations from 1924 to 1984 were estimated by multiple linear regression with the other stations in the area. In the case of a few missing values in the earlier portion of the Wallaceburg record bivariate linear regression with the Ridgetown record was used. Complete coverage became available for all of the above mentioned stations, excluding St. Anne's, from 1975 for temperature and from 1970 for precipitation.

Thirteen mean monthly temperature values for St.Anne's were correlated with coresponding values for all other stations. Correlation coefficients with Wallaceburg and Ridgetown were the best at $r = 0.997$. Multiple linear regression was used to estimate monthly St. Anne's records from these two stations for the period 1925-84.

The St Anne's Island precipitation gauge is a Belfort type recording rain gauge. Gauges at all other stations are Standard Canadian rain gauges. The Belfort type gauge is taller than the Canadian gauge and it is believed that because of wind turbulence they undercatch precipitation (Griffiths, 1966). In addition, there are some drawbacks in the location of the gauge that might make it unrepresentative of precipitation over the entire delta. St. Anne's Island is located on the easternmost portion of the delta and is comprised mainly of land cleared for agriculture, a considerably different surface cover than elsewhere on the islands of the delta. The presence of Lake St. Clair provides a further complicating factor. The influence of the lake on the precipitation pattern of the delta might not be accurately represented by a single guage. However, the data from St. Anne's were considered useful, particularily over the monthly time period required for this study, due to the relatively small size of the area and the lack of topographical variation.

Twenty-two total monthly precipitation values from St. Anne's were correlated with coresponding values for all other stations. This was done for all months except December, January and February as there were no St. Anne's values for these months. Correlation coefficients ranged from r = 0.430 for Sarnia and r = 0.934 for Dresden. Correlation with the Wallaceburg record was only r = 0.551. Good correlations were found with most of the other stations, the best being Dresden and Ridgetown (r = 0.891), Courtright (r = 0.746), and Chatham (r = 0.717). Multiple linear regression was used to estimate St. Anne's precipitation for the months March to November from these four stations for the period 1970 to 1984. The 15 year monthly estimates were next regressed with the corresponding monthly values for Ridgetown and Wallaceburg to provide monthly equations to estimate St. Anne's precipitation to 1925.

A long record of total bright sunshine hours (1919-85) has been kept at the Harrow Agricultural Research Station near Lake Erie. The only other station in the entire region to measure this variable is Sarnia, but for a much shorter period (1969-85). Monthly values were compared for each station and no spatial trend was apparent during any month in the data. A simple averaging technique was felt to be the best estimate of Walpole Island sunshine for the 1969-85 period since its location is about midway between the two stations. Individual monthly estimates were then regressed with the known Harrow values to extend the estimated Walpole Island record to 1919.

Mean monthly Lake St. Clair levels were obtained from circulars published by the Canada Centre for Inland Waters for the period 1977-84. These measurements were recorded at Belle River on the opposite side of Lake

St. Clair. Lake level data for the period 1901-76 were obtained from model estimates produced by the Great Lakes Institute at the University of Windsor.

It was important to include prior growth as an independent predictor variable because photosynthates retained from previous growing seasons are an expression of prior climate that can affect growth during the current growing season (Fritts, 1976). Table (4.3) and Table (4.6) show that significant first order autocorrelation still exists in the mean red oak chronologies. Since the standardization and merging procedures is intended to eliminate much of the trend associated with growth and competition it was assumed that at least the remaining first order autocorrelation had climatic value.

4.4 Response Function Analysis

Response function analysis, as outlined in Fritts et al. (1971) and Fritts (1976) and used by Ashby and Fritts (1972), Puckett (1982) and Hamilton and Luckman (1985) was used to determine the relationship of tree growth to climate. This method of analysis decomposes climatic data time series' into orthogonal components which represent uncorrelated modes of behavior. Orthogonal variables have proven to be more stable than monthly climatic data in multiple regression because variable intercorrelation has been removed. The climatic data were transformed into orthogonal amplitudes using principal components analysis. The amplitudes were used, along with indices of prior growth, in stepwise multiple regression analysis to predict ring-width indices.

Initially a correlation matrix was calculated from climatic data,

$$ {}_{m}C_{m} = 1/n * {}_{m}F_{n}F'_{m} \quad , $$

where m is the number of monthly climatic variables and n is the number of years used in the analysis, ${}_{m}F_{n}$ is the matrix of standardized climatic data and (') denotes its transpose.

A principal component matrix, E, was next calculated using the BASIC routine of Alonso (1981),

$$ {}_{m}C_{m}\,E_{m} = {}_{m}E_{m}\,L_{m}, $$

where mLm is the eigenvalue matrix and mCm is the correlation matrix. Factor scores, or amplitudes, were then calculated as,

$$ {}_{m}A_{n} = {}_{m}E'_{m}\,F_{n}, $$

where A is the matrix of factor scores and E' is the transpose of E. The factor score, or amplitude, matrix is assumed to be representative of the data matrix F.

The amplitudes of the principal components were then used in a stepwise mutiple regression analysis to predict the tree-ring chronology,

$$ {}_1P_n = {}_1R_p \, A_n \, , $$

where ${}_1P_n$ are the estimated ring-width indices for n years and ${}_1R_p$ are the significant partial regression coefficients associated with each of the amplitudes of the selected set of p principal component amplitudes. Each regression coefficient value expresses the relative importance of each amplitude in predicting growth. A value of zero was assigned to the amplitude if it was not significant.

The number of amplitudes used in the stepwise multiple regression was reduced due to the loss of degrees of freedom due to autocorrelation in the tree-growth series. This was accomplished after Fritts (1976),

$$ n' = n \, \frac{1 - r_1}{1 + r_1} $$

where n' is the effective sample size, n is the number of observations and r_1 is the first order autocorrelation in the series.

The common descriptive statistics associated with multiple regression were retained. These included the F ratio and its level of significance, the percent of variation in tree growth explained, the multiple correlation coefficient R and associated R^2 value, and the autocorrelation of residuals.

The response function was calculated,

$$ {}_1T_m = {}_1R_p\, E'_m \ , $$

where ${}_1T_m$ is the response function with a weight corresponding to each of the original climatic variables. An estimate of ring-width indices , ${}_1P_n$, based solely upon climatic variables was determined by multiplying the original climatic data, mFn, by the response function ${}_1T_m$,

$$ {}_1P_n = {}_1T_m\, F_n \ . $$

The standard errors of the regression coefficients were used to derive the confidence limits for each element of the response function employing the following transformation,

$$ {}_mS_m = {}_mE_p\, U_p\, U_p\, E_m' $$

where ${}_{p}U_{p}$ is the diagonal matrix of the standard errors of the elements of ${}_{1}R_{p}$, and ${}_{m}S_{m}$ is a symmetric matrix whose diagonal elements are the square of the standard errors of the elements of ${}_{1}T_{m}$. In other words, the standard errors of the response function are derived from the variances of the regression coefficients. The product of the variances and the eigenvector matrix (${}_{m}E_{p}$) are multiplied by the transpose of the eigenvector matrix (${}_{p}E'_{m}$) (Brett, 1978). This serves to distribute the square of the errors to each standard error in proportion to the squares of the elements of the eigenvector. The standard errors of the response function elements (${}_{m}S_{m}$) are multiplied by the appropriate F value with V1/V2 degrees of freedom then taking the square root. V1 has the value of 1 while V2 is equal to the effective sample size minus the number of non-zero coefficients and less 2 more degrees of freedom (d.f. = n -k-2). The effective sample size is equal to the number of years of observation (Fritts, 1976). The vertical lines in a response function show the F at 95% confidence limits. A variable is significant to tree growth if its bar does not contact the zero axis.

The prior growth year was then added as a predictor variable to account for autocorrelation in the ring-width and ring-area series. Residuals between actual and predicted tree growth were then checked for autocorrelation. Either a negative or sufficiently low correlation ensures that autocorrelation is not a problem (Fritts, 1976). The BASIC computer programs written and used to develop the response functions and their confidence limits are listed in Appendix C.

CHAPTER V

ANALYSIS OF THE DATA

5.1 Introduction

This investigation began with a general model based upon the relationship between the growth of red oak trees on Walpole Island and the independent variables precipitation, temperature, sunshine and lake levels. The initial response functions were developed on the basis of 48 climatic variables. Mean monthly temperatures, total monthly precipitation, total monthly bright sunshine hours and mean monthly Lake St. Clair levels for the period April 1 to September 30 of the previous growing season and April 1 to September 30 of the current growing season were used. Indices for one year of prior growth were later added but were observed separately in order to maintain simplicity in the growth-climate model.

5.2 Sixty Year Response Functions

Sixty year ring-width and ring-area response functions were developed for the period 1925 to 1984. This period represented the longest period with complete independent variable data coverage.

Table (5.1) shows the descriptive statistics associated with the two separate response functions. The high autocorrelation in the ring-width chronology resulted in a significant reduction in the effective sampling size through loss of degrees of freedom. The resultant response functions were thus both based on the best 12 amplitudes for comparative purposes. The addition of a 13th amplitude, in both cases, did not increase the tree-growth variation explained by more than 1% . Climatic variables explained about 45% and 37% of the growth variance in the ring-width and ring-area mean chronologies, respectively. The ring-width response function was significant at the 0.025 level. The ring-area response function was only marginally significant. With the addition of prior growth indices as predictor variables the variation in ring-width and ring-area explained was increased by about 21.25% and 15.4% , respectively. The larger increase for ring-widths was due to the weak climate and tree-growth relationship for the 60 year period and to the large first order autocorrelation in the mean ring-width chronology.

Figure (5.1) shows the 60 year ring-width response function and Figure (5.2) shows the 60 year ring-area response function. Each element of a response function shows the relative effect of increased or decreased mean monthly temperature, total monthly precipitation, total monthly bright sunshine hours and mean

TABLE (5.1)

Descriptive Statistics Associated with the Sixty Year Ring-Width and Ring-Area Response Functions

	Ring-Width (1925-84) (W60)	Ring-Area (1925-84) (A60)
Amplitudes Used:	12	12
F Ratio:	3.23	2.30
P:	<0.025	<0.100
% Variation Explained:	45.21%	37.04%
Multiple R:	0.672	0.609
Autocorr. of Errors:	0.568	0.515
% Variation Explained: Plus 1 Year Prior Growth:	66.46%	53.41%
Autocorr. of Errors: Plus 1 Year Prior Growth:	0.213	0.216

FIGURE (5.1)

Ring-Width Response Function for the Period 1925 to 1984
Vertical Lines Show Approximate 95% Confidence Limits

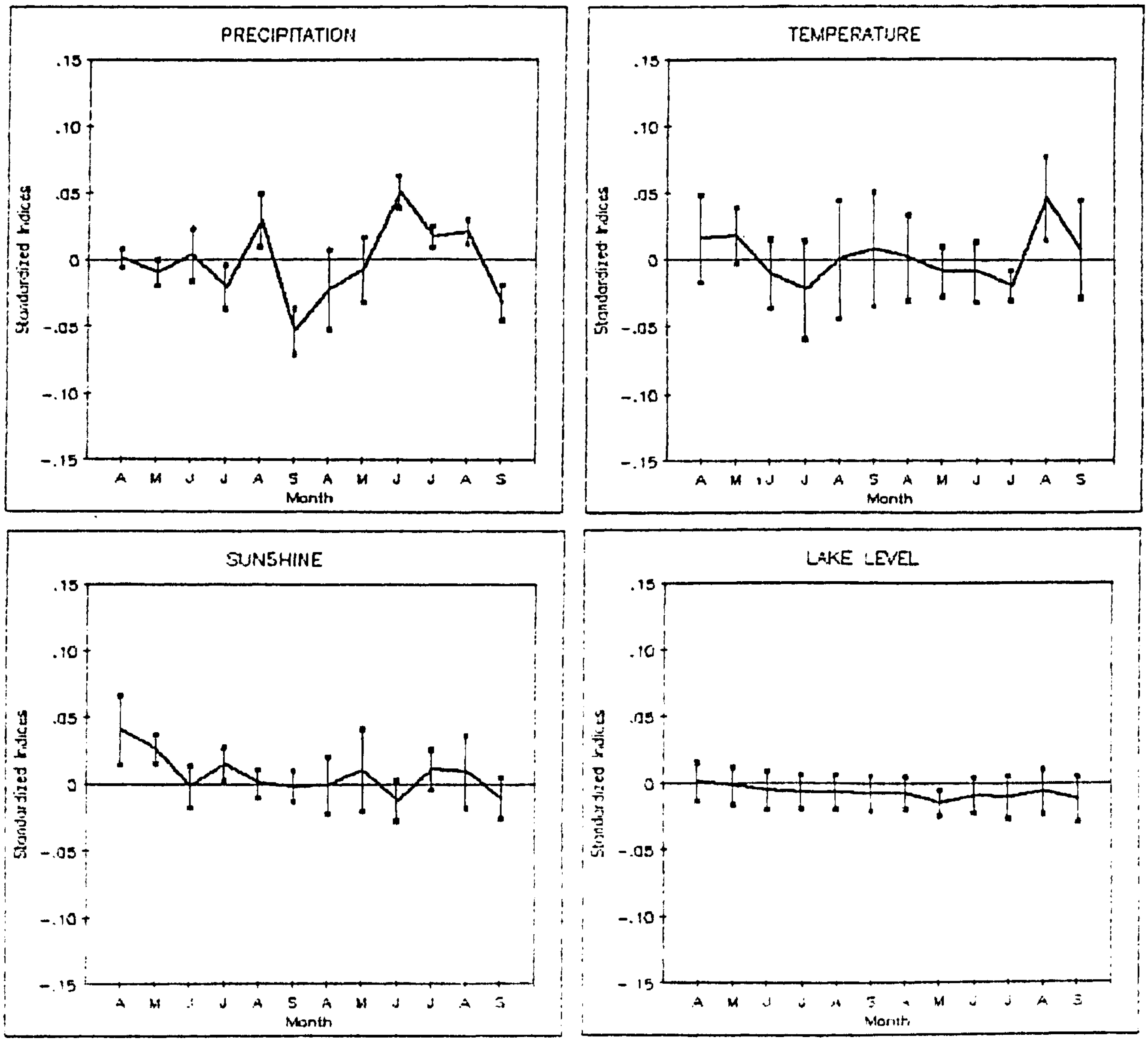
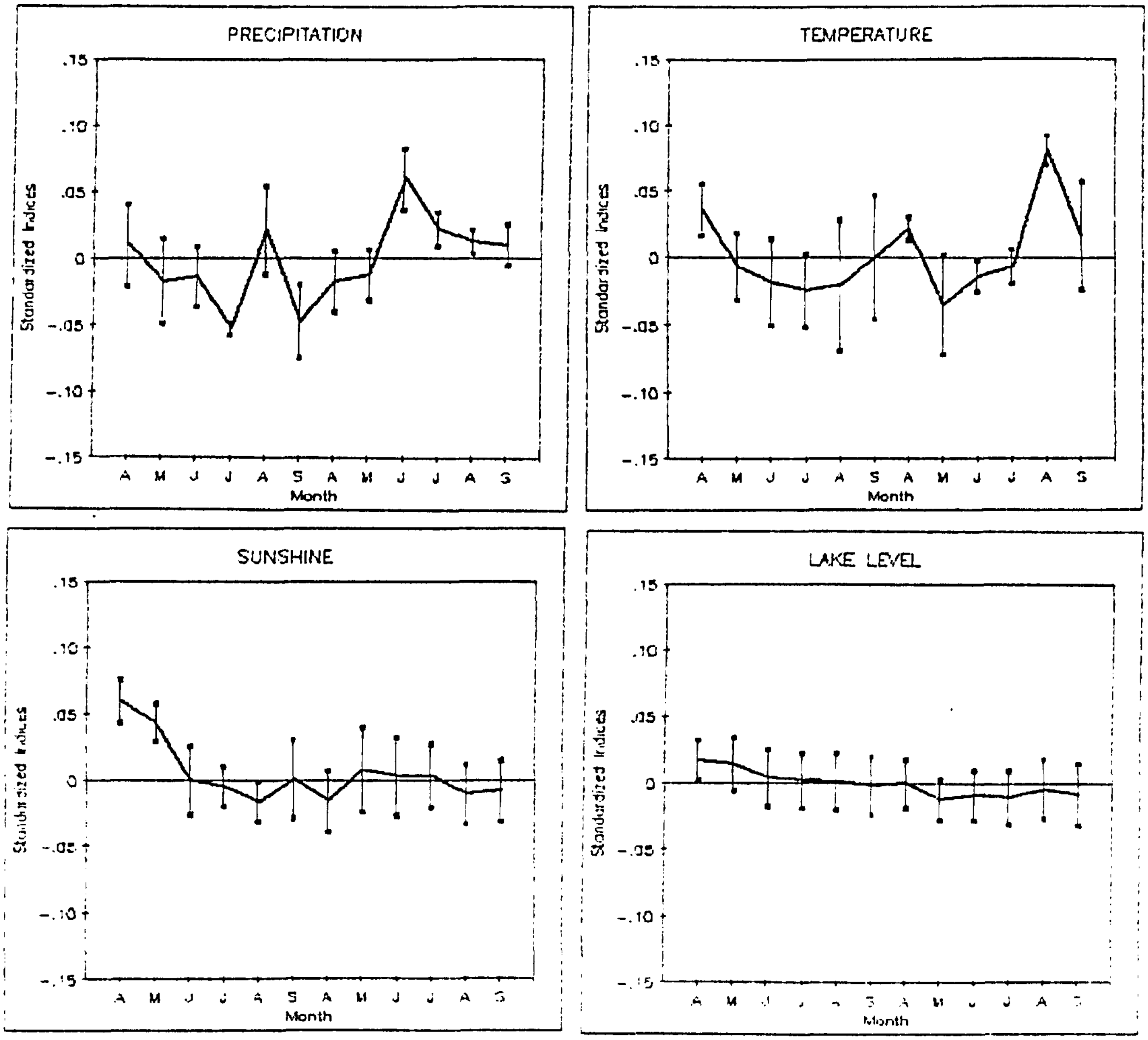


FIGURE (5.2)

Ring-Area Response Function for the Period 1925 to 1984
Vertical Lines Show Approximate 95% Confidence Limits



monthly lake levels on the standardized growth indices for the 60 year period. Negative values indicate an inverse effect on growth while positive values indicate a direct effect on growth. The vertical lines through each element show approximate 95% confidence limits. A variable is felt to be significant if its confidence band does not contact the zero axis.

Thirteen elements of the ring-width response function were found to be significant. For precipitation they were May and July of the previous year (negative), August of the previous year (positive), September of the previous year (negative), June, July and August of the current year (positive) and September of the current year (negative). For temperature they were July of the current year (negative) and August of the current year (positive). For sunshine they were April and May of the previous year (positive) and for lake levels May of the current year (negative).

Twelve elements of the ring-area response function were found to be significant. The ring-area response function was quite similar to the ring-width response function with a repetition in the significance of many of the main elements. Notable differences were the addition of both previous and current year April temperatures (positive) and previous year April lake levels (positive).

Figure (5.3) shows the mean ring-width chronology and predicted indices from the 1925 to 1984 response function. Figure (5.4) shows the ring-width residuals, or the mean ring-width chronology minus the predicted ring-widths for the same response function. Figure (5.5) shows the mean ring-area chronology and the predicted indices from the 1925 to 1984 response function while Figure (5.6) shows the residuals from the same response function. Examination of the ring-width and ring-area residual figures reveal two distinct but similar periods of non-association between tree-growth and climatic variables. These two periods were from 1935 to 1940 and from 1973 to 1984.

Ashby and Fritts (1972) found monthly temperature and precipitation variables to account for 59% of the growth variance of a 55 year ring-width chronology of white oak trees in northern Illinois-Indiana. The relatively weak relationship found in this study between tree growth and added climatic variables led to the necessity of examining shorter time periods.

The 60 year ring-width and ring-area mean chronologies had a correlation coefficient of 0.84 with a 0.001 significance level. The two response functions also revealed a high degree of visual similarity as seen in Figure (5.1) and Figure (5.2). Therefore, only the response of the ring-width mean chronology was further

FIGURE (5.3)
MEAN RING—WIDTH CHRONOLOGY AND
PREDICTED INDICES FROM THE
1925 TO 1984 RESPONSE FUNCTION

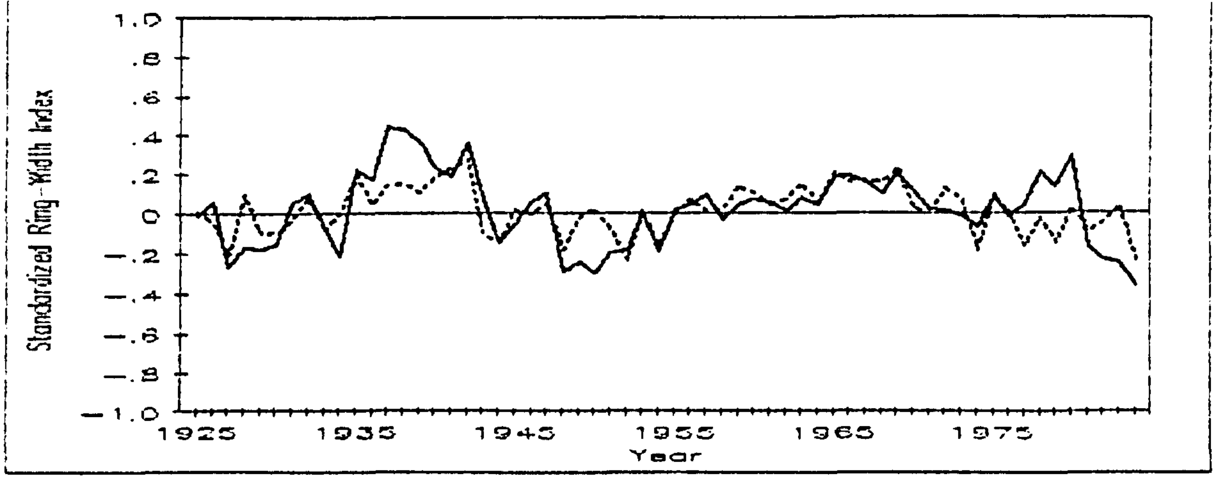


FIGURE (5.4)
RING—WIDTH RESIDUALS OR MEAN RING—WIDTH
CHRONOLOGY MINUS THE PREDICTED RING—WIDTHS
FROM THE 1925 TO 1984 RESPONSE FUNCTION

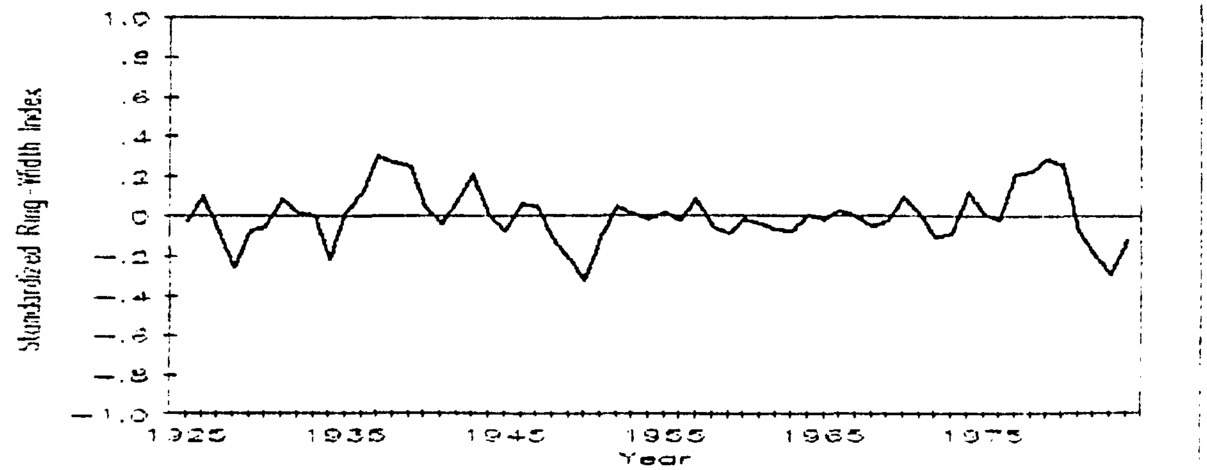


FIGURE (5.5)
MEAN RING—AREA CHRONOLOGY AND PREDICTED INDICES FROM THE 1925 TO 1984 RESPONSE FUNCTION

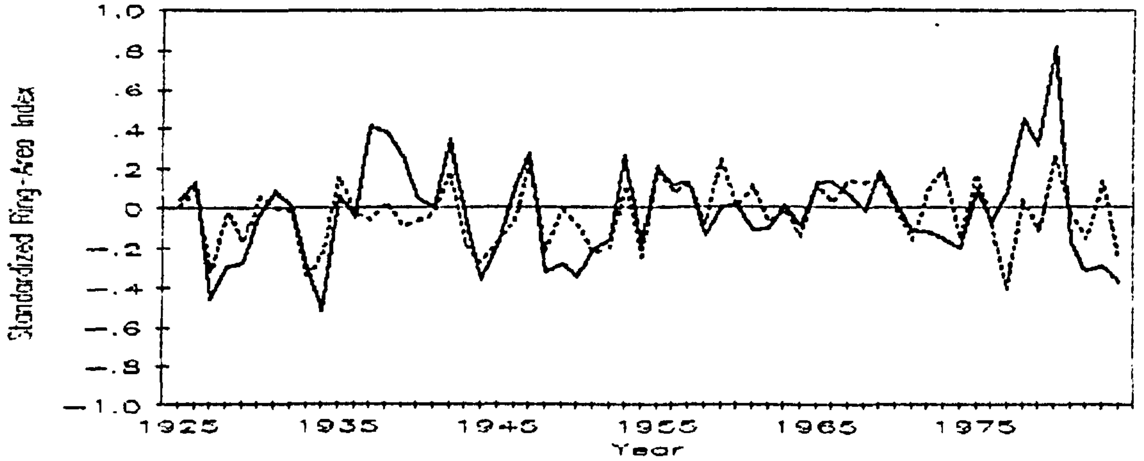
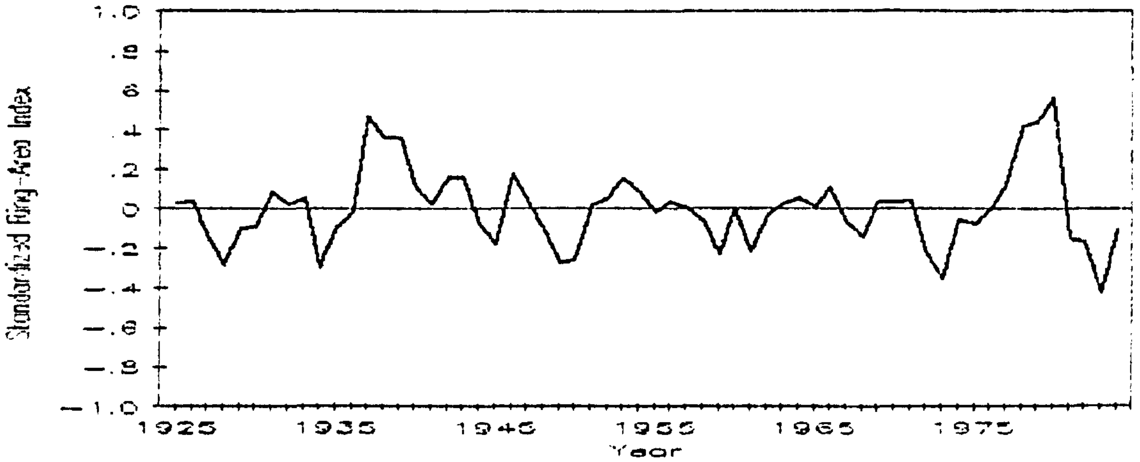


FIGURE (5.6)
RING—AREA RESIDUALS OR MEAN RING—AREA CHRONOLOGY MINUS THE PREDICTED RING—AREAS FROM THE 1925 TO 1984 RESPONSE FUNCTION



analyzed because of the better climate-growth relationship.

5.3 Thirty Year Response Functions

The 1925 to 1984 period was divided into two consecutive thirty year periods. This was done in order to investigate the possibility of a changing relationship of the growth of red oak trees on Walpole Island to climatic variables considered. Individual response functions were developed for an early period, 1925 to 1954, and a late period, 1955 to 1984.

Table (5.2) shows the descriptive statistics associated with the ring-width response function for the two periods. Again, the high autocorrelation in the ring-width chronologies resulted in a reduction in the effective sampling size. The resultant response functions were thus based on the best six amplitudes for comparative purposes. The best six amplitudes of the principal components matrix for the period 1925 to 1954 explained about 46.0% of the total variation in the climatic data set. The best six amplitudes of the principal components matrix were also used for the period 1955 to 1984 and explained about 36.3% of the variation in that climatic data set. Climatic variables explained about 68.5% of the growth variance during the early period and about 71% of the growth variance during the later period. The relationships were

TABLE (5.2)

Descriptive Statistics Associated with the Thirty Year Ring-Width Response Functions

	Ring-Width	
	1925-54 (W30A)	1955-84 (W30B)
Amplitudes Used:	6	6
F Ratio:	8.36	5.54
P:	<0.01	<0.025
% Variation Explained:	68.55%	59.11%
Multiple R:	0.828	0.769
Autocorr. of Errors:	0.134	0.250
% Variation Explained: Plus 1 Year Prior Growth:	75.84%	67.41%
Autocorr. of Errors: Plus 1 Year Prior Growth:	-0.243	-0.112

significant at the 0.025 level or less. With the addition of prior growth indices as predictor variables the variation in ring-width explained was increased about 7.3% in the early period and about 6.8% in the late period.

Figure (5.7) shows the 1925 to 1954 ring-width response function. Twenty-one elements of the ring-width response function were found to be significant. For precipitation they were June of the previous year (positive), April and September of the current year (negative) and June of the current year (positive). For temperature they were June of the previous year (negative), July of the current year (negative) and August of the current year (positive). For sunshine they were June of the previous year (negative) and July and September of both the current and previous years (positive) and May and June of the current year (negative). For lake levels they were June, July and August of the previous year (negative) and April, May, July and August of the current year (negative).

Figure (5.8) shows the 1955 to 1984 ring-width response function. Twenty-four elements of the ring-width response function were found to be significant. For precipitation they were May of the previous year (positive), June and July of the previous year (negative), June and September of the current year (positive) and July and August of the current year (negative). For temperature they were April of the previous year (positive), June and

FIGURE (5.7)

Ring-Width Response Function for the Period 1925 to 1954
Vertical Lines Show Approximate 95% Confidence Limits

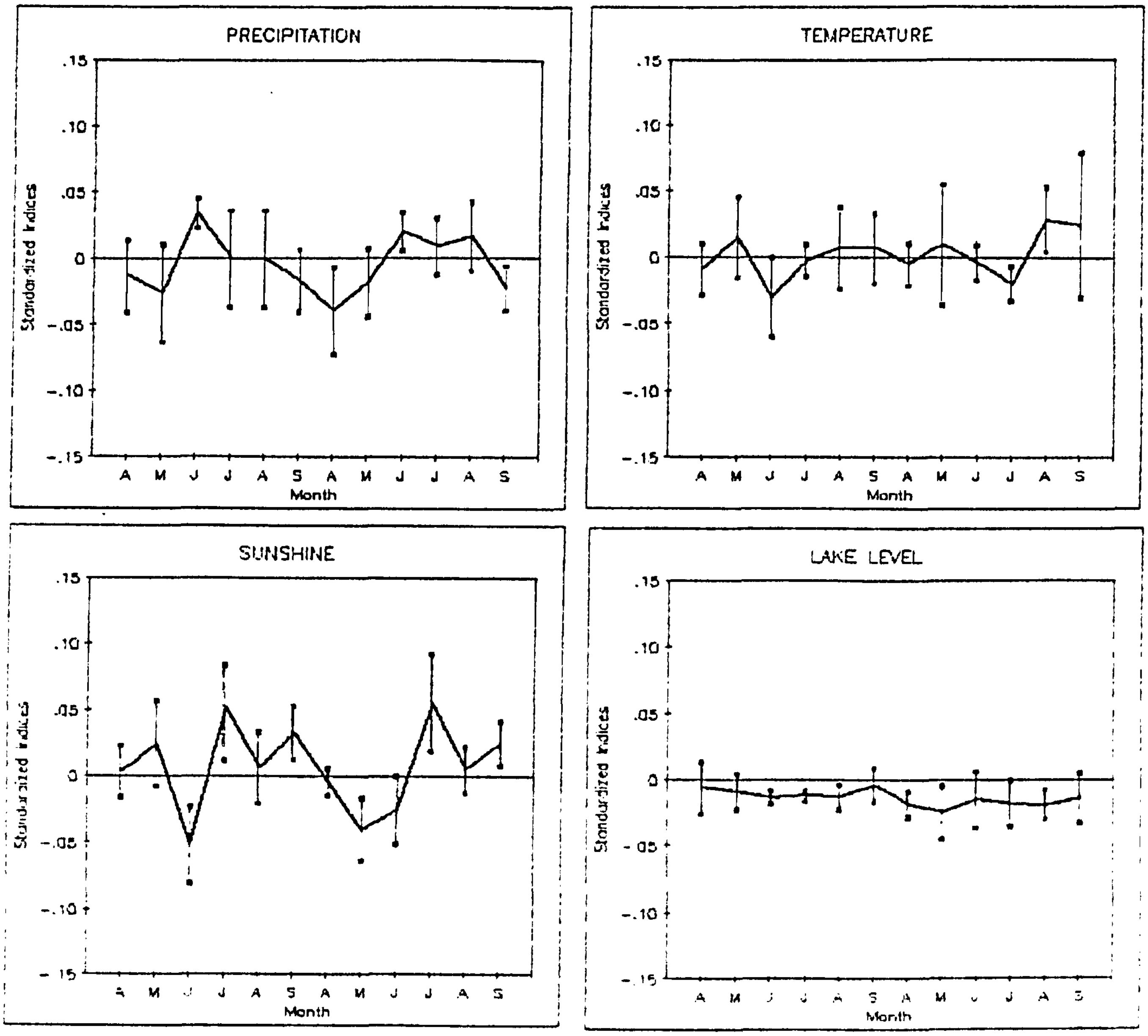
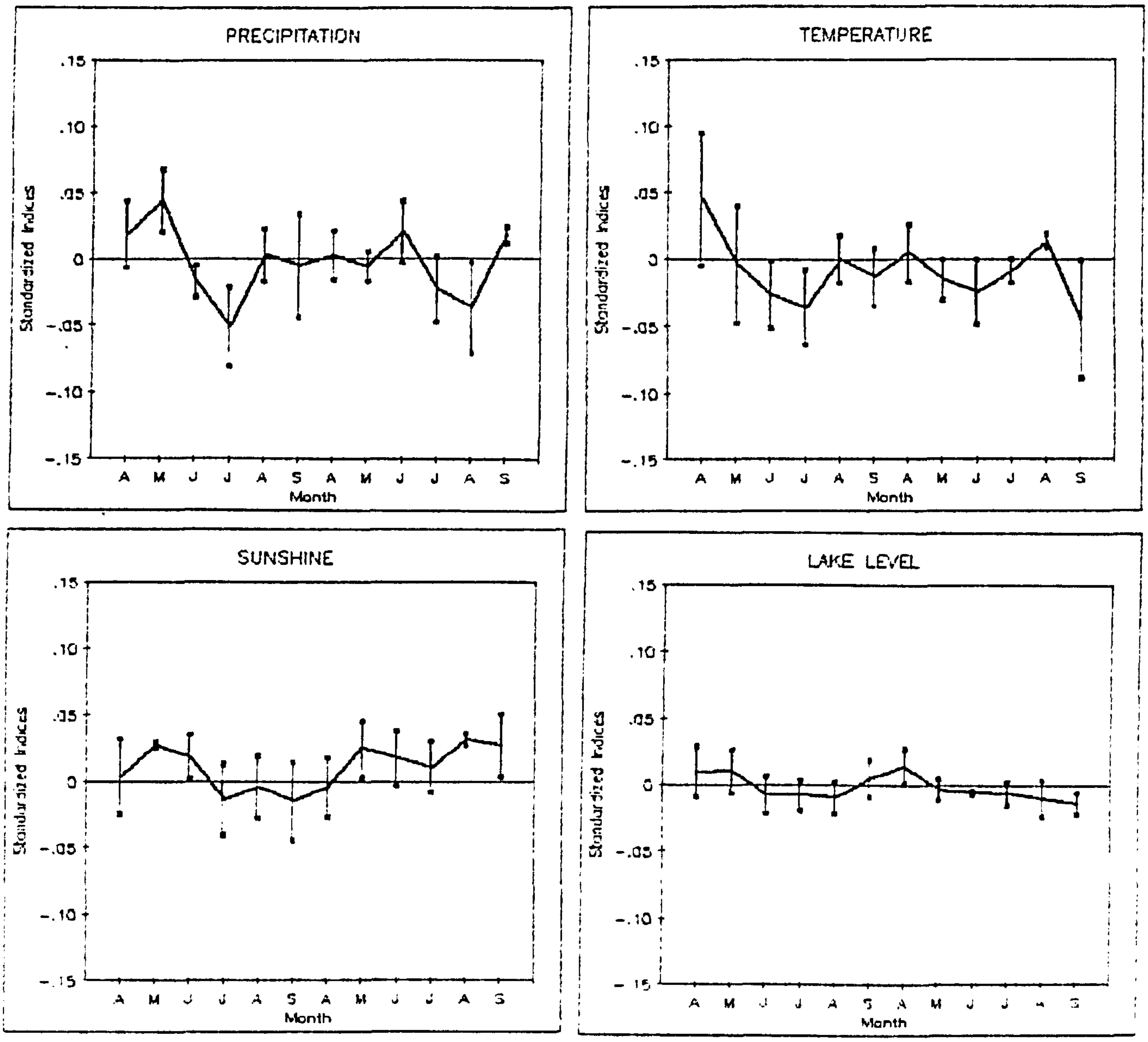


FIGURE (5.8)

Ring-Width Response Function for the Period 1955 to 1984
Vertical Lines Show Approximate 95% Confidence Limits



PRECIPITATION

TEMPERATURE

SUNSHINE

LAKE LEVEL

July of the previous year (negative), May, June, July and September of the current year (negative) and August of the current year (positive). For sunshine they were May and June of the previous year and May, June, August and September of the current year (positive). For lake levels they were April of the current year (positive) and June and September of the current year (negative). (positive) and August lake levels of the previous year (negative).

Figure (5.9) shows the mean chronology and predicted indices from the 1925 to 1954 ring-width response function. Figure (5.10) shows the mean chronology and predicted indices from the 1955 to 1984 ring-width response function. The two specific periods of non-association between tree-growth and climate, as previously seen in the 60 year response functions, are again evident. This is especially pronounced during the late 1930's and the late 1970's and early 1980's.

5.4 Environmental Change

It was assumed that the relationship of tree growth to the environmental variables considered would remain constant if the important environmental factors remained the same. The observed changing relationship suggested that environmental conditions have changed over the 60 year period of analysis. The monthly climatic data

FIGURE (5.9)
MEAN RING—WIDTH CHRONOLOGY AND
PREDICTED INDICES FROM THE
1925 TO 1954 RESPONSE FUNCTION

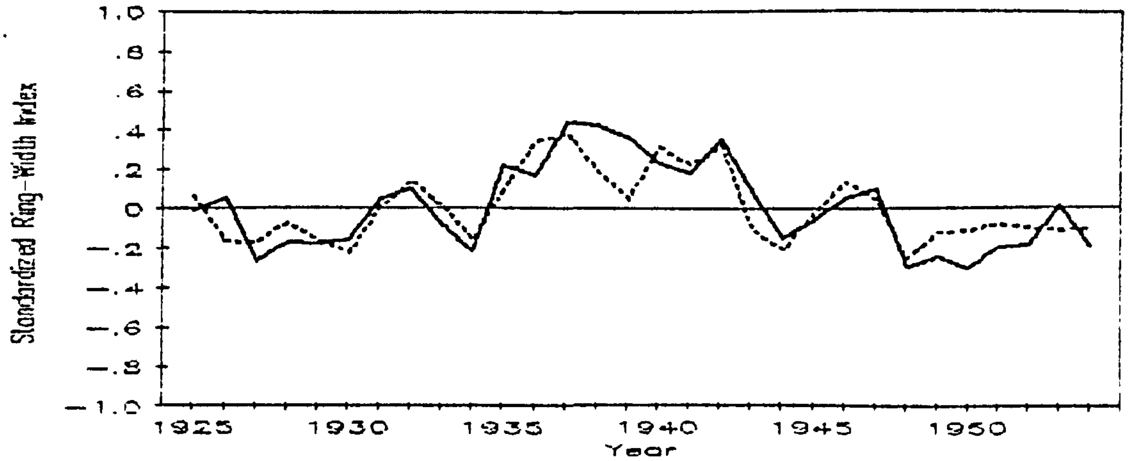
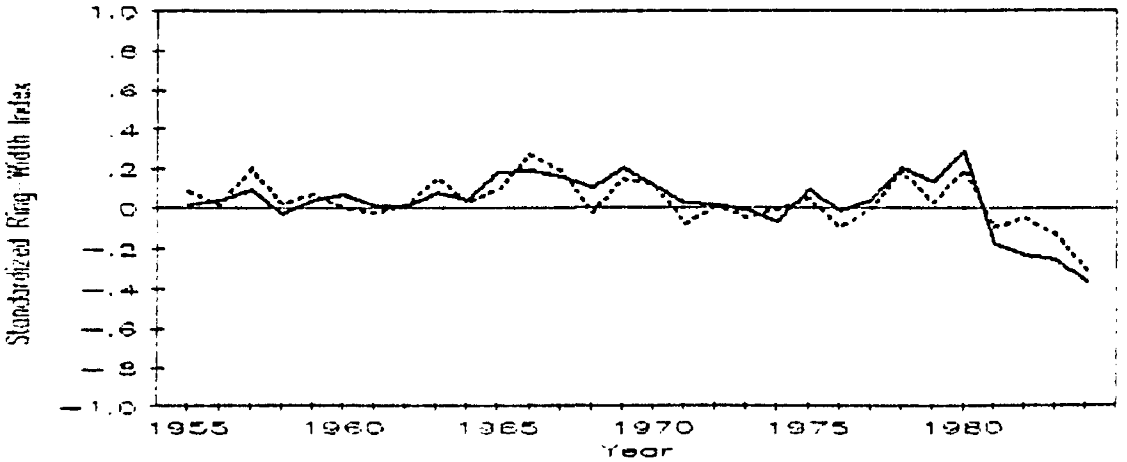


FIGURE (5.10)
MEAN RING—WIDTH CHRONOLOGY AND
PREDICTED INDICES FROM THE
1955 TO 1984 RESPONSE FUNCTION



were tested for homogeneity between periods to determine whether climatic change might have been responsible for the observed changing relationship.

Changes in the climate of the Northern Hemisphere during this century have been well documented (Budyko, 1977). A warming trend began in the 1920's and peaked in the 1940's. There has been a cooling trend since that time. Precipitation changes during this century are more difficult to determine because of the regional nature of variation in the element. Diaz and Quayle (1980) found that for eastern North America as a whole there has been generally more precipitation but less variability since 1955 than in the 30 years prior to that. This would be accompanied by similar changes in mean cloud cover with a reduction in total sunshine hours. In addition, during the past 100 years there have been both extremely low, and high, Great Lakes and thus river and groundwater levels.

Statistical t-tests and F-tests were employed to test whether the means and variances, respectively, of the monthly climatic data for the two periods used in the study were similar. Table (5.3) shows the results of the climatic data test. Twenty-four months were tested, April to September for each of the temperature, precipitation, sunshine and lake level data sets. Nine of the 24 variables used in the response function analyses were found to be significantly different at the 0.05 level. These

TABLE (5.3)

Statistical t-Test and F Test Results to Test Whether the Means and Variances, Respectively, Between the 1925-54 and 1955-84 Periods were Significantly Different

	Difference Between Means (t-Test)		Difference Between Variances (F Test)	
Variable	t	P	F	P
* P4	0.160	-	2.218	0.025
P5	0.695	-	1.342	-
P6	-1.061	-	1.030	-
P7	-0.931	-	1.023	-
* P8	-2.420	0.010	2.366	0.025
P9	-0.164	-	1.668	-
T4	-0.586	-	1.197	-
T5	-0.307	-	1.553	-
T6	1.261	-	1.238	-
* T7	2.432	0.010	1.085	-
T8	0.935	-	1.020	-
T9	1.218	-	1.100	-
S4	-1.189	-	1.083	-
S5	-0.449	-	1.097	-
S6	-0.617	-	1.020	-
* S7	1.643	-	1.934	0.050
* S8	2.308	0.025	1.473	-
S9	1.358	-	1.138	-
* L4	-1.980	0.050	1.210	-
* L5	-1.988	0.050	1.141	-
L6	-1.635	-	1.096	-
L7	-1.587	-	1.173	-
* L8	-1.784	0.050	1.266	-
* L9	-1.924	0.050	1.427	-

P4 is April Precipitation; L9 is September Lake Levels

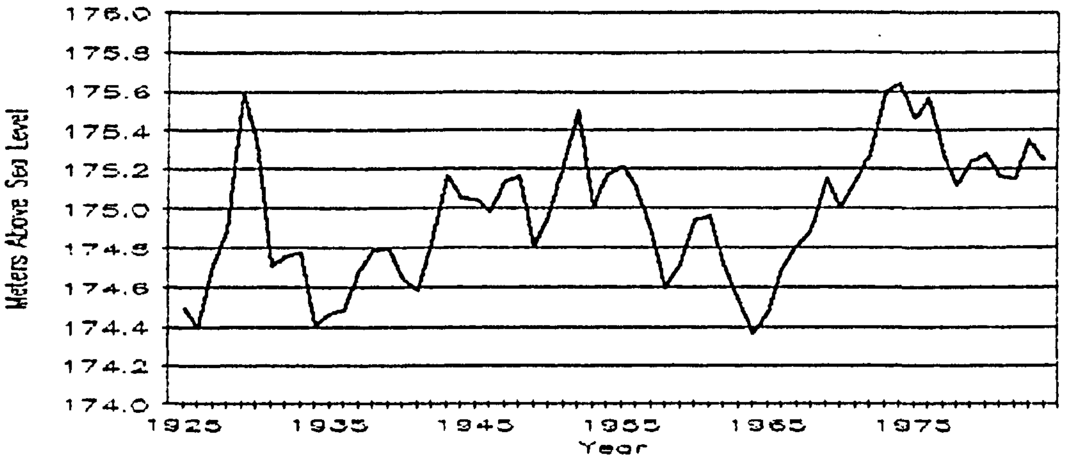
* Significantly Different at the 0.050 level or less

were April and August precipitation, July temperatures, July and August sunshine and April, May, August and September lake levels. Figure (5.11) shows mean May Lake St. Clair levels for the period 1925 to 1984. The remaining environmental variables which were found to be significantly different in their variances or means are shown in Figure (D1) to Figure (D9) in Appendix D.

5.5 Periods of Low and High Lake Levels

Two periods were observed, in conjunction with Figure (5.3) to Figure (5.6) and Figure (5.9) and Figure (5.10), when the residuals between actual and predicted tree growth were noticeably large. Examination of the mean lake level charts in Figure (5.11) and in Appendix D reveals that these two periods, the late 1930's and early 1940's and the late 1970's and early 1980's, were periods of relatively low and high lake levels, respectively, during the past 60 years. Lake and river level data have been successfully correlated with the growth of trees (Stockton and Fritts, 1973; Cook and Jacoby, 1983). St. Clair River delta water table levels have been shown to be closely related to fluctuations in St. Clair River and Lake St. Clair water levels (Jiwani, 1983). Extreme fluctuations in Lake St. Clair levels might be responsible for variation through time in the growth

FIGURE (5.11)
MEAN MAY LAKE ST. CLAIR LEVELS
MEASURED AT BELLE RIVER, ONTARIO
FOR THE PERIOD 1925 TO 1984



response of red oak trees on the delta to the other environmental variables examined. These two periods were more closely examined to determine ring-width response to the environmental variables during periods of extreme lake levels.

Ring-width response functions were developed for individual environmental variables for two periods of 11 years each, 1932 to 1942 being a period of extremely low lake levels and 1974 to 1984 being a period of extremely high lake levels. Independent variables were examined separately because of the short periods involved.

Principal components were extracted from the 12x11 matrices of each of the original temperature, precipitation, sunshine and lake level data for the two periods. For the 1932 to 1942 period the best three amplitudes of the precipitation principal components matrix explained about 53.9% of the variance in the original data set, for temperature the best three amplitudes explained about 44.8% of the varaince, for sunshine the best three amplitudes explained about 29.8% of the variance and for lake levels the best three amplitudes explained about 38.5% of the variance. For the 1974 to 1984 period the best three amplitudes of the precipitation principal components matrix explained about 27.1% of the variance, for temperature the best three amplitudes explained about 43.1% of the variance, for sunshine the best three amplitudes explained about 30.6% of the variance and for lake levels the best three amplitudes explained about 25.2% of the original data variance. Only the best 3 amplitudes were used in the multiple regressions due to loss of degrees of freedom because of autocorrelation in the ring-width series'.

Table (5.4) shows the descriptive statistics associated with the individual 11 year response functions during the 2 periods of extreme lake levels. Figure (5.12) shows the ring-width response function for the 1932 to 1942 period of extremely low lake levels. Figure (5.13) shows the ring-width for the 1974 to 1984 period of extremely high lake levels.

The relationship of tree growth to precipitation and lake levels during the period of low lake levels was only marginally significant at the 0.1 level. The temperature and sunshine relationships were stronger at the 0.05 level. None of the relationships during the high lake level period were significant.

Seventeen elements of the 1932 to 1942 ring-width response function were found to be significant. For precipitation they were June and September of the previous year and June and July of the current year (positive). For temperature they were June of the previous year and September of the current year (negative) and April of the current year (positive). For sunshine they were June and

TABLE (5.4)

Descriptive Statistics Associated with the Individual Eleven Year Ring-Width Response Functions During Periods of Low and High Lake Levels

Low Lake Levels (1932-42)	Precipit'n	Temperature	Sunshine	Lake Levels
Amplitudes Used:	3	3	3	3
F Ratio:	7.41	13.13	11.70	8.63
P:	<0.10	<0.050	<0.050	<0.10
% Variation Explained:	76.05	84.91	83.38	78.72
Multiple R:	0.872	0.923	0.913	0.887

High Lake Levels (1974-84)	Precipit'n	Temperature	Sunshine	Lake Levels
Amplitudes Used:	3	3	3	3
F Ratio:	2.33	0.84	1.45	1.49
P:	-	-	-	-
% Variation Explained:	49.94	26.48	38.33	38.97
Multiple R:	0.707	0.515	0.619	0.624

FIGURE (5.12)

Ring-Width Response Functions for the Period of Extremely Low Lake Levels, 1932 to 1942. Vertical Lines Show Approximate 95% Confidence Limits

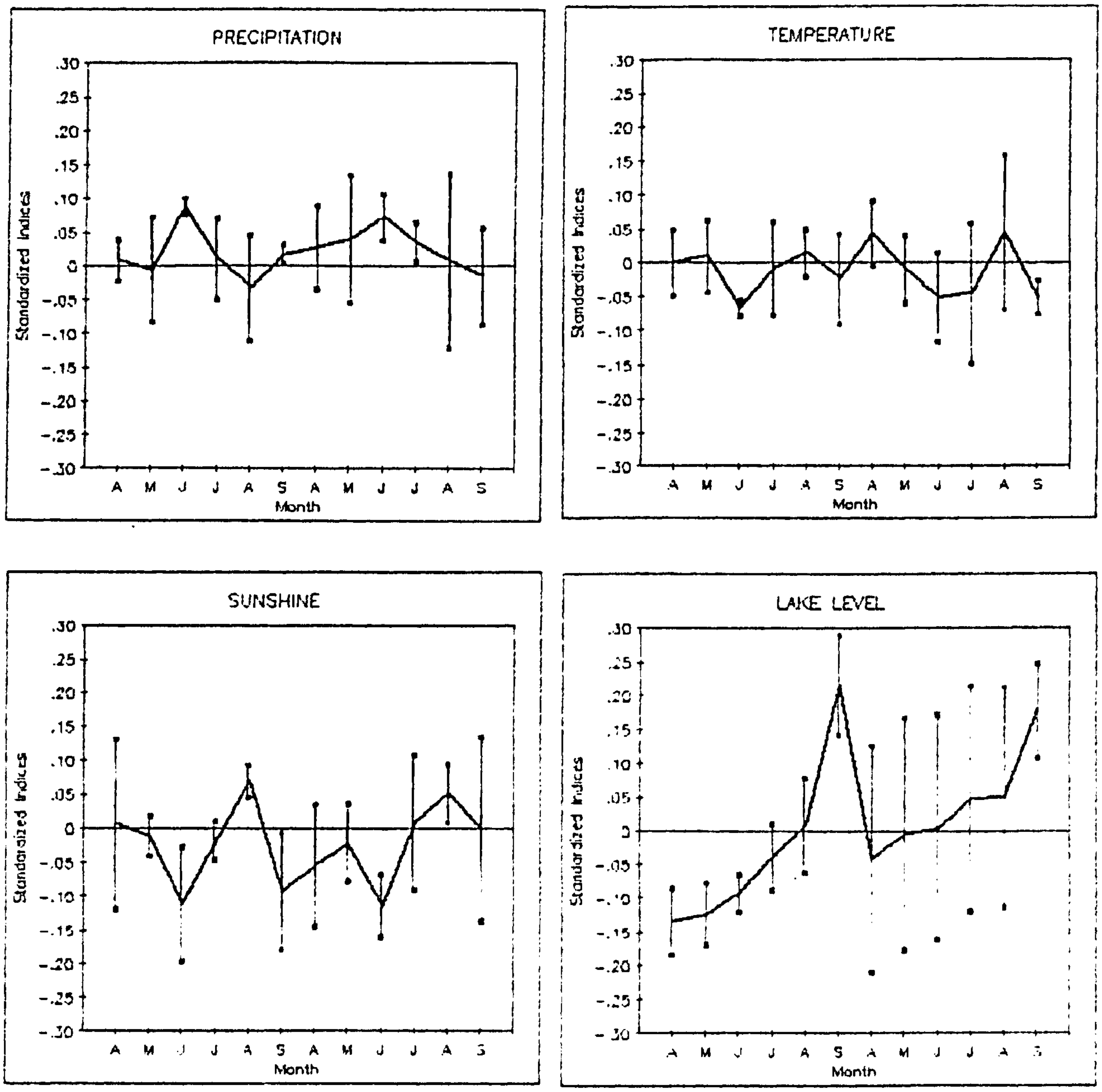
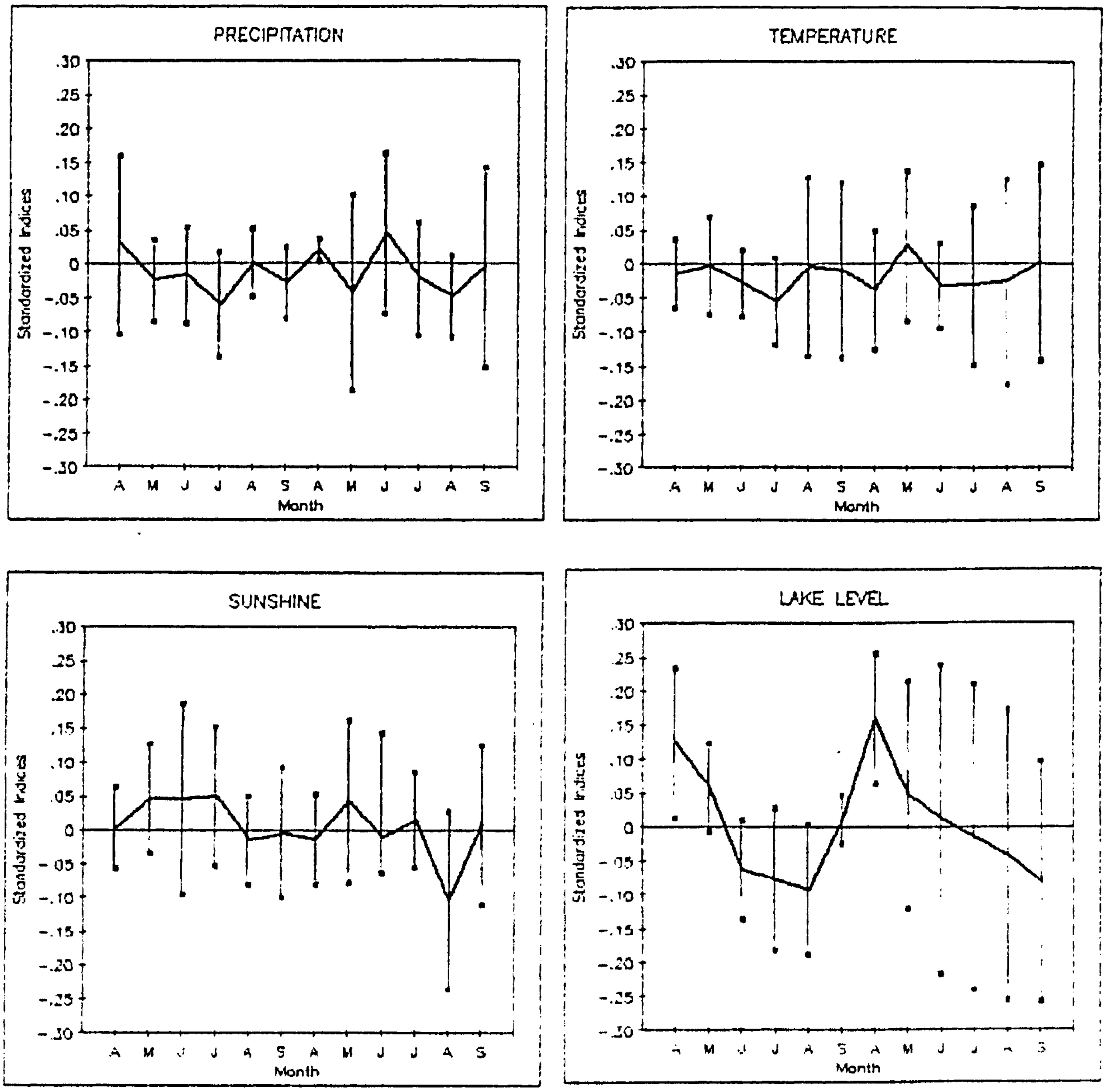


FIGURE (5.13)

Ring-Width Response Functions for the Period of Extremely High Lake Levels, 1974 to 1984. Vertical Lines Show Approximate 95% Confidence Limits



September of the previous year and June of the current year (negative) and August of both the previous and current years (positive). For lake levels they were April, May and June of the previous year (negative) and September of both the previous and current years (positive).

Five elements of the 1974 to 1984 ring-width response functions were found to be significant. These were current August precipitation (positive) and previous April and May and current April lake levels (positive) and previous August lake levels (negative).

CHAPTER VI

INTERPRETATIONS

6.1 Introduction

The use of the standardization and response function analysis procedures to develop and quantify the tree growth/environmental relationships involved several *a priori* decisions. The potential for subjectivity in many of these decisions was quite high. It therefore became necessary to adhere to the basic principles of dendroclimatology to reduce the degree of subjectivity in both the *a priori* decisions and in the subsequent *posteriori* interpretations.

The uniformitarian principle and the principle of limiting factors, as outlined by Fritts (1976), are basic to the study of dendroclimatology. Any analysis of tree growth/environment relationships must include a broad range of both present and past variability. However, some extraneous factors which could influence the growth of natural vegetation cannot be accurately quantified on the local level. These factors include the more recent introduction of pollutants into the atmosphere. As a result, it becomes necessary to determine the possible changes which might have occurred in the value and/or magnitude of the most limiting growth factor and to apply this knowledge to future growth/environment relationships.

The relationship of the growth of red oak trees to environmental variables has been seen to change over the past 60 years. This suggests that there have been changes in the value and/or magnitude of the most limiting growth factor. The water cycle is basic to the understanding of forest ecology. Most forests of the world are under water stress for at least part of the annual cycle and can occasionally be subjected to extreme water stress on an interannual basis. The water cycle strongly affects both the behavior and growth of trees through soil moisture availability and through stream flow and ground water supply. Water level appears to be a primary controlling factor in both the distribution and growth response of red oak trees on the St. Clair River delta.

6.2 Standardization Accuracy

The standardization procedure for the removal of the growth trend from a tree-ring series is at present a major unresolved problem of dendroclimatology (Hamilton and Luckman, 1985). The most widely used and accepted techniques involve the application of linear, exponential or polynomial functions to an individual series

(Fritts, 1976; Hughes and Kelly, 1982). Several other techniques, such as the smoothing spline (Cook and Peters, 1981; Peters et. al., 1981), the incremental polynomial function (Warren, 1980) and the digital filter technique (Parker, 1971; Parker et. al., 1982), have also been applied.

The actual ring-widths measured for the Walpole Island red oak trees had relatively low mean sensitivity statistics, as seen in Table (4.3). It was felt that the application of the best fit exponential or quadratic function to each ring-width series was sufficient in order to remove most of the apparent growth trend. The remaining autocorrelation in the final ring-width mean chronology was r = 0.60, being slightly higher than that found in other studies of oak trees in eastern North America (Ashby and Fritts, 1972; Puckett, 1982). This indicates the possibility that some growth trend still remained in the ring-width chronology.

The actual ring-areas measured had much higher mean sensitivity statistics, as seen in Table (4.6). The experimental application of Fourier smoothing without the fast Fourier transform (Aubanel and Oldham, 1985) had some distinct advantages over other available methods. This included the option of selecting the degree of smoothing to be applied and the absence of pre-assumptions about the shape of the growth curve to be standardized. The remaining autocorrelation in the final ring-area mean chronology was $r = 0.33$ and was more comparable to values derived from other oak mean chronologies in eastern North America. Ideally, all of the growth trend should be removed, leaving only the environmental response. This problem in the discipline remains unresolved.

6.3 Response Function Accuracy

The use of response function analysis also involves several a priori decisions of a subjective nature. The regression of orthogonalized climatic variables with tree growth indices requires a number of decisions. These decisions deal with which environmental variables to include and also the actual number of environmental variables to include, which confidence limits to establish and the number of eigenvectors to allow as predictors in the regression. These decisions can affect the response function in unpredictable ways and can lead to errors in the final interpretation (Blasing, Solomon and Duvick, 1984).

There have been several methods used to express the relative importance of monthly climatic variables, usually precipitation and temperature, in influencing the growth of trees. The earliest studies, such as Diller (1935), simply calculated correlation coefficients between what was felt to be an important climatic variable and ring-width. Coile (1936) calculated several correlation coefficients to determine which of a number of climatic variables was best related to ring-width. Stepwise multiple regression was eventually used as an analytical tool (Fritts,1960; Schulman and Bryson, 1965) but was hampered by covariance in preditor variables. This causes an important variable to be rejected by a more important combination of other variables in the regression equation.

Response functions were introduced by Fritts et al. (1971). They have since been used in numerous studies (Ashby and Fritts, 1972; Fritts, 1976; Cook and Jacoby, 1977; Hughes et al., 1978; Duvick and Blasing, 1981; Puckett, 1984) and have become the most common method of establishing the relationship between tree growth and climate. They provide estimates of standardized tree growth variations based on corresponding climatic variations. Several orthogonalized independent predictor variables are tested on the basis of their relationship to the dependent variable. Variables which pass the test at a selected confidence level are included in the regression equation. The final response function contains one element for each of the original unorthogonalized climatic variables. The effect of the original climatic variables are again tested at a selected confidence level for significance. Indices of prior growth are normally included in the original response function analysis. However, they may be separately analyzed in order to differentiate between climatic and quasi-climatic effects.

Numerous strengths and weaknesses have become apparent in response function analysis (Blasing, Solomon and Duvick, 1984). They have become a useful tool in estimating the changes in average ring-width that would occur under future climatic changes (Cooper et al., 1979). Response functions have also been useful in identifying the climatic variable for which a past history can be approximated from tree-ring records. In addition they have been effectively used to determine they changing response of tree growth to the same climatic variables over time (Puckett, 1982).

On the other hand, a change in the number of climatic variables to be transformed into eigenvectors can unpredictably alter the shape of the response function. Also, there is no clear criteria for establishing the best confidence level for screening eigenvectors. The inclusion of higher-order eigenvectors serves to depict the fine scale structure of the response function but also might include irrelevant detail due to error in the original climatic measurements. The addition of prior growth indices can significantly alter the portion of the response function which is intended to be determined by only climatic relationships.

In this study, the same 48 environmental variables, precipitation, temperature, sunshine and lake levels for April to September of both the previous and current growing seasons, were used to develop all response functions of 30 years or greater. Twelve variables from each of the same four environmental elements were used for each of the 11 year response functions. It was felt that these variables would adequately describe the the broad range of growth related environmental factors. Numerous response functions were originally developed using only precipitation and temperature variables. In addition, total monthly degree-days were employed in the place of the temperature variables. In all cases, the same basic relationships were found but their use accounted for a smaller proportion of variance in growth indices. Consequently, the temperature variables were retained and further environmental variables were added to the investigation.

The criterion used for screening eigenvectors in multiple regression was that which was used in classic stepwise multiple regression analysis. An eigenvector amplitude was retained in the regression if the resulting F-ratio remained above the value of 1.0 (Fritts, 1976). In the shorter 30 and 11 year response functions, however, the loss of degrees of freedom due to autocorrelation in the mean chronology being analyzed resulted in the inclusion of even fewer eigenvector amplitudes. Higher-order eigenvectors were considered in this study because of what was felt to be high quality regional environmental records.

6.4 Response Function Interpretations

The theoretical formulation of this study was based on the hypothesis which stated that inferences could be drawn from the manner in which the growth of the natural vegetation of Walpole Island was related to environmental variables. This study initially analyzed two separate indexes of tree growth, a ring-width mean chronology and a more experimental ring-area mean chronology. The ring-width mean chronology was developed by more conventional standardization methods (exponential or quadratic smoothing). The ring-area mean chronology was developed by more experimental standardization methods (Fourier smoothing). Statistical response functions were developed to describe the response of the two separate sets of growth indices to environmental variables. It was originally intended to analyze the two growth responses separately. However, a high degree of similarity became apparent between ring-width and ring-area response functions using the same environmental variables for the same time periods.

The ring-width and ring-area response functions developed over the 60 year time frame were found to be quite similar. Therefore, in order to seek simplicity in the interpretation of a complex set of relationships only the ring-width response functions were further analyzed.

6.4.1 Sixty and Thirty Year Response Functions

Table (6.1) shows the significant environmental elements for the ring-width response functions for the 60 and 30 year periods of analysis. The positive effect of precipitation during the height of the current growing season in the 60 year model implies that the more moisture there is available to the soil then the longer the time before moisture stress becomes the most limiting factor to growth. This also implies that the opposite effect would apply. The negative coefficients for precipitation relationships during the previous season are likely the result of the favorable effects of that element during the current season. Positive effects during the year of growth are often highly favorable to growth phenomena such as flowering and fruiting in that year but can cause the same phenomena to be subdued in the following year (Fritts, 1976). The negative effect of current July temperatures indicate higher evaporative stress during the hottest growing season month would result in lower growth.

TABLE (6.1)

Significant Environmental Elements for the Ring-Width Response Function for the 60 Year 30 Year Periods of Analysis

Environmental Element	60 Year (1925-84)		30 Year (1925-54)		30 Year (1955-84)	
	Prev Year	Curr Year	Prev Year	Curr Year	Prev Year	Curr Year
Precipitation						
# April	(-)			(-)		
May					(+)	
June		(+)	(+)	(+)	(-)	(+)
July	(-)	(+)			(-)	(-)
# August	(+)	(+)				(-)
September	(-)	(-)		(-)		(+)
Temperature						
April					(+)	
May						
June			(-)		(-)	(-)
# July		(-)		(-)	(-)	(-)
August		(+)		(+)		(+)
September						(-)
Sunshine						
April	(+)					
May	(+)			(-)	(+)	(+)
June			(-)	(-)	(+)	
# July			(+)	(+)		
# August						(+)
September			(+)	(+)		(+)
Lake Level						
# April				(-)		(+)
# May		(-)		(-)		
June			(-)			
July			(-)	(-)		
# August			(-)	(-)		
# September						(-)

Months with significant differences between 1925-54 and 1955-84 periods.

The positive temperature effect late in the current season is related to more favorable temperatures for growth later in the season. The positive effects of bright sunshine are seen early in the previous season causing the early establishment of favorable cell development for future growth even if more limiting factors occur later in the season.

A weak relationship over the 60 year period of analysis was found when comparisons were made to previous studies employing the same methods and fewer environmental variables. In addition, the first order autocorrelation of errors for both ring-width and ring-area response functions were quite high, as seen in Table (5.1), indicating that autocorrelation was still a problem. The observed relationships, however, appear to be plausible in light of the interpretations. They can be viewed as a skeleton description of the response of red oak trees to most general changes in the environment that might occur. An analysis of shorter time periods was felt necessary in order to investigate the possibility of a changing growth/environment relationship.

The most striking feature of Table (6.1) is the addition of several significant sunshine and lake level elements to both 30 year response functions. A wholesale change can be seen from the early period to the later period in the effects of the important precipitation elements. The four significant precipitation elements in the first period were previous and current June (positive) and current May and May (negative). This changed to seven significant elements in the later period, previous May (positive), previous June and July (negative), current July and August (negative) and current June and September (positive). A similar change can be seen in the temperature elements. The three significant temperature elements in the first period were previous June (negative) and current July (negative) and August (positive). This also changed to seven significant elements in the later period, previous April (positive) and June and July (negative) and current June, July and September (negative) and August (positive).

The changing effects of sunshine on growth are also evident. During the 1925-54 period, negative effects can be seen early in both the previous and current years with positive effects later in both the previous and current years. During the 1955-84 period there is a distinct change to exclusively positive effects of the sunshine elements early in the previous year and both early and late in the current year. There is an introduction of significant lake level elements in the 30 year response functions. During the 1925-54 period there were negative lake level effects during the height of the current growing season. During the 1955-84 period the number of significant lake level elements was greatly reduced and also changed to positive effects early in the current season and negative effects later in the current season.

It is obvious that no simple explanation exists for the dramatic change in the overall relationship of the growth of red oaks to the same environmental variables between the two periods. An examination of Table (5.3) and the environmental variable charts in Appendix D provide some possible explanations. A change in the constancy of moisture input during in the growing season might account for the observed shift in the growth pattern.

Significant decreases in total bright July, August and September sunshine hours from the early to the later period were also observed. This is likely the cause of the reduction in the number of times this element exerted a positive effect on growth. Significant increases in all mean monthly Lake St. Clair levels were found from the early period to the later period. An examination of the lake level charts in Appendix D shows that during the early period there were a number of consecutive years of extremely low lake levels and during the later period there were a number of concsecutive years of extremely high lake levels. However, there were annual fluctuations to the opposite extremes during both periods. This could provide an initial explanation for the observed change in both the nature and timing of the lake level relationships.

6.4.2 Periods of Low and High Lake Levels

Table (6.2) shows the significant environmental elements for the ring-width response function for the 11 year periods of extremely low and high lake levels. During the period of low lake levels precipitation relationships were all positive both during the previous and current growing seasons. Lake levels exerted negative effects early in the previous year and positive effects late in both the previous and current years. Negative temperature effects are seen in the previous June and current September while positive temperature effects were seen in April of the current year. Negative sunshine effects were seen in June and September of the previous year and in June of the current year while positive effects were seen in August of both the previous and current years.

The observed precipitation and lake level relationships are those which can be expected for a period of general moisture stress. The presence of lower lake and thus river and ground water levels means that the trees have less water than average to draw from during the course of the growing season. High lake levels and thus ground

TABLE (6.2)

Significant Environmental Elements for the Ring-Width Response Functions for the 11 Year Periods of Extremely Low and High Lake Levels

Environmental Element	Low Lake Levels (1932-42)		High Lake Levels (1974-84)	
	Previous Year	Current Year	Previous Year	Current Year
Precipitation				
April				(+)
May				
June	(+)	(+)		
July		(+)		
August				
September	(+)			
Temperature				
April		(+)		
May				
June	(-)			
July				
August				
September		(-)		
Sunshine				
April				
May				
June	(-)	(-)		
July				
August	(+)	(+)		
September	(-)			
Lake Level				
April	(-)		(+)	(+)
May	(-)			
June	(-)			
July				
August				
September	(+)	(+)		

water levels at this time of year would result in a situation where there is too much moisture and too little oxygen available to the roots. The positive lake level relationships late in the previous and current years occurred at times of moisture stress. The lack of sufficient ground water from which to draw resulted in decreased growth both in the current and subsequent seasons. Precipitation effects were entirely positive during this period as was expected. Low or high precipitation months either alleviate or introduce moisture stress, respectively, in the absence of a sufficient ground water supply.

The temperature and sunshine effects are somewhat more perplexing and are no doubt controlled by the limiting hydrologic factor. The negative temperature effects mean that lower temperatures during a period of lower water availability cause decreased evaporative stress and and thus enhanced growth. Conversely, higher temperatures in the specified months cause higher evaporative stress and thus lower growth. The positive temperature effect occurs early in the current year, a time when surface and soil moisture is high, evaporative demands are low and favorable temperatures would enhance growth. Negative sunshine effects are seen during June of both the previous and current years. This is the month of most positive solar radiation and thus potential photosynthetic activity. High levels of intense sunshine coupled with reduced water availability could initiate plant stress. In addition, slightly lower levels of positive solar radiation at times of moisture stress could be more favorable to growth. Positive effects are seen during August of both the previous and current years. Years with lower total sunshine hours during these late season months, coupled with water stress would have negative effects on growth. Conversely, a higher number of sunshine hours during these months would enhance growth given adequate moisture and thermal requirements.

The period of high lake levels is characterized by the almost complete absence of significant elements. Positive precipitation and lake level effects are seen early in the current growing season. This indicates the influence of favorable moisture conditions on growth during the early stages of seasonal growth. The lack of relationship between the environment and growth during this period is not suprising. An examination of the residual charts in Figure (5.4) and Figure (5.6) show that this was a major period of poor overall predictability. During many years, even the sign of the particular growth index was not accurately predicted. This was not the case for the earlier period of extremely low lake levels. While the predictability of the ring indices during this early period was low the signs of the particular growth indices were generally accurate.

6.5 The Soil-Plant Water Cycle

The relationship of the growth of red oak trees to environmental variables has been seen to change over the past 60 years. An examination of the environmental variables used to develop the tree growth response functions indicated that some precipitation, temperature and sunshine variables that were used have significantly changed from the early 1925-54 period to the later 1955-84 period. It has been demonstrated that these changes could in part be responsible for some changes in the growth/environment relationship. It has also been shown that all lake level variables used in the analysis have shown significant changes between the two periods. An examination of the charts in Appendix D shows that there has been an increase of approximately 0.8 meters in mean Lake St. Clair level from the period 1932-42 to the period 1974-84. A similar change in the delta ground water level would produce drastic differences in the availability of water to the trees growing in the Walpole Island public bush.

The northern red oak trees of Walpole Island are a deep rooted species growing on a relatively well-drained fine sandy loam soil. Under normal lake level and thus river and ground water conditions they would derive most of their water requirements from the water table supply. However, extreme conditions such as either extremely low or extremely high lake levels would introduce moisture stress and environmental shock due to lower respiratory gas exchange, respectively.

The water cycle is basic to the understanding of forest ecology. Most forests of the world undergo moisture stress for at least part of the annual cycle and can be occasionally subjected to extreme moisture stress. The water cycle strongly affects both the behavior and growth of trees through soil water and soil air availability and through lake level, stream flow and thus ground water availability.

The moisture supply available to tree roots is inversely related to the air supply to them (Spurr and Barnes, 1973). Soil pores can can be either filled with moisture or air. An increase in one element automatically decreases the other. Both air and water must be available to the roots for optimum tree development. This implies that the smaller soil pores should be filled with water and the larger pores filled with air.

6.5.1 Ground Water and Trees

The availability of a water table to tree roots, such as with the Walpole Island public bush, can have both positive and negative effects. Under normal conditions it provides additional water for transpiration. However, this water consumption is often not necessary because the tree may already be absorbing sufficient moisture to transport the optimum amount of nutrients and necessary water to the foliage (Spurr and Barnes, 1973). Negative effects of a water table on tree growth include the prevention of the downward development of roots due to lack of oxygen below the water line for root development.

The presence of a fluctuating water table, as is also the case with the Walpole Island public bush, can also have positive and negative effects on growth. High soil water tables have a low capability for dissolving and removing soil nutrients (Spurr and Barnes, 1973). They also suffer from a lack of oxygen due to stagnant conditions. Lower soil water tables tend to have freer movement and thus have the ability to transport substantial quantities of nutrients and dissolved air. This condition is more favorable to growth. An extremely low water table, however, can leave the tree roots high and dry and thus introduce moisture stress conditions.

Water availability, through the input of precipitation and fluctuations of the Walpole Island water table, in conjunction with interannual fluctuations in river and lake levels, appears to be the primary limiting factor in the growth of red oak trees in the public bush area. Moisture stress and environmental shock relating to low and high water table levels, respectively, can have negative effects on tree growth. Favorable growth can occur during a period of low water table providing the precipitation, temperature and sunshine inputs are sufficient to meet the growth demands of the tree. Favorable growth can also occur during a period of high water table providing the evaporative demands are high and the precipitation inputs are low to moderate.

6.5 Air Pollution

A final explanation is that air pollution, either by itself or in combination with other factors such as the availability of water, has influenced the changing relationship of tree growth to climate. Numerous studies have shown that both point-source and nonpoint-source levels of various types of air pollutants have had negative effects on the growth of trees (Vins, 1970; Polge, 1970; Parker et al., 1974; Lawhon and Woods, 1976; McClenahen, 1978; Mann et al., 1980; McLaughlin et al., 1980). The relationship of various air pollutants to the growth of trees through multiple regression analyses have also shown the negative effect on growth (Phillips et al., 1977a, 1977b; Fox and Nash, 1980; Johnson et al, 1981). Response function analysis has been applied to infer the negative effects of air pollutants on the growth of trees in eastern North America (Ashby and Fritts, 1972; Puckett, 1982).

The metabolic processes and photosynthetic capacity of trees can be severely inhibited by toxic substances in the air. Continued exposure to such substances for a number of years would cause a gradual decline in ring width (Fritts, 1976). An examination of the mean chronologies in Figure (4.3) and Figure (4.6) show a general decline in standardized ring-width and ring-area indices beginning in the 1960's with a brief recovery period about 1980 but a more rapid decline since then. This general decline in tree growth corresponds with general increases in atmospheric pollutants in eastern North America (Puckett, 1982).

CHAPTER VII

SUMMARY AND RECOMMENDATIONS

7.1 Introduction

Most tree-ring studies in North America have, until recently, concentrated on coniferous tree species' and have been conducted in areas which are extremely sensitive to a single climatic variable. These areas include the American southwest, where moisture availability is the most limiting factor to tree growth, and alpine and sub-alpine sites where temperature represents the most limiting growth factor. In subhumid temperate regions, such as the Great Lakes area, tree growth has been found to be related to a more complex interaction of variables. This study has analyzed the growth response of one particular deciduous species, northern red oak (*Quercus rubra*), to a broad range of environmental variables.

7.2 Review of Objectives

The hypothesis stated that inferences could be drawn from the manner in which the growth of the local natural vegetation of Walpole Island in the St. Clair River delta was related to environmental variables. Since the main objective of dendroclimatology is to statistically describe past climate by analyzing the structure of the annual growth-rings of trees, the general approach, or rationale, of that discipline was adhered to in this investigation. This general rationale is to express the nature of a complex system in such a manner that it may be subjected to hypothesis testing and conceptual development. It thus became necessary to simplify the system and to describe it with the use of a model or a series of models. The internal workings of the system were thus visualized as a process-network model where there are a network of linkages between conditions, or states, in the climate-plant system. It was felt that a detailed reconstruction of the relationship between environmental conditions and the growth of natural vegetation could provide both locally and regionally significant information. Walpole Island is located on the northeastern shores of Lake St. Clair opposite the large industrial complex of Detroit, Michigan and Windsor, Ontario. It represents an important location with respect to changing environmental conditions. Such a reconstruction could eventually be incorporated into a regionally based estimate of the frequency and geographic extent of environmental change.

7.3 Review of Methods and Procedures

The data required in this study were tree growth measurements and climatic and climatically related environmental variables. Each data set was then averaged and transformed for the purposes of the analysis. It was important to strictly adhere to a number of procedures and principles to ensure the correct collection and processing of the tree ring and climatic data and to reduce potential error. This began with a clear definition of the pertinent study variables, an effective sampling design and field plan, and a justifiable mode of analysis to assess the hypothesis.

Two separate dependent variables were initially considered in this investigation. They were annual tree-ring width and annual tree-ring area. The public bush area of Walpole Island was felt to be the most climatically sensitive available area of the delta from which to sample trees. The ring-width mean chronology was developed by more conventional standardization methods (exponential or quadratic smoothing). The ring-area mean chronology was developed by more experimental standardization methods (Fourier smoothing). Statistical response functions were developed to describe the response of the growth indexes to environmental variables.

Response function analysis was employed to describe the relationship of tree growth to the selected environmental variables. Response functions have been used in numerous studies and have become the most common method of establishing the relationship between tree growth and climate. They provide estimates of standardized tree growth anomalies based on corresponding climatic anomalies. Indices of prior growth were separately analyzed in order to differentiate between climatic and quasi-climatic effects.

The investigation began with a general model based upon the relationship between the growth of red oak trees on Walpole Island and the independent precipitation, temperature, sunshine and lake level variables. The initial response functions were developed on the basis of 48 climatic variables. Mean monthly temperatures, total monthly precipitation, total monthly bright sunshine hours and mean monthly Lake St. Clair levels for the period April 1 to September 30 of the previous growing season and April 1 to September of 30 the current growing season were used.

7.4 Review of Findings

It was originally intended to analyze the ring-width and ring-area growth responses separately. However, the ring-width and ring-area response functions developed over the same time frame were found to be quite similar. Therefore, in order to seek interpretative simplicity in a complex set of relationships, only the significant environmental elements for the ring-width response functions were analyzed.

A weak relationship over the 60 year period of analysis from 1925 to 1984 was found when comparisons were made to previous studies employing the same methods and fewer environmental variables. In addition, the first order autocorrelation of errors for both ring-width and ring-area response functions were quite high. The observed relationships, however, appeared to be plausible in light of the interpretations. They can be viewed as a skeleton description of the response of red oak trees to most general changes in the environment that might occur.

An analysis of shorter time periods was felt necessary in order to investigate the possibility of a changing growth/environment relationship. Two separate 30 year periods were analyzed, an early 1925-54 period and a later 1955-84 period. Several significant sunshine and lake level elements were added to each 30 year response function. Also, many of the months which were found to be significantly different between the 2 periods in the environmental change analysis were months when major changes occurred in many of the relationships between the early and later periods.

A wholesale change was seen from the early period to the later period in the effects of the important precipitation and temperature elements. The changing effects of sunshine on growth were also evident. Also, during the 1925-54 period there were negative lake level effects during the height of the current growing season. During the 1955-84 period this was seen to change to positive effects early in the current season and negative effects later in the current season.

The most notable changes in the environmental variables were in mean Lake St. Clair levels. In the early period there were a number of consecutive years of extremely low lake levels and during the later period there were a number of consecutive years of extremely high lake levels. However, there were annual fluctuations to the opposite extremes during both periods.

A further analysis was made of even shorter 11 year periods of extremely low and high lake levels. The observed precipitation and lake level relationships for the period of extremely low lake levels were those which were expected for a period of general moisture stress. The presence of lower lake and thus river and ground water levels means that the trees have less water than average to draw from during the course of the growing season. Precipitation effects were entirely direct during this period as was expected. High precipitation months alleviate moisture stress in the absence of a sufficient ground water supply. The temperature and sunshine effects are somewhat more perplexing and were likely controlled by the limiting hydrologic factor. The period of high lake levels was characterized by the almost complete absence of significant elements. An examination of the residual charts has shown that this was a major period of especially poor overall predictability.

The northern red oak trees of Walpole Island are a deep rooted species growing on a relatively well-drained fine sandy loam soil. Water availability, through the input of precipitation and fluctuations of the Walpole Island water table, in conjunction with fluctuations in river and lake levels, appears to be the primary limiting factor in the growth of red oak trees in the public bush area. Moisture stress and environmental shock relating to low and high water table levels, respectively, can have negative effects on tree growth. Favorable growth can occur during a period of low water table providing the precipitation, temperature and sunshine inputs are appropriate to meet the growth demands of the tree. Favorable growth can also occur during a period of high water table providing the evaporative demands are high and the precipitation inputs are low to moderate. The more recent introduction of air pollutants, in combination with other factors such as the availability of water, might also have influenced the changing relationship of tree growth to climate.

7.5 Recommendations and Applications

The end results of many studies are often only partially successful. However, the intermediate procedures and results can provide some satisfaction for the efforts. In general, the results discussed have met the initial objectives. The tree growth/environmental relationships can be useful to both foresters and the environmental impact assessors.

Although only one species of tree was analyzed in this study it is evident that the public bush area of Walpole Island is closely linked to the ground water supply and its annual fluctuations. It is too soon to determine whether the recent artificial lowering of the water table by the construction of drainage ditches will improve the growth of the islands natural vegetation. Since 1980, there has been a rapid decline in the growth of the red oak trees in the public bush. This is directly coincident with extremely high lake and thus river and ground water levels. There appears to be a very fine distinction between what is too high and what is too low a water table for maximum red oak production. Either too much or too little water can be inhibiting to growth.

The environmental impact assessor might derive information concerning the impacts of fluctuating Great Lakes levels on natural vegetation. In addition, conclusions might be drawn concerning the impact of a vast industrial complex on the natural environment. This study might also stimulate further interest in other sensitive species of deciduous tree in the southern Great Lakes basin.

APPENDIX A

Original Tree-Ring Measurements and Calculations for the Seventeen Red Oak Trees

Red Oak Tree # 1 Core # 1 = North Side and Core # 2 = South Side
All measurements in millimeters

Year	Ring No.	North Early	North Late	South Early	South Late	Early Mean	Late Mean	Annual Mean
1985	1	.550	1.075	.625	.800	.587	.938	1.525
1984	2	.600	1.025	.750	.850	.675	.937	1.612
1983	3	1.075	1.875	.825	.925	.950	1.400	2.350
1982	4	.900	2.125	.775	1.700	.838	1.912	2.750
1981	5	1.000	2.325	1.025	1.125	1.012	1.725	2.737
1980	6	1.175	1.875	.850	2.575	1.012	2.225	3.237
1979	7	1.625	3.125	1.250	1.325	1.438	2.225	3.662
1978	8	1.225	4.075	1.325	3.250	1.275	3.663	4.938
1977	9	1.075	2.500	1.125	3.325	1.100	2.913	4.012
1976	10	1.150	3.325	1.075	1.700	1.112	2.512	3.625
1975	11	.850	2.325	.925	2.500	.887	2.412	3.300
1974	12	1.125	3.250	.600	1.575	.862	2.412	3.275
1973	13	1.250	2.950	.775	1.850	1.012	2.400	3.412
1972	14	1.025	3.875	.900	1.450	.962	2.662	3.625
1971	15	1.550	3.750	.825	1.700	1.188	2.725	3.912
1970	16	1.200	5.500	.900	2.400	1.050	3.950	5.000
1969	17	1.025	4.575	.825	3.375	.925	3.975	4.900
1968	18	1.050	3.800	.875	3.025	.963	3.412	4.375
1967	19	1.400	2.550	1.050	3.525	1.225	3.037	4.262
1966	20	1.375	4.525	1.175	4.375	1.275	4.450	5.725
1965	21	1.250	3.875	1.100	3.900	1.175	3.887	5.062
1964	22	1.475	2.375	.925	2.750	1.200	2.563	3.762
1963	23	1.000	2.525	.875	3.550	.938	3.037	3.975
1962	24	.800	2.375	.750	3.625	.775	3.000	3.775
1961	25	.950	2.125	.825	2.750	.887	2.438	3.325
1960	26	.725	2.550	.800	2.500	.762	2.525	3.287
1959	27	.775	2.375	.575	2.075	.675	2.225	2.900
1958	28	.950	1.850	.900	1.800	.925	1.825	2.750
1957	29	.850	2.075	.925	1.450	.887	1.762	2.650
1956	30	.550	2.325	.850	1.525	.700	1.925	2.625
1955	31	.875	.825	.625	2.050	.750	1.437	2.187
1954	32	.550	1.000	.525	1.050	.537	1.025	1.562
1953	33	.475	.775	.750	1.825	.612	1.300	1.912
1952	34	.500	.800	.550	1.225	.525	1.012	1.537
1951	35	.475	.700	.650	.925	.563	.813	1.375
1950	36	.675	.925	.625	.575	.650	.750	1.400
1949	37	.650	.725	.550	.850	.600	.787	1.387
1948	38	.625	1.300	.775	.850	.700	1.075	1.775
1947	39	.550	1.550	.825	2.175	.687	1.862	2.550
1946	40	.375	1.525	.700	2.575	.537	2.050	2.587
1945	41	.475	1.750	.800	2.550	.637	2.150	2.787
1944	42	.675	1.475	.925	2.250	.800	1.862	2.662
1943	43	.600	3.250	.775	2.300	.688	2.775	3.462

1942	44	.725	2.600	.900	3.525	.813	3.063	3.875
1941	45	.575	2.775	.575	2.300	.575	2.537	3.112
1940	46	.525	2.675	.550	2.900	.537	2.787	3.325
1939	47	.600	2.100	.525	2.250	.563	2.175	2.737
1938	48	.525	4.625	.375	2.550	.450	3.588	4.038
1937	49	.300	2.350	.300	2.750	.300	2.550	2.850
1936	50	.225	2.625	.200	2.300	.212	2.462	2.675
1935	51	.300	.600	.300	2.300	.300	1.450	1.750
1934	52	.300	1.200	.100	.525	.200	.862	1.062
1933	53	.350	2.025	.250	1.175	.300	1.600	1.900
1932	54	.250	1.525	.075	1.800	.162	1.662	1.825
1931	55	.550	.525	.225	1.000	.387	.762	1.150
1930	56	.100	.875	.175	.550	.137	.712	.850

Red Oak Tree # 2 Core # 3 = North Side and Core # 4 = South Side
All measurements in millimeters

Year	Ring No.	North Early	North Late	South Early	South Late	Early Mean	Late Mean	Annual Mean
1985	1	1.150	1.450	.925	.925	1.037	1.188	2.225
1984	2	1.050	1.200	.950	.925	1.000	1.063	2.063
1983	3	1.225	1.575	1.050	1.900	1.137	1.737	2.875
1982	4	1.375	2.300	1.225	2.375	1.300	2.337	3.637
1981	5	1.625	3.000	1.150	2.400	1.387	2.700	4.087
1980	6	1.900	3.925	1.550	4.100	1.725	4.012	5.737
1979	7	2.050	3.600	1.900	4.300	1.975	3.950	5.925
1978	8	1.950	3.625	1.300	3.750	1.625	3.688	5.313
1977	9	1.825	4.525	1.875	3.800	1.850	4.163	6.013
1976	10	1.950	2.450	1.450	2.550	1.700	2.500	4.200
1975	11	1.850	4.375	1.325	3.850	1.587	4.113	5.700
1974	12	1.450	4.550	1.625	2.875	1.537	3.712	5.250
1973	13	1.275	3.025	1.350	3.050	1.312	3.037	4.350
1972	14	1.800	2.850	1.575	2.625	1.688	2.737	4.425
1971	15	1.850	3.425	2.050	2.375	1.950	2.900	4.850
1970	16	1.800	4.050	2.125	3.300	1.962	3.675	5.637
1969	17	1.625	4.375	1.975	3.750	1.800	4.063	5.863
1968	18	1.675	2.325	1.525	2.750	1.600	2.537	4.137
1967	19	1.725	3.275	1.725	2.350	1.725	2.813	4.537
1966	20	1.525	3.075	1.500	2.375	1.512	2.725	4.237
1965	21	1.500	3.875	1.175	2.775	1.337	3.325	4.662
1964	22	1.625	1.925	.825	2.000	1.225	1.962	3.187
1963	23	1.775	2.625	1.175	1.550	1.475	2.087	3.562
1962	24	1.250	3.325	.800	2.300	1.025	2.813	3.837
1961	25	2.050	3.625	1.025	2.925	1.537	3.275	4.812
1960	26	1.450	3.375	1.350	2.375	1.400	2.875	4.275
1959	27	1.250	3.875	1.400	2.625	1.325	3.250	4.575

1958	28	1.350	3.925	1.350	2.975	1.350	3.450	4.800
1957	29	1.550	3.075	1.150	2.650	1.350	2.862	4.212
1956	30	1.850	2.800	1.125	2.925	1.488	2.862	4.350
1955	31	1.450	3.350	1.400	3.550	1.425	3.450	4.875
1954	32	1.800	2.550	1.550	2.500	1.675	2.525	4.200
1953	33	1.525	4.450	1.250	4.550	1.387	4.500	5.887
1952	34	1.550	2.850	1.275	3.125	1.412	2.987	4.400
1951	35	1.600	2.375	1.325	2.850	1.462	2.612	4.075
1950	36	1.825	1.400	1.275	2.325	1.550	1.862	3.412
1949	37	1.300	2.300	1.075	3.525	1.188	2.912	4.100
1948	38	1.175	1.050	.950	1.100	1.063	1.075	2.137
1947	39	1.450	3.125	1.550	2.450	1.500	2.787	4.287
1946	40	1.425	3.775	1.125	2.025	1.275	2.900	4.175
1945	41	1.500	2.950	1.425	1.550	1.462	2.250	3.712
1944	42	1.625	3.300	1.250	2.400	1.438	2.850	4.287
1943	43	1.625	3.625	1.400	2.750	1.512	3.188	4.700
1942	44	1.675	2.825	1.875	3.700	1.775	3.262	5.037
1941	45	1.250	2.900	1.425	3.250	1.337	3.075	4.412
1940	46	1.450	3.150	1.475	2.900	1.462	3.025	4.487
1939	47	1.300	3.800	1.350	3.275	1.325	3.537	4.862
1938	48	1.950	4.925	1.800	3.550	1.875	4.238	6.113
1937	49	1.225	3.650	1.325	4.050	1.275	3.850	5.125
1936	50	1.125	2.800	.875	2.500	1.000	2.650	3.650
1935	51	.750	2.425	.975	2.175	.862	2.300	3.162
1934	52	.850	.775	.950	.850	.900	.813	1.712
1933	53	1.075	1.375	.575	1.525	.825	1.450	2.275
1932	54	1.175	3.625	1.025	2.050	1.100	2.837	3.937
1931	55	1.125	4.025	.800	2.300	.963	3.162	4.125
1930	56	.850	3.125	.475	2.150	.662	2.637	3.300
1929	57	.800	1.900	.475	1.050	.637	1.475	2.112
1928	58	.825	1.800	.350	1.250	.587	1.525	2.112
1927	59	.675	.950	.350	.700	.512	.825	1.337
1926	60	.500	.925	.525	.700	.512	.813	1.325
1925	61	.525	1.125	.500	.825	.512	.975	1.487
1924	62	.575	1.100	.575	1.225	.575	1.162	1.737
1923	63	.900	1.450	.750	1.225	.825	1.337	2.162
1922	64	.975	1.925	.525	1.400	.750	1.662	2.412
1921	65	.625	1.400	.500	1.275	.563	1.337	1.900
1920	66	.550	1.075	.475	.850	.512	.962	1.475
1919	67	.425	.825	.550	1.050	.487	.938	1.425
1918	68	.800	1.325	.575	.950	.668	1.137	1.825
1917	69	.525	1.575	.575	1.050	.550	1.313	1.362
1916	70	.450	1.350	.525	.850	.487	1.100	1.587
1915	71	.500	1.300	.625	.975	.563	1.087	1.650
1914	72	.725	1.450	.550	.875	.637	1.162	1.800
1913	73	.975	1.900	.325	1.100	.650	1.500	2.150
1912	74	.675	1.625	.550	1.050	.612	1.337	1.950
1911	75	.450	1.000	.400	.775	.425	.887	1.312

1910	76	.575	1.475	.500	1.275	.537	1.375	1.912
1909	77	.525	1.775	.350	1.325	.438	1.550	1.987
1908	78	.450	1.175	.350	1.300	.400	1.238	1.637
1907	79	.525	1.325	.350	1.150	.438	1.237	1.675

Red Oak Tree # 3 Core # 7 (North Side) and Core # 8 (South Side)
All measurements in millimeters

Year	Ring No.	North Early	North Late	South Early	South Late	Early Mean	Late Mean	Annual Mean
1985	1	.775	1.100	1.175	.750	.975	.925	1.900
1984	2	.775	.925	1.150	4.300	.962	2.612	3.575
1983	3	1.025	.875	1.400	3.050	1.212	1.962	3.175
1982	4	.850	1.325	1.450	3.625	1.150	2.475	3.625
1981	5	1.150	.900	1.050	3.525	1.100	2.212	3.312
1980	6	1.325	2.675	1.475	1.775	1.400	2.225	3.625
1979	7	1.300	2.425	1.175	4.500	1.238	3.462	4.700
1978	8	1.600	2.450	.725	3.625	1.162	3.037	4.200
1977	9	1.475	2.175	1.450	3.625	1.462	2.900	4.362
1976	10	1.600	1.300	1.425	4.250	1.512	2.775	4.287
1975	11	1.200	3.150	1.225	3.700	1.212	3.425	4.637
1974	12	.975	2.625	1.600	4.900	1.287	3.762	5.050
1973	13	1.400	1.950	1.100	3.675	1.250	2.812	4.062
1972	14	1.225	3.025	1.225	2.925	1.225	2.975	4.200
1971	15	1.450	2.175	1.125	2.475	1.287	2.325	3.612
1970	16	1.475	3.375	1.550	2.575	1.512	2.975	4.487
1969	17	1.325	3.275	.450	2.500	.887	2.887	3.775
1968	18	1.300	2.500	1.250	.925	1.275	1.712	2.987
1967	19	1.400	2.925	1.825	3.625	1.612	3.275	4.887
1966	20	1.375	2.350	.975	3.550	1.175	2.950	4.125
1965	21	1.350	2.650	.850	4.025	1.100	3.337	4.437
1964	22	1.450	2.225	.600	4.375	1.025	3.300	4.325
1963	23	1.450	2.100	1.150	4.550	1.300	3.325	4.625
1962	24	1.275	2.550	.950	3.975	1.112	3.262	4.375
1961	25	1.025	3.300	1.025	2.900	1.025	3.100	4.125
1960	26	1.525	2.525	1.425	3.125	1.475	2.825	4.300
1959	27	1.425	3.075	.775	3.875	1.100	3.475	4.575
1958	28	1.100	2.175	.600	2.150	.850	2.162	3.012
1957	29	1.050	2.125	.525	2.000	.787	2.063	2.850
1956	30	.725	1.600	.775	1.525	.750	1.563	2.313
1955	31	.800	1.100	.600	1.575	.700	1.337	2.037
1954	32	.900	.900	.750	.575	.825	.737	1.562
1953	33	.600	1.075	.525	1.025	.563	1.050	1.612
1952	34	.575	1.350	.725	.725	.650	1.037	1.687
1951	35	.700	.900	.800	1.100	.750	1.000	1.750
1950	36	.900	.625	.700	1.500	.800	1.063	1.862

1949	37	.650	.825	.875	.900	.762	.862	1.625
1948	38	.450	.700	.975	.875	.712	.787	1.500
1947	39	.525	1.950	1.000	1.650	.762	1.800	2.562
1946	40	1.000	1.750	1.100	2.425	1.050	2.087	3.137
1945	41	1.025	1.350	.800	2.575	.912	1.962	2.875
1944	42	.600	.875	1.325	2.650	.962	1.762	2.725
1943	43	.875	.975	1.025	3.250	.950	2.112	3.062
1942	44	1.200	2.150	1.400	3.475	1.300	2.813	4.112
1941	45	.850	2.475	1.050	3.750	.950	3.112	4.062
1940	46	.975	2.025	.800	3.450	.887	2.737	3.625
1939	47	.900	3.425	.875	2.800	.887	3.112	4.000
1938	48	1.000	3.925	.725	1.825	.862	2.875	3.737
1937	49	1.025	3.650	1.050	2.500	1.037	3.075	4.112
1936	50	.975	3.825	.750	3.550	.862	3.688	4.550
1935	51	1.175	3.800	.925	3.050	1.050	3.425	4.475
1934	52	1.200	1.975	.825	2.575	1.012	2.275	3.287
1933	53	.950	2.625	.600	1.600	.775	2.112	2.987
1932	54	.875	3.025	.550	1.200	.712	2.112	2.825
1931	55	.900	2.100	.300	.575	.600	1.337	1.937
1930	56	.550	2.200	.400	.575	.475	1.387	1.862
1929	57	.825	1.975	.300	1.150	.562	1.563	2.125
1928	58	.700	1.850	.525	1.125	.612	1.488	2.100
1927	59	.550	.925	.625	1.150	.587	1.037	1.625
1926	60	.325	1.125	.175	1.725	.250	1.425	1.675
1925	61	.525	.975	.525	1.275	.525	1.125	1.650
1924	62	.500	.950	.300	.850	.400	.900	1.300
1923	63	.550	1.550	.450	1.125	.500	1.337	1.837
1922	64	.550	1.850	.475	1.375	.512	1.613	2.125
1921	65	.625	1.6600	.200	2.050	.412	1.825	2.237
1920	66	.450	1.525	.275	2.050	.362	1.787	2.150
1919	67	.600	1.425	.325	.525	.462	.975	1.437
1918	68	.650	1.300	.225	1.075	.438	1.188	1.625
1917	69	.525	2.100	.375	.725	.450	1.412	1.862
1916	70	.500	2.750	.425	.500	.462	1.625	2.087
1915	71	.425	2.775	.200	1.050	.313	1.912	2.225
1914	72	.450	1.275	.325	.750	.388	1.012	1.400
1913	73	.375	1.775	.425	.350	.400	1.062	1.462
1912	74	.350	.525	.300	.600	.325	.563	.887
1911	75	.425	.675	.325	1.325	.375	1.000	1.375
1910	76	.250	1.075	.500	.900	.375	.987	1.362
1909	77	.325	.375	.425	1.200	.375	.787	1.162
1908	78	.325	.400	.675	1.600	.500	1.000	1.500
1907	79	.450	.575	.550	2.475	.500	1.525	2.025
1906	80	.400	1.200	.300	1.900	.350	1.550	1.900
1905	81	.525	1.325	.400	1.425	.463	1.375	1.837
1904	82	.500	1.575	.350	1.300	.425	1.438	1.962
1903	83	.575	2.150	.300	1.175	.437	1.062	2.100
1902	84	.500	2.475	.500	1.900	.500	2.188	2.686

1901	85	.425	2.400	.625	2.025	.525	2.212	2.737
1900	86	.375	2.150	.375	1.300	.375	1.725	2.100
1899	87	.450	1.950	.150	1.325	.300	1.637	1.937
1898	88	.425	1.450	.150	1.375	.287	1.412	1.700

Red Oak Tree # 4 Core # 9 = North Side and Core # 10 = South Side
All measurements in millimeters

Year	Ring No.	North Early	North Late	South Early	South Late	Early Mean	Late Mean	Annual Mean
1985	1	.500	1.275	.550	1.925	.525	1.600	2.125
1984	2	.525	.475	.675	.725	.600	.600	1.200
1983	3	.875	.875	.775	1.125	.825	1.000	1.825
1982	4	.475	1.175	.625	2.2775	.550	1.725	2.275
1981	5	.850	.950	1.075	1.675	.962	1.313	2.275
1980	6	.850	2.375	1.125	4.425	.987	3.400	4.388
1979	7	.700	2.300	1.100	3.975	.900	3.137	4.037
1978	8	.900	1.325	1.075	3.650	.987	2.487	3.475
1977	9	.650	1.275	.750	3.375	.700	2.325	3.025
1976	10	.950	.525	.925	2.500	.938	1.512	2.450
1975	11	.550	1.825	.775	3.100	.662	2.462	3.125
1974	12	.550	1.050	.675	2.550	.612	1.800	2.412
1973	13	.800	.975	.600	3.400	.700	2.187	2.887
1972	14	.950	1.100	1.050	3.275	1.000	2.187	3.187
1971	15	.500	1.450	1.250	2.025	.875	1.737	2.612
1970	16	.850	1.175	.975	2.675	.912	1.925	2.837
1969	17	.875	1.425	.900	2.825	.887	2.125	3.012
1968	18	.275	1.400	1.225	2.450	.750	1.925	2.675
1967	19	.800	1.825	1.275	2.775	1.037	2.300	3.337
1966	20	.650	1.675	1.075	2.475	.862	2.075	2.937
1965	21	.650	1.250	.775	2.325	.713	1.787	2.500
1964	22	.725	.825	.800	2.625	.762	1.725	2.487
1963	23	.750	1.850	1.075	2.800	.912	2.325	3.237
1962	24	.675	1.525	.550	2.800	.612	2.162	2.775
1961	25	.475	1.100	.950	2.000	.712	1.550	2.262
1960	26	.525	.950	.825	1.600	.675	1.275	1.950
1959	27	.525	1.250	1.050	1.100	.787	1.175	1.962
1958	28	.600	2.050	.750	2.275	.675	2.162	2.837
1957	29	.725	1.550	.675	1.900	.700	1.725	2.425
1956	30	.675	2.200	1.050	2.925	.862	2.562	3.425
1955	31	.575	2.050	.650	2.400	.612	2.225	2.837
1954	32	.775	2.200	.625	1.700	.700	1.950	2.650
1953	33	.925	2.375	.850	2.125	.887	2.250	3.137
1952	34	.675	2.250	.575	1.825	.625	2.037	2.662
1951	35	.625	2.650	.650	2.275	.637	2.462	3.100
1950	36	.450	1.900	.575	2.050	.512	1.975	2.487

1949	37	.625	1.775	.550	1.975	.587	1.875	2.462
1948	38	.450	.975	.625	1.050	.537	1.012	1.550
1947	39	.500	1.775	.475	2.325	.487	2.050	2.537
1946	40	.600	2.425	.700	2.300	.650	2.362	3.012
1945	41	.450	1.875	.650	2.150	.550	2.012	2.562
1944	42	.600	1.375	.525	2.025	.563	1.700	2.262
1943	43	.700	1.325	.700	2.175	.700	1.750	2.450
1942	44	.400	2.200	.475	2.800	.438	2.500	2.937
1941	45	.475	1.625	.625	2.275	.550	1.950	2.500
1940	46	.400	1.600	.600	2.300	.500	1.950	2.450
1939	47	.500	2.250	.400	3.550	.450	2.900	3.350
1938	48	.500	2.150	.225	3.475	.362	2.813	3.175
1937	49	.300	2.450	.450	2.200	.375	2.325	2.700
1936	50	.200	1.575	.250	2.100	.225	1.837	2.062
1935	51	.325	1.625	.450	2.625	.388	2.125	2.512
1934	52	.275	.625	.250	1.050	.262	.838	1.100
1933	53	.200	1.000	.275	1.825	.237	1.412	1.650
1932	54	.225	1.525	.350	1.700	.287	1.612	1.900
1931	55	.075	1.375	.225	1.050	.150	1.212	1.362

Red Oak Tree # 5 Core # 11 = North Side and Core # 12 = South Side
All measurements in millimeters

Year	Ring No.	North Early	North Late	South Early	South Late	Early Mean	Late Mean	Annual Mean
1985	1	1.000	1.900	.800	1.775	.900	1.837	2.737
1984	2	.825	1.350	.850	1.150	.837	1.250	2.087
1983	3	1.175	1.400	1.325	1.325	1.250	1.362	2.612
1982	4	.850	1.625	1.150	1.375	1.000	1.500	2.500
1981	5	1.050	1.050	.950	1.275	1.000	1.162	2.162
1980	6	1.025	2.800	1.100	4.250	1.062	3.525	4.587
1979	7	1.375	1.475	.875	3.950	1.125	2.712	3.837
1978	8	.800	1.725	1.150	2.075	.975	1.900	2.875
1977	9	1.275	1.525	1.350	2.050	1.312	1.787	3.100
1976	10	.975	1.800	1.325	2.525	1.150	2.162	3.312
1975	11	.825	1.900	1.450	2.925	1.137	2.412	3.550
1974	12	1.050	1.025	1.275	2.575	1.162	1.800	2.962
1973	13	1.450	2.100	1.150	4.150	1.300	3.125	4.425
1972	14	1.400	2.050	1.325	4.175	1.362	3.113	4.475
1971	15	1.100	1.350	1.025	2.700	1.062	2.025	3.087
1970	16	.700	2.275	.900	3.025	.800	2.650	3.450
1969	17	.650	2.900	.650	3.475	.650	3.188	3.837
1968	18	1.150	2.075	1.400	3.475	1.275	2.775	4.050
1967	19	.875	2.525	1.050	3.200	.963	2.862	3.825
1966	20	.950	2.540	1.250	3.075	1.100	2.807	3.907
1965	21	1.025	2.150	1.300	2.600	1.162	2.375	3.537

1964	22	.875	1.650	1.175	2.450	1.025	2.050	3.075
1963	23	.950	1.825	1.150	3.325	1.050	2.575	3.625
1962	24	1.025	1.650	1.175	2.700	1.100	2.275	3.375
1961	25	.950	1.600	1.300	3.175	1.125	2.387	3.512
1960	26	.700	2.025	1.125	3.200	.912	2.612	3.525
1959	27	.700	1.750	1.125	2.950	.912	2.350	3.262
1958	28	.600	1.325	1.000	2.650	.800	1.987	2.787
1957	29	.800	1.525	1.100	2.775	.950	2.150	3.100
1956	30	.925	1.350	.975	2.525	.950	1.937	2.887
1955	31	.610	1.725	.700	2.725	.655	2.225	2.880
1954	32	.585	.705	.675	1.375	.630	1.040	1.670
1953	33	.510	1.205	.600	1.875	.555	1.540	2.095
1952	34	.800	.730	.575	1.400	.688	1.065	1.752
1951	35	.550	.925	.675	1.400	.612	1.162	1.775
1950	36	.700	.600	.800	.550	.750	.575	1.325
1949	37	.625	1.975	.650	1.625	.637	1.800	2.438
1948	38	.650	1.125	.750	1.225	.700	1.175	1.875
1947	39	.925	2.900	.775	4.025	.850	3.462	4.312
1946	40	.700	2.550	1.050	3.750	.875	3.150	4.025
1945	41	.550	2.300	.525	2.725	.537	2.512	3.050
1944	42	.775	1.125	.900	1.300	.838	1.212	2.050
1943	43	.875	2.375	.750	3.375	.813	2.875	3.688
1942	44	.500	3.175	.850	2.875	.675	3.025	3.700
1941	45	.725	3.075	.600	3.800	.662	3.437	4.100
1940	46	.400	3.200	.825	3.600	.612	3.400	4.012
1939	47	.450	3.375	.800	3.400	.625	3.387	4.012
1938	48	.525	3.325	.775	2.975	.650	3.150	3.800
1937	49	.475	2.450	.650	2.925	.563	2.687	3.250
1936	50	.600	1.900	.350	2.225	.475	2.063	2.537
1935	51	.350	1.900	.500	2.850	.425	2.375	2.800

Red Oak Tree # 6 Core # 13 = North Side and Core # 14 = South Side

All measurements in millimeters

Year	Ring No.	North Early	North Late	South Early	South Late	Early Mean	Late Mean	Annual Mean
1985	1	.400	.950	.200	.500	.300	.725	1.025
1984	2	.375	1.150	.775	1.050	.575	1.100	1.675
1983	3	.975	.600	.900	.800	.938	.700	1.637
1982	4	.650	.800	.875	.875	.762	.838	1.600
1981	5	.875	.875	.475	1.800	.675	1.337	2.012
1980	6	.925	2.275	.725	2.525	.825	2.400	3.225
1979	7	.750	1.150	1.150	1.400	.950	1.275	2.225
1978	8	1.025	1.275	1.150	1.200	1.087	1.237	2.325
1977	9	.375	.900	.875	.925	.625	.912	1.537
1976	10	1.200	1.275	.950	1.250	1.075	1.262	2.337

1975	11	1.025	1.375	.925	1.800	.975	1.587	2.562
1974	12	.825	2.250	.950	1.800	.887	2.025	2.912
1973	13	1.250	1.300	.775	1.775	1.012	1.537	2.550
1972	14	1.350	2.250	.425	2.225	.887	2.237	3.125
1971	15	.750	2.950	1.250	1.500	1.000	2.225	3.225
1970	16	1.250	2.825	1.650	.975	1.450	1.900	3.750
1969	17	.950	2.475	1.150	.775	1.050	1.625	2.675
1968	18	1.475	2.325	1.050	1.325	1.262	1.825	3.087
1967	19	1.125	1.925	1.300	1.450	1.212	1.688	2.900
1966	20	1.025	2.400	.850	1.200	.937	1.800	2.737
1965	21	1.450	1.975	.900	1.100	1.175	1.537	2.712
1964	22	.900	2.975	1.000	2.225	.950	2.600	3.550
1963	23	1.400	1.700	1.375	1.675	1.387	1.688	3.075
1962	24	.625	2.925	1.325	1.600	.975	2.262	3.237
1961	25	1.425	1.950	.825	1.500	1.125	1.725	2.850
1960	26	1.450	3.250	1.350	2.400	1.400	2.825	4.225
1959	27	1.300	3.525	1.150	1.600	1.225	2.563	3.787
1958	28	.800	3.100	1.050	1.650	.925	2.375	3.300
1957	29	1.350	3.400	1.275	2.350	1.312	2.875	4.187
1956	30	1.200	3.225	1.275	2.300	1.237	2.762	4.000
1955	31	1.300	3.250	1.050	3.200	1.175	3.225	4.400
1954	32	1.150	2.450	.750	2.150	.950	2.300	3.250
1953	33	1.275	3.500	.900	3.325	1.087	3.413	4.500
1952	34	1.175	2.525	.975	2.250	1.075	2.387	3.462
1951	35	1.225	2.350	.825	1.825	1.025	2.087	3.112
1950	36	1.050	2.025	.850	2.000	.950	2.012	2.962
1949	37	.550	2.775	.800	1.975	.675	2.375	3.050
1948	38	.700	1.450	.725	2.075	.712	1.762	2.475
1947	39	.750	4.700	.975	3.700	.862	4.200	5.063
1946	40	.475	3.225	.575	1.850	.525	2.538	3.063
1945	41	1.350	2.150	1.500	1.675	1.425	1.912	3.337
1944	42	1.050	2.700	.950	2.125	1.000	2.412	3.412
1943	43	.650	3.175	1.150	2.625	.900	2.900	3.800
1942	44	.975	4.050	1.575	3.650	1.275	3.850	5.125
1941	45	.925	2.950	1.525	2.825	1.225	2.887	4.112
1940	46	.625	2.875	1.375	2.850	1.000	2.862	3.862
1939	47	1.450	2.025	1.025	2.925	1.237	2.475	3.712
1938	48	1.150	2.925	.950	3.400	1.050	3.162	4.212
1937	49	.600	2.950	1.800	3.075	1.200	3.012	4.212
1936	50	.825	2.975	.825	2.900	.825	2.938	3.762
1935	51	.700	2.525	.925	2.975	.813	2.750	3.563
1934	52	.600	.775	.975	.850	.787	.813	1.600
1933	53	.625	1.125	1.300	1.375	.963	1.250	2.212
1932	54	.425	1.975	1.225	2.525	.925	2.250	3.075
1931	55	.225	1.125	.900	1.850	.563	1.488	2.050
1930	56	.725	.975	1.125	1.425	.925	1.200	2.125
1929	57	.550	.850	.800	1.025	.675	.937	1.612
1928	58	.425	.925	.875	.925	.650	.925	1.575

1927	59	.625	.450	.750	.575	.688	.512	1.200
1926	60	.600	1.050	.925	2.125	.762	1.587	2.350
1925	61	.575	1.650	1.000	2.125	.787	1.887	2.675
1924	62	.525	1.700	1.025	2.325	.775	2.012	2.787
1923	63	.425	1.800	1.175	2.175	.800	1.987	2.787
1922	64	.700	1.725	1.125	2.450	.912	2.087	3.000
1921	65	.750	1.300	.750	2.300	.750	1.800	2.550
1920	66	.525	1.150	.825	1.200	.675	1.175	1.850
1919	67	.250	.775	.875	.825	.563	.800	1.362
1918	68	.450	.975	.850	2.500	.650	1.737	2.387
1917	69	.450	1.150	.850	1.650	.650	1.400	2.050
1916	70	.525	1.475	.650	1.050	.588	1.262	1.850
1915	71	.925	1.675	.825	1.875	.875	1.775	2.650
1914	72	.325	1.150	.975	.725	.650	.937	1.587
1913	73	.425	.700	.700	1.575	.562	1.137	1.700
1912	74	.375	.975	1.125	1.250	.750	1.112	1.862
1911	75	.550	1.075	1.150	2.050	.850	1.562	2.412
1910	76	.500	.850	1.300	2.225	.900	1.537	2.437
1909	77	.300	1.025	.725	2.600	.512	1.813	2.325
1908	78	.375	.600	1.025	2.175	.700	1.387	2.087
1907	79	.425	1.150	.800	1.925	.612	1.537	2.150
1906	80	.525	1.100	1.000	2.825	.762	1.962	2.725
1905	81	.600	1.175	.950	3.025	.775	2.100	2.875
1904	82	.350	.925	.875	3.050	.612	1.987	2.600
1903	83	.250	1.575	1.150	2.550	.700	2.062	2.762
1902	84	.400	1.100	.750	3.725	.575	2.412	2.987
1901	85	.625	1.550	.625	2.375	.625	1.962	2.587
1900	86	.350	1.625	.775	2.900	.563	2.262	2.825
1899	87	.550	1.750	.675	2.025	.612	1.887	2.500
1898	88	.325	1.425	.600	1.950	.462	1.688	2.150
1897	89	.200	1.775	.475	1.300	.337	1.537	1.875
1896	90	.300	.400	.425	1.050	.362	.725	1.087

Red Oak Tree # 7 Core # 15 = North Side and Core # 16 = South Side
All measurements in millimeters

Year	Ring No.	North Early	North Late	South Early	South Late	Early Mean	Late Mean	Annual Mean
1985	1	1.050	1.550	.900	2.100	.975	1.825	2.800
1984	2	.775	1.650	1.000	1.375	.887	1.512	2.400
1983	3	.500	1.750	.900	1.650	.700	1.700	2.400
1982	4	.900	1.150	.775	.950	.838	1.050	1.887
1981	5	.800	1.050	1.025	1.425	.912	1.238	2.150
1980	6	1.275	2.650	1.200	3.600	1.237	3.125	4.362
1979	7	1.525	2.550	.750	4.975	1.137	3.763	4.900
1978	8	.900	3.800	1.200	4.600	1.050	4.200	5.250

1977	9	1.275	3.775	1.050	4.100	1.162	3.937	5.100
1976	10	1.050	2.550	1.025	3.650	1.037	3.100	4.137
1975	11	1.175	3.300	1.050	3.550	1.113	3.425	4.537
1974	12	1.225	2.675	.950	1.800	1.087	2.237	3.325
1973	13	1.400	2.350	1.000	3.600	1.200	2.975	4.175
1972	14	1.175	2.575	.875	4.075	1.025	3.325	4.350
1971	15	1.200	2.375	1.225	3.975	1.212	3.175	4.387
1970	16	1.375	2.825	1.225	3.525	1.300	3.175	4.475
1969	17	1.400	3.625	1.475	3.875	1.437	3.750	5.187
1968	18	1.300	3.475	1.100	3.800	1.200	3.637	4.837
1967	19	1.400	3.500	.650	4.400	1.025	3.950	4.975
1966	20	1.000	3.600	1.200	2.775	1.100	3.188	4.287
1965	21	1.400	2.600	.825	2.875	1.112	2.737	3.850
1964	22	1.225	2.600	1.300	3.775	1.262	3.188	4.450
1963	23	1.475	2.050	1.450	2.925	1.462	2.487	3.950
1962	24	.950	1.725	.825	2.750	.887	2.237	3.125
1961	25	.525	2.475	.725	2.750	.625	2.612	3.237
1960	26	.550	1.625	.675	1.550	.612	1.587	2.200
1959	27	.850	1.300	.450	2.000	.650	1.650	2.300
1958	28	.650	1.325	.475	1.975	.563	1.650	2.212
1957	29	.875	2.075	.800	2.075	.838	2.075	2.912
1956	30	.900	1.100	.550	1.875	.725	1.487	2.212
1955	31	.875	3.550	.950	2.300	.912	2.925	3.837
1954	32	.800	2.600	.900	2.050	.850	2.325	3.175
1953	33	.750	3.050	.500	2.525	.625	2.787	3.412
1952	34	.675	1.925	.325	2.125	.500	2.025	2.525
1951	35	.600	1.775	.300	1.775	.450	1.775	2.225
1950	36	.575	.975	.450	1.325	.512	1.150	1.662
1949	37	.525	1.500	.475	1.550	.500	1.525	2.025
1948	38	.550	.900	.400	.600	.475	.750	1.225
1947	39	.475	2.525	.450	2.200	.462	2.362	2.825
1946	40	.675	2.475	.400	1.825	.537	2.150	2.687
1945	41	1.000	1.900	.450	1.550	.725	1.725	2.450
1944	42	.825	2.125	.275	1.050	.550	1.587	2.137
1943	43	.925	1.875	.675	1.650	.800	1.762	2.562
1942	44	.350	3.200	.325	2.575	.337	2.887	3.225
1941	45	.625	2.525	.475	2.675	.550	2.600	3.150
1940	46	1.150	2.500	.900	2.200	1.025	2.350	3.375
1939	47	.675	3.625	.975	3.675	.825	3.650	4.475
1938	48	.450	3.775	.600	3.800	.525	3.787	4.312
1937	49	.500	3.675	.200	2.875	.350	3.275	3.625
1936	50	.475	2.575	.300	2.300	.387	2.437	2.825
1935	51	.925	2.550	.450	3.100	.688	2.825	3.512
1934	52	.350	1.400	.150	1.350	.250	1.375	1.625
1933	53	.475	1.375	.350	.925	.412	1.150	1.562
1932	54	.425	3.100	.200	1.925	.313	2.512	2.825
1931	55	.175	2.525	.225	1.325	.200	1.925	2.125
1930	56	.250	1.725	.225	1.300	.237	1.512	1.750

1929	57	.175	1.025	.175	1.050	.175	1.037	1.212
1928	58	.350	1.150	.100	1.375	.225	1.262	1.487
1927	59	.175	.800	.075	1.250	.125	1.025	1.150
1926	60	.250	1.300	.125	1.050	.188	1.175	1.363
1925	61	.175	1.225	.200	1.075	.188	1.150	1.337
1924	62	.275	.475	.150	.375	.212	.425	.637
1923	63	.700	1.125	.275	1.025	.487	1.075	1.562

Red Oak Tree # 8 (Slab # 1) Radius # 1 and Radius # 2
Chronology begins in 1983. All measurements in millimeters.

Year	Ring No.	Radius 1 Early	Radius 1 Late	Radius 2 Early	Radius 2 Late	Early Mean	Late Mean	Annual Mean
1985	1							
1984	2							
1983	3	.800	1.800	.500	.950	.650	1.375	2.025
1982	4	.525	2.175	.450	.950	.487	1.562	2.050
1981	5	.725	2.250	.350	.600	.537	1.425	1.962
1980	6	.775	4.300	.525	2.015	.650	3.157	3.807
1979	7	1.400	2.050	.450	.575	.925	1.312	2.237
1978	8	1.400	2.500	.225	1.600	.812	2.050	2.862
1977	9	.525	2.375	.275	1.300	.400	1.837	2.237
1976	10	.900	1.575	.450	.975	.675	1.275	1.950
1975	11	.800	1.750	.150	.725	.475	1.237	1.712
1974	12	.625	.500	.250	.650	.438	.575	1.012
1973	13	.725	1.450	.425	.650	.575	1.050	1.625
1972	14	.225	1.300	.250	.750	.237	1.025	1.262
1971	15	.600	1.025	.525	1.800	.563	1.412	1.975
1970	16	.400	1.225	.525	1.375	.463	1.300	1.762
1969	17	.475	1.800	.425	1.275	.450	1.537	1.987
1968	18	.575	1.725	.525	1.050	.550	1.387	1.937
1967	19	.625	1.175	.200	1.550	.412	1.363	1.775
1966	20	.375	1.550	.600	1.000	.487	1.275	1.762
1965	21	.475	1.550	.450	1.450	.462	1.500	1.962
1964	22	.675	.875	.425	1.500	.550	1.188	1.737
1963	23	.925	1.125	.375	1.100	.650	1.112	1.762
1962	24	.550	1.500	.225	1.050	.387	1.275	1.662
1961	25	.675	1.525	.200	1.225	.437	1.375	1.812
1960	26	.475	.950	.400	.775	.438	.862	1.300
1959	27	.625	.925	.400	2.050	.512	1.487	2.000
1958	28	.450	.925	.425	1.050	.438	.988	1.425
1957	29	.800	1.150	.400	1.550	.600	1.350	1.950
1956	30	.550	1.050	.275	1.575	.412	1.313	1.725
1955	31	.450	1.275	.150	1.600	.300	1.438	1.737
1954	32	.525	1.175	.475	1.125	.500	1.150	1.650
1953	33	.625	1.525	.425	1.475	.525	1.500	2.025

1952	34	.775	1.200	.525	1.250	.650	1.225	1.875
1951	35	.250	1.900	.175	1.225	.212	1.562	1.775
1950	36	.675	1.275	.375	1.000	.525	1.137	1.662
1949	37	.475	1.250	.625	1.125	.550	1.188	1.737
1948	38	.475	1.150	.525	1.400	.500	1.275	1.775
1947	39	.550	1.900	.175	.975	.362	1.437	1.800
1946	40	.750	1.775	.675	1.550	.712	1.662	2.375
1945	41	.600	1.050	.575	1.650	.587	1.350	1.937
1944	42	.925	1.175	.325	2.175	.625	1.675	2.300
1943	43	.275	1.950	.475	1.800	.375	1.875	2.250
1942	44	.775	2.075	.475	2.025	.625	2.050	2.675
1941	45	.925	1.925	.550	2.725	.737	2.325	3.062
1940	46	.550	2.375	.750	2.750	.650	2.563	3.212
1939	47	.550	2.725	1.025	4.575	.787	3.650	4.438
1938	48	.675	3.125	.875	3.275	.775	3.200	3.975
1937	49	1.125	3.850	.650	3.650	.887	3.750	4.637
1936	50	1.200	2.900	.650	3.600	.925	3.250	4.175
1935	51	.900	3.875	.475	3.100	.688	3.487	4.175
1934	52	.725	3.100	.750	2.075	.737	2.587	3.325
1933	53	.950	3.800	.650	2.850	.800	3.325	4.125
1932	54	1.250	2.450	.925	2.350	1.087	2.400	3.487
1931	55	.725	3.700	.600	2.800	.662	3.250	3.912
1930	56	.625	3.775	.675	1.525	.650	2.650	3.300
1929	57	.800	2.725	.700	1.475	.750	2.100	2.850
1928	58	.400	3.075	.150	2.825	.275	2.950	3.225
1927	59	.775	1.750	.550	2.550	.662	2.150	2.812
1926	60	.675	2.550	.450	3.325	.562	2.938	3.500
1925	61	.950	2.050	.425	2.625	.687	2.337	3.025
1924	62	.725	3.050	.600	2.700	.662	2.875	3.537
1923	63	1.025	2.650	.550	3.650	.787	3.150	3.937
1922	64	1.200	1.900	.475	3.175	.837	2.537	3.375
1921	65	1.225	2.300	.625	2.950	.925	2.625	3.550
1920	66	1.200	2.725	.325	2.400	.762	2.563	3.325
1919	67	1.750	3.075	.400	2.125	1.075	2.600	3.675
1918	68	1.075	1.675	.175	1.525	.625	1.600	2.225
1917	69	.650	2.075	.275	1.800	.462	1.937	2.400
1916	70	.225	1.325	.275	2.025	.250	1.675	1.925

Red Oak Tree # 9 (Slab # 2) Radius # 1 and Radius # 2
All measurements in millimeters

Year	Ring No.	1 Early	1 Late	2 Early	2 Late	Early Mean	Late Mean	Annual Mean
1985	1							
1984	2							
1983	3	.825	2.075	.600	3.075	.712	2.575	3.287

1982	4	.200	1.550	.950	1.350	.575	1.450	2.025
1981	5	.525	3.075	.750	4.775	.637	3.925	4.563
1980	6	.725	2.875	1.275	2.600	1.000	2.737	3.737
1979	7	1.100	2.800	.775	3.175	.937	2.987	3.925
1978	8	1.100	2.600	.450	3.450	.775	3.025	3.800
1977	9	.900	1.450	.775	1.625	.838	1.537	2.375
1976	10	.850	2.225	.525	2.600	.688	2.413	3.100
1975	11	.875	1.525	.575	1.550	.725	1.537	2.262
1974	12	.850	2.975	.475	1.550	.662	2.262	2.925
1973	13	.900	2.725	.350	2.150	.625	2.438	3.063
1972	14	.700	3.150	.325	2.225	.512	2.688	3.200
1971	15	.325	2.475	.400	1.625	.362	2.050	2.412
1970	16	.425	3.325	.525	2.250	.475	2.788	3.262
1969	17	.300	2.275	.575	1.325	.437	1.800	2.237
1968	18	.550	2.200	.550	1.700	.550	1.950	2.500
1967	19	.650	4.275	.750	2.625	.700	3.450	4.150
1966	20	.550	6.975	.975	4.700	.762	5.938	6.600
1965	21	.350	3.050	.200	2.550	.275	2.800	3.075
1964	22	.360	2.275	.275	2.175	.287	2.225	2.512
1963	23	.225	2.075	.175	2.125	.200	2.100	2..300
1962	24	.400	2.050	.275	1.850	.337	1.950	2.287
1961	25	.425	4.375	.600	3.700	.512	4.038	4.550
1960	26	.350	3.8550	.700	6.850	.525	5.350	5.875
1959	27	.475	4.025	.250	4.175	.362	4.100	4.463
1958	28	.225	4.125	.450	2.600	.337	3.363	3.700
1957	29	.425	6.175	.550	5.550	.487	5.863	6.350
1956	30	.225	3.850	.375	4.050	.300	3.950	4.250
1955	31	.100	2.275	.225	2.350	.163	2.313	2.475
1954	32	.125	1.975	.200	2.850	.163	2.413	2.575
1953	33	.100	1.875	.075	1.900	.087	1.887	1.975
1952	34	.100	1.350	.150	1.825	.125	1.587	1.712
1951	35	.075	.975	.075	1.025	.075	1.000	1.075
1950	36	.075	.600	.075	.475	.075	.537	.612
1949	37	.100	1.175	.225	.650	.163	.912	1.075
1948	38	.175	1.075	.225	2.050	.200	1.562	1.762
1947	39	.100	1.025	.225	1.425	.163	1.225	1.387
1946	40	.150	1.300	.200	2.175	.175	1.737	1.912
1945	41	.050	1.275	.050	1.800	.050	1.537	1.587
1944	42	.100	1.400	.050	2.425	.075	1.912	1.987
1943	43	.100	2.525	.175	2.600	.137	2.563	2.700
1942	44	.125	2.075	.250	2.400	.188	2.237	2.425
1941	45	.025	.875	.050	1.650	.037	1.262	1.300
1940	46	.025	.200	.050	.250	.037	.225	.262
1939	47	.175	.500	.125	.550	.150	.525	.675
1938	48	.125	1.875	.125	2.175	.125	2.025	2.150
1937	49	.150	.925	.075	.725	.112	.825	.977
1936	50	.150	1.700	.200	2.575	.175	2.137	2.312
1935	51	.200	.475	.150	1.200	.175	.837	1.012

Red Oak Tree # 10 (Slab # 3) Radius # 1 and Radius # 2
All measurements in millimeters

Year	Ring No.	1 Early	1 Late	2 Early	2 Late	Early Mean	Late Mean	Annual Mean
1985	1							
1984	2							
1983	3	.625	.250	.600	.300	.612	.275	.887
1982	4	1.125	1.025	.800	.375	.963	.700	1.662
1981	5	.975	1.400	.825	1.100	.900	1.250	2.150
1980	6	1.100	1.600	.925	1.700	1.012	1.650	2.662
1979	7	1.250	2.600	2.025	2.050	1.637	2.325	3.962
1978	8	.925	2.150	.800	2.750	.863	2.450	3.312
1977	9	1.350	2.425	1.100	.800	1.225	1.612	2.837
1976	10	1.125	2.475	1.425	1.475	1.275	1.975	3.250
1975	11	.850	4.075	1.200	3.550	1.025	3.813	4.837
1974	12	1.000	1.400	1.200	2.775	1.100	2.087	3.187
1973	13	.900	1.600	1.325	2.675	1.112	2.137	3.250
1972	14	.650	1.525	1.550	3.450	1.100	2.487	3.587
1971	15	.625	1.325	1.550	3.875	1.087	2.600	3.687
1970	16	1.050	.775	1.775	3.300	1.412	2.037	3.450
1969	17	1.325	1.125	1.125	4.825	1.225	2.975	4.200
1968	18	2.050	3.175	.900	6.825	1.475	5.000	6.475
1967	19	1.650	4.450	1.650	4.575	1.650	4.513	6.163
1966	20	1.500	3.550	1.175	4.075	1.337	3.813	5.150
1965	21	1.075	4.150	1.400	6.025	1.237	5.088	6.325
1964	22	1.950	3.375	1.675	7.500	1.813	5.438	7.250
1963	23	1.975	7.325	1.875	5.225	1.925	6.275	8.200
1962	24	1.450	7.850	1.025	4.950	1.237	6.400	7.637
1961	25	1.900	7.325	2.000	4.100	1.950	5.712	7.662
1960	26	1.900	8.975	1.600	7.775	1.750	8.375	10.125
1959	27	1.525	9.500	1.600	6.550	1.563	8.025	9.587
1958	28	1.425	6.325	1.900	4.650	1.613	5.487	7.100
1957	29	1.100	4.050	1.475	3.425	1.287	3.737	5.025
1956	30	1.025	3.050	1.600	4.525	1.313	3.788	5.100
1955	31	.750	1.725	1.075	4.625	.912	3.175	4.088
1954	32	.750	1.250	1.275	3.025	1.012	2.137	3.150
1953	33	.600	2.600	1.025	3.625	.812	3.112	3.925
1952	34	.750	1.150	.650	3.000	.700	2.075	2.775
1951	35	.800	1.275	.800	3.175	.800	2.225	3.025
1950	36	1.275	2.300	1.275	2.050	1.275	2.175	3.450
1949	37	1.075	3.800	1.750	2.400	1.412	3.100	4.512
1948	38	1.500	5.375	1.350	4.200	1.425	4.788	6.213
1947	39	1.525	7.375	1.125	5.200	1.325	6.288	7.613
1946	40	1.400	5.525	.850	3.525	1.125	4.525	5.650
1945	41	.800	3.700	.650	4.075	.725	3.888	4.612
1944	42	.875	2.150	1.025	1.675	.950	1.912	2.862
1943	43	1.325	6.325	1.325	5.850	1.325	6.087	7.412

1942	44	1.850	8.350	1.025	6.325	1.438	7.337	8.775
1941	45	1.525	6.075	.950	4.050	1.237	5.063	6.300
1940	46	1.175	5.475	1.425	3.575	1.300	4.525	5.825
1939	47	.825	5.450	1.125	3.775	.975	4.612	5.587
1938	48	1.250	4.250	1.325	2.550	1.287	3.400	4.687
1937	49	1.350	6.625	.850	4.675	1.100	5.650	6.750
1936	50	1.075	3.575	.675	3.300	.875	3.438	4.312
1935	51	.625	3.025	.475	3.475	.550	3.250	3.600
1934	52	.725	1.275	.725	2.175	.725	1.725	2.450
1933	53	.525	3.275	.650	2.775	.588	3.025	3.612
1932	54	.250	3.125	.375	2.425	.313	2.775	3.087
1931	55	.300	1.700	.425	1.550	.362	1.625	1.987
1930	56	.200	1.875	.525	1.825	.362	1.850	2.212
1929	57	.450	1.675	.425	1.550	.438	1.613	2.050
1928	58	.275	1.525	.300	1.975	.287	1.750	2.037
1927	59	.250	1.325	.400	1.375	.325	1.350	1.675
1926	60	.150	.600	.125	.550	.137	.575	.712
1925	61	.200	.925	.150	1.050	.175	.988	1.162
1924	62	.125	1.275	.200	1.025	.163	1.150	1.312

Red Oak Tree # 11 (Slab # 4) Radius 1 and Radius 2
All measurements in millimeters

Year	Ring No.	1 Early	1 Late	2 Early	2 Late	Early Mean	Late Mean	Annual Mean
1985	1							
1984	2							
1983	3	1.375	2.600	.800	1.575	1.087	2.087	3.175
1982	4	1.325	2.275	.850	1.225	1.087	1.750	2.837
1981	5	1.400	2.550	1.150	1.275	1.275	1.912	3.187
1980	6	1.650	5.825	.500	2.725	1.075	4.275	5.350
1979	7	1.775	4.875	1.400	1.325	1.587	3.100	4.688
1978	8	1.450	5.200	.625	3.400	1.037	4.300	5.337
1977	9	1.025	5.675	.800	2.875	.912	4.275	5.188
1976	10	1.450	3.925	.675	2.250	1.062	3.087	4.150
1975	11	1.100	4.375	.675	2.775	.887	3.575	4.463
1974	12	1.025	3.800	.650	2.050	.837	2.925	3.762
1973	13	1.450	4.025	.550	2.675	1.000	3.350	4.350
1972	14	1.275	3.825	.825	1.875	1.050	2.850	3.900
1971	15	1.075	5.525	.475	3.375	.775	4.450	5.225
1970	16	1.250	4.900	.625	2.925	.938	3.912	4.850
1969	17	1.250	4.675	.775	3.625	1.012	4.150	5.163
1968	18	1.100	4.375	.575	3.775	.837	4.075	4.913
1967	19	.575	4.550	.750	2.675	.662	3.612	4.275
1966	20	1.525	3.800	.675	2.625	1.100	3.212	4.312
1965	21	1.100	4.575	.575	3.800	.837	4.188	5.025

1964	22	1.225	3.800	.800	2.625	1.012	3.212	4.225
1963	23	1.125	3.600	.550	2.925	.837	3.262	4.100
1962	24	1.075	3.875	.500	3.100	.787	3.487	4.275
1961	25	1.300	3.000	.425	3.025	.862	3.012	3.875
1960	26	.925	3.825	.375	3.150	.650	3.487	4.137
1959	27	1.200	2.775	.400	3.275	.800	3.025	3.825
1958	28	.900	3.600	.525	3.525	.713	3.563	4.275
1957	29	.550	4.250	.525	3.400	.537	3.825	4.362
1956	30	.675	3.550	.725	3.125	.700	3.337	4.037
1955	31	.675	4.025	.350	4.050	.512	4.037	4.550
1954	32	.850	2.525	.525	2.750	.688	2.637	3.325
1953	33	.700	3.300	.250	3.275	.475	3.287	3.762
1952	34	.375	2.625	.225	3.150	.300	2.887	3.187
1951	35	.350	2.350	.225	2.800	.287	2.575	2.862
1950	36	.425	2.400	.175	2.275	.300	2.337	2.637
1949	37	.325	1.900	.275	1.700	.300	1.800	2.100
1948	38	.550	3.325	.575	3.575	.562	3.450	4.012
1947	39	.375	2.925	.325	4.100	.350	3.512	3.862
1946	40	.400	2.950	.425	3.750	.412	3.350	3.762
1945	41	.125	2.275	.275	3.900	.200	3.087	3.287
1944	42	.200	1.625	.275	2.025	.237	1.825	2.062
1943	43	.650	2.100	.275	3.075	.462	2.587	3.050
1942	44	.575	3.050	.200	3.750	.387	3.400	3.787
1941	45	.475	2.400	.250	2.775	.362	2.587	2.950
1940	46	.200	2.325	.250	2.450	.225	2.387	2.612
1939	47	.400	2.025	.100	2.300	.250	2.162	2.412
1938	48	.300	2.175	.200	2.150	.250	2.162	2.412
1937	49	.250	2.325	.225	2.950	.237	2.637	2.875
1936	50	.125	2.400	.250	1.675	.188	2.037	2.225
1935	51	.275	2.100	.075	2.075	.175	2.087	2.262
1934	52	.150	1.000	.275	1.050	.212	1.025	1.237
1933	53	.225	1.375	.250	1.525	.237	1.450	1.687
1932	54	.075	1.400	.100	1.950	.087	1.675	1.762
1931	55	.125	1.250	.275	1.125	.200	1.188	1.387
1930	56	.050	1.350	.175	.875	.112	1.112	1.225
1929	57	.100	1.425	.175	1.525	.137	1.475	1.612
1928	58	.125	1.975	.150	1.525	.137	1.750	1.887
1927	59	.175	1.400	.100	1.125	.137	1.262	1.400
1926	60	.200	1.325	.250	1.200	.225	1.262	1.487
1925	61	.100	1.550	.100	1.075	.100	1.313	1.412
1924	62	.125	1.875	.200	1.200	.163	1.537	1.700

Red Oak Tree # 12 (Slab # 5) Radius 1 and Radius 2
All measurements in millimeters

Year	Ring No.	1 Early	1 Late	2 Early	2 Late	Early Mean	Late Mean	Annual Mean
1985	1							
1984	2							
1983	3	.750	1.800	.550	2.350	.650	2.075	2.725
1982	4	.250	2.150	.550	2.400	.400	2.275	2.675
1981	5	.750	2.525	.525	2.150	.637	2.337	2.975
1980	6	1.000	4.825	1.200	6.675	1.100	5.750	6.850
1979	7	.950	4.525	1.150	3.300	1.050	3.913	4.963
1978	8	1.425	6.575	1.300	7.300	1.363	6.938	8.300
1977	9	1.275	6.575	1.150	7.150	1.212	6.863	8.075
1976	10	1.400	4.575	.950	7.825	1.175	6.200	7.375
1975	11	1.125	4.375	.900	5.675	1.012	5.025	6.038
1974	12	.800	4.900	.450	5.825	.625	5.363	5.988
1973	13	.750	5.100	1.100	5.100	.925	5.100	6.025
1972	14	1.200	3.800	.800	2.775	1.000	3.287	4.287
1971	15	1.100	4.025	.800	2.800	.950	3.412	4.362
1970	16	1.125	4.925	.675	3.875	.900	4.400	5.300
1969	17	.400	5.125	1.000	4.975	.700	5.050	5.750
1968	18	.725	4.575	.650	4.400	.688	4.488	5.175
1967	19	.750	3.800	.425	2.550	.587	3.175	3.762
1966	20	.875	3.075	.250	2.775	.563	2.925	3.487
1965	21	.525	4.700	.125	2.200	.325	3.450	3.775
1964	22	.725	2.950	.150	1.650	.437	2.300	2.737
1963	23	.450	2.425	.150	1.800	.300	2.112	2.412
1962	24	.250	2.125	.275	1.300	.262	1.712	1.975
1961	25	.400	1.475	.300	1.225	.350	1.350	1.700
1960	26	.125	1.825	.075	1.550	.100	1.688	1.787
1959	27	.275	1.500	.275	2.025	.275	1.762	2.037
1958	28	.400	2.050	.375	2.300	.388	2.175	2.562
1957	29	.525	2.350	.425	1.775	.475	2.063	2.537
1956	30	.350	1.875	.300	1.675	.325	1.775	2.100
1955	31	.275	2.725	.300	2.500	.287	2.612	2.900
1954	32	.500	1.925	.250	1.775	.375	1.850	2.225
1953	33	.600	2.625	.500	2.225	.550	2.425	2.975
1952	34	.750	2.325	.125	1.550	.438	1.937	2.375
1951	35	.650	2.550	.175	1.875	.412	2.212	2.625
1950	36	.400	1.350	.050	1.025	.225	1.187	1.412
1949	37	.225	1.625	.050	1.675	.137	1.650	1.787
1948	38	.150	.950	.050	.800	.100	.875	.975
1947	39	.550	2.775	.275	2.600	.412	2.688	3.100
1946	40	.425	2.725	.025	2.450	.225	2.567	2.812
1945	41	.225	2.475	.050	2.000	.137	2.237	2.375
1944	42	.225	2.200	.275	1.275	.250	1.737	1.987
1943	43	.400	2.100	.175	1.650	.287	1.875	2.162
1942	44	.275	3.225	.275	2.625	.275	2.925	3.200

1941	45	.200	2.625	.025	2.050	.113	2.337	2.450
1940	46	.500	2.475	.075	2.175	.287	2.325	2.612
1939	47	.375	3.250	.050	2.025	.212	2.637	2.850
1938	48	.300	3.050	.150	2.125	.225	2.587	2.812
1937	49	.225	3.150	.250	2.250	.237	2.700	2.937
1936	50	.200	2.150	.225	1.275	.212	1.712	1.925
1935	51	.175	2.075	.025	2.075	.100	2.075	2.175
1934	52	.075	1.100	.100	.725	.087	.912	1.000
1933	53	.175	1.200	.050	.925	.112	1.063	1.175
1932	54	.175	1.575	.050	1.375	.112	1.475	1.587
1931	55	.050	1.450	.025	1.075	.037	1.262	1.300
1930	56	.050	.525	.050	.475	.050	.500	.550
1929	57	.050	.550	.050	.500	.050	.525	.575
1928	58	.050	.450	.050	.425	.050	.438	.487
1927	59	.025	.275	.250	.250	.137	.262	.400
1926	60	.025	.300	.250	.325	.137	.313	.450
1925	61	.050	.650	.050	.650	.050	.650	.700
1924	62	.050	.700	.050	.675	.050	.687	.737
1923	63	.050	.800	.050	.825	.050	.813	.862
1922	64	.050	.825	.050	.800	.050	.813	.862
1921	65	.050	1.075	.050	1.050	.050	1.063	1.112
1920	66	.050	.500	.050	.475	.050	.487	.537
1919	67	.050	.600	.050	.625	.050	.612	.662
1918	68	.050	.675	.050	.675	.050	.675	.725
1917	69	.050	1.200	.050	1.225	.050	1.212	1.262
1916	70	.050	.825	.050	.825	.050	.825	.875

Red Oak Tree # 13 (Slab # 6) Radius # 1 and Radius # 2
All measurements in millimeters

Year	Ring No.	1 Early	1 Late	2 Early	2 Late	Early Mean	Late Mean	Annual Mean
1985	1							
1984	2							
1983	3	.525	.700	.475	.550	.500	.625	1.125
1982	4	.475	.925	.525	.850	.500	.887	1.387
1981	5	.450	.600	.275	.950	.362	.775	1.137
1980	6	.725	1.475	.700	1.050	.712	1.262	1.975
1979	7	.600	.850	.750	1.275	.675	1.062	1.737
1978	8	.775	1.550	.575	2.025	.675	1.787	2.462
1977	9	.650	1.350	.575	2.050	.612	1.700	2.312
1976	10	.725	1.325	1.425	2.100	1.075	1.712	2.787
1975	11	.850	2.250	1.025	3.450	.937	2.850	3.787
1974	12	.600	.750	.775	2.000	.687	1.375	2.062
1973	13	.825	1.200	1.300	1.375	1.062	1.287	2.350
1972	14	.800	1.250	1.300	2.775	1.050	2.012	3.062

1971	15	.800	1.400	1.525	2.600	1.162	2.000	3.162
1970	16	1.275	2.200	1.925	3.800	1.600	3.000	4.600
1969	17	.975	2.875	1.175	4.225	1.075	3.550	4.625
1968	18	.625	2.225	2.550	3.350	1.587	2.788	4.375
1967	19	.775	2.550	1.875	5.900	1.325	4.225	5.550
1966	20	.525	2.700	1.800	6.925	1.163	4.812	5.975
1965	21	.725	2.600	1.400	7.575	1.062	5.088	6.150
1964	22	.775	2.700	1.500	4.900	1.138	3.800	4.937
1963	23	.850	2.300	1.050	4.925	.950	3.612	4.562
1962	24	.800	1.975	1.125	4.950	.963	3.463	4.425
1961	25	.750	2.050	1.525	3.275	1.137	2.662	3.800
1960	26	.975	2.525	.450	4.875	.712	3.700	4.412
1959	27	1.025	2.075	1.025	3.950	1.025	3.012	4.037
1958	28	.950	2.375	1.375	2.800	1.162	2.587	3.750
1957	29	1.450	4.075	1.300	4.550	1.375	4.312	5.687
1956	30	2.475	5.600	1.650	5.625	2.062	5.612	7.675
1955	31	.875	7.550	1.000	3.300	.938	5.425	6.362
1954	32	1.200	5.175	1.150	1.450	1.175	3.312	4.487
1953	33	.650	7.800	1.350	1.425	1.000	4.612	5.612
1952	34	.600	2.275	1.050	1.375	.825	1.825	2.650
1951	35	.625	3.100	1.275	2.050	.950	2.575	3.525
1950	36	.575	3.325	.700	2.500	.637	2.913	3.550
1949	37	.450	1.775	.700	2.075	.575	1.925	2.500
1948	38	.750	.900	.450	1.075	.600	.987	1.587
1947	39	.800	1.225	1.400	1.600	1.100	1.412	2.512
1946	40	.675	1.700	1.000	2.025	.837	1.862	2.700
1945	41	.700	1.200	.925	1.775	.812	1.487	2.300
1944	42	.725	1.325	1.375	2.125	1.050	1.725	2.775
1943	43	.575	1.825	1.125	3.575	.850	2.700	3.550
1942	44	1.125	1.450	.975	4.700	1.050	3.075	4.125
1941	45	.975	1.775	1.050	3.975	1.012	2.875	3.887
1940	46	1.325	2.450	1.800	3.775	1.562	3.112	4.675
1939	47	1.150	3.225	1.375	5.150	1.262	4.187	5.450
1938	48	1.400	3.825	1.475	5.125	1.437	4.475	5.912
1937	49	1.025	4.700	1.500	5.500	1.262	5.100	6.362
1936	50	.950	2.425	1.275	2.600	1.112	2.512	3.625
1935	51	1.000	2.625	1.150	2.400	1.075	2.512	3.587
1934	52	.525	1.575	.950	2.125	.737	1.850	2.587
1933	53	.775	1.450	1.200	2.200	.987	1.825	2.812
1932	54	1.050	1.375	1.000	1.800	1.025	1.588	2.613
1931	55	.875	2.150	1.125	3.200	1.000	2.675	3.675
1930	56	.750	1.775	1.800	3.225	1.275	2.500	3.775
1929	57	1.075	2.025	1.350	3.900	1.212	2.962	4.175
1928	58	.725	2.325	.775	3.775	.750	3.050	3.800
1927	59	1.150	2.375	1.325	2.350	1.237	2.363	3.600
1926	60	.675	3.825	1.350	4.400	1.012	4.112	5.125
1925	61	.950	3.275	1.075	3.475	1.012	3.375	4.387
1924	62	.975	3.800	1.450	4.325	1.212	4.062	5.275

1923	63	.625	3.725	1.500	4.475	1.063	4.100	5.163
1922	64	.825	2.675	1.125	4.200	.975	3.438	4.412
1921	65	.875	4.400	1.375	5.125	1.125	4.763	5.888
1920	66	.775	4.675	.800	5.050	.787	4.863	5.650
1919	67	.725	3.050	.825	3.325	.775	3.188	3.962
1918	68	.450	2.725	.450	3.825	.450	3.275	3.725
1917	69	.350	3.175	.475	3.325	.412	3.250	3.662
1916	70	.400	2.425	.425	2.350	.412	2.387	2.800
1915	71	.200	2.325	.125	2.550	.163	2.437	2.600
1914	72	.175	1.450	.450	2.100	.313	1.775	2.087
1913	73	.250	1.450	.125	2.050	.188	1.750	1.937
1912	74	.100	1.875	.100	1.850	.100	1.863	1.962

Red Oak Tree # 14 (Slab # 7) Radius # 1 and Radius # 2
All measurements in millimeters

Year	Ring No.	1 Early	1 Late	2 Early	2 Late	Early Mean	Late Mean	Annual Mean
1985	1							
1984	2							
1983	3	.600	2.050	1.025	1.625	.812	1.837	2.650
1982	4	.750	1.525	.875	2.325	.813	1.925	2.737
1981	5	.500	2.025	1.375	2.275	.938	2.150	3.087
1980	6	1.200	3.200	1.150	3.900	1.175	3.550	4.725
1979	7	1.100	2.400	1.425	3.025	1.262	2.712	3.975
1978	8	.475	3.050	1.100	4.275	.787	3.663	4.450
1977	9	1.125	3.050	.925	5.100	1.025	4.075	5.100
1976	10	1.225	2.000	1.250	3.325	1.237	2.663	3.900
1975	11	.925	2.800	1.250	3.650	1.087	3.225	4.312
1974	12	.875	2.700	.625	3.800	.750	3.250	4.000
1973	13	.575	2.550	.875	3.475	.725	3.012	3.737
1972	14	1.225	.725	.975	3.775	1.100	2.250	3.350
1971	15	.900	3.500	.800	4.025	.850	3.762	4.612
1970	16	1.400	2.750	1.425	2.700	1.412	2.725	4.137
1969	17	.650	4.275	.950	4.950	.800	4.613	5.413
1968	18	.975	2.950	.750	4.850	.862	3.900	4.762
1967	19	.650	3.900	.875	3.425	.762	3.662	4.425
1966	20	.525	2.525	.575	4.400	.550	3.462	4.012
1965	21	.950	3.550	.625	3.800	.787	3.675	4.462
1964	22	.950	3.525	.975	3.575	.962	3.550	4.512
1963	23	.600	3.025	.725	4.025	.662	3.525	4.187
1962	24	.450	3.750	.775	3.825	.612	3.788	4.400
1961	25	.475	3.950	.700	4.525	.587	4.238	4.825
1960	26	.550	3.425	.675	4.625	.612	4.025	4.638
1959	27	.825	3.225	1.050	4.500	.938	3.862	4.800
1958	28	.525	3.450	.550	4.575	.537	4.013	4.550

1957	29	.725	3.825	.600	4.625	.662	4.225	4.888
1956	30	.725	3.750	.750	4.350	.737	4.050	4.787
1955	31	.250	3.900	.650	4.000	.450	3.950	4.400
1954	32	.500	3.200	.525	3.600	.512	3.400	3.912
1953	33	.550	3.800	.525	4.850	.537	4.325	4.862
1952	34	.675	3.150	.175	5.150	.425	4.150	4.575
1951	35	.125	2.625	.300	3.750	.212	3.188	3.400
1950	36	.275	1.475	.350	2.775	.312	2.125	2.437
1949	37	.200	1.300	.675	2.375	.437	1.837	2.275
1948	38	.450	2.600	.375	4.8000	.412	3.700	4.112
1947	39	.500	4.000	.450	5.275	.475	4.638	5.113
1946	40	.450	3.925	.125	4.850	.287	4.387	4.675
1945	41	.300	2.850	.275	3.925	.287	3.387	3.675
1944	42	.300	1.800	.350	2.325	.325	2.062	2.387
1943	43	.450	3.525	.450	2.750	.450	3.137	3.587
1942	44	.275	4.200	.125	3.750	.200	3.975	4.175
1941	45	.200	3.275	.125	2.450	.163	2.862	3.025
1940	46	.225	2.625	.150	2.600	.188	2.612	2.800
1939	47	.125	2.625	.150	2.700	.137	2.662	2.800
1938	48	.125	3.300	.175	2.750	.150	3.025	3.175
1937	49	.175	3.625	.150	3.300	.162	3.462	3.625
1936	50	.125	2.000	.050	2.275	.087	2.137	2.225
1935	51	.200	1.650	.125	2.800	.163	2.225	2.387
1934	52	.175	.875	.200	1.525	.188	1.200	1.387
1933	53	.150	1.575	.175	1.725	.162	1.650	1.812
1932	54	.250	1.775	.125	1.800	.188	1.787	1.975
1931	55	.250	1.150	.075	1.575	.162	1.362	1.525
1930	56	.200	1.050	.075	1.425	.137	1.238	1.375
1929	57	.200	1.075	.125	1.150	.163	1.112	1.275
1928	58	.125	1.100	.075	1.575	.100	1.337	1.437
1927	59	.125	.875	.075	1.550	.100	1.212	1.312
1926	60	.150	1.050	.075	1.275	.112	1.162	1.275
1925	61	.125	1.125	.050	1.200	.087	1.162	1.250
1924	62	.100	1.075	.100	1.075	.100	1.075	1.175
1923	63	.050	.800	.050	.750	.050	.775	.825

Red Oak tree # 15 (Slab # 8) Radius # 1 and Radius # 2
All measurements in millimeters

Year	Ring No.	1 Early	1 Late	2 Early	2 Late	Early Mean	Late Mean	Annual Mean
1985	1							
1984	2							
1983	3	1.225	3.825	1.700	2.200	1.462	3.012	4.475
1982	4	1.475	2.775	1.525	2.175	1.500	2.475	3.975
1981	5	1.450	5.150	1.025	3.275	1.237	4.212	5.450

1980	6	1.325	3.675	1.600	2.575	1.462	3.125	4.587
1979	7	2.075	5.850	1.675	3.575	1.875	4.712	6.587
1978	8	1.975	4.850	1.400	3.225	1.688	4.037	5.725
1977	9	1.975	4.325	1.350	3.050	1.662	3.698	5.350
1976	10	2.300	4.800	.900	4.400	1.600	4.600	6.200
1975	11	1.450	5.025	1.475	3.375	1.462	4.200	5.663
1974	12	2.425	3.550	1.950	3.550	2.187	3.550	5.737
1973	13	1.850	4.950	1.150	3.675	1.500	4.313	5.813
1972	14	1.475	4.125	.800	3.575	1.137	3.850	4.988
1971	15	2.025	5.525	1.075	4.025	1.550	4.775	6.325
1970	16	1.250	6.175	.925	5.075	1.087	5.625	6.713
1969	17	1.575	5.750	1.025	5.075	1.300	5.413	6.713
1968	18	.950	3.975	1.525	4.450	1.237	4.212	5.450
1967	19	1.775	4.650	1.250	5.400	1.512	5.025	6.537
1966	20	2.050	5.700	.950	5.950	1.500	5.825	7.325
1965	21	1.425	5.550	1.575	2.625	1.500	4.087	5.587
1964	22	2.125	5.650	1.850	6.200	1.988	5.925	7.912
1963	23	1.600	7.050	1.350	5.150	1.475	6.100	7.575
1962	24	2.275	6.450	1.225	7.100	1.750	6.775	8.525
1961	25	1.525	7.800	1.500	6.875	1.512	7.338	8.850
1960	26	2.025	8.675	1.525	8.375	1.775	8.525	10.300
1959	27	1.550	5.775	1.475	6.025	1.512	5.900	7.413
1958	28	1.925	6.075	1.750	6.400	1.837	6.238	8.075
1957	29	1.525	7.275	1.275	6.900	1.400	7.088	8.488
1956	30	1.950	8.050	1.675	5.850	1.813	6.950	8.762
1955	31	2.025	7.650	2.075	6.275	2.050	6.963	9.013
1954	32	2.150	7.150	1.250	7.125	1.700	7.138	8.837
1953	33	1.175	7.050	1.400	6.150	1.287	6.600	7.887
1952	34	2.075	7.200	1.400	7.075	1.737	7.138	8.875
1951	35	1.650	6.125	1.700	5.200	1.675	5.663	7.338
1950	36	1.200	5.875	1.025	5.800	1.112	5.838	6.950
1949	37	1.075	4.950	1.025	4.700	1.050	4.825	5.875
1948	38	1.900	5.400	1.350	4.450	1.625	4.925	6.550
1947	39	1.275	4.950	1.050	4.275	1.162	4.613	5.775
1946	40	1.525	4.600	.925	4.100	1.225	4.350	5.575
1945	41	1.300	4.550	1.175	3.800	1.238	4.175	5.412
1944	42	.950	4.425	.875	3.775	.912	4.100	5.013
1943	43	.900	4.150	.600	4.000	.750	4.075	4.825
1942	44	.225	2.625	.400	2.775	.313	2.700	3.012
1941	45	.125	1.950	.300	2.100	.212	2.025	2.237
1940	46	.150	1.150	.275	1.650	.212	1.400	1.612
1939	47	.275	.850	.350	1.150	.312	1.000	1.712
1938	48	.375	2.400	.100	2.725	.237	2.563	2.800
1937	49	.200	.775	.150	.525	.175	.650	.825
1936	50	.225	1.975	.100	1.400	.163	1.788	1.950
1935	51	.075	1.050	.075	1.275	.075	1.162	1.237

Red Oak Tree # 16 (Slab # 9) Radius # 1 and Radius # 2
All measurements in millimeters

Year	Ring No.	1 Early	1 Late	2 Early	2 Late	Early Mean	Late Mean	Annual Mean
1985	1							
1984	2							
1983	3	.175	1.425	.450	2.225	.313	1.825	2.137
1982	4	.250	1.075	.425	2.775	.337	1.925	2.262
1981	5	.350	1.475	.275	4.025	.312	2.750	3.062
1980	6	.200	.600	.225	1.025	.212	.812	1.025
1979	7	.325	1.150	.150	1.125	.237	1.137	1.375
1978	8	.300	.900	.150	1.150	.225	1.025	1.250
1977	9	.200	.525	.075	.625	.137	.575	.712
1976	10	.125	.550	.050	.800	.087	.675	.762
1975	11	.100	.550	.100	1.075	.100	.812	.912
1974	12	.100	.900	.075	1.425	.087	1.162	1.250
1973	13	.100	.800	.150	1.550	.125	1.175	1.300
1972	14	.225	.975	.125	1.875	.175	1.425	1.600
1971	15	.100	1.125	.225	2.050	.163	1.587	1.750
1970	16	.125	1.350	.175	2.550	.150	1.950	2.100
1969	17	.100	1.425	.250	2.500	.175	1.962	2.137
1968	18	.125	.675	.250	2.275	.188	1.475	1.662
1967	19	.150	.775	.200	2.475	.175	1.625	1.800
1966	20	.150	1.375	.250	3.125	.200	2.250	2.450
1965	21	.200	1.150	.100	3.075	.150	2.112	2.262
1964	22	.200	.850	.175	3.025	.188	1.937	2.125
1963	23	.200	.900	.150	2.975	.175	1.938	2.112
1962	24	.200	1.175	.150	4.400	.175	2.787	2.962
1961	25	.125	1.100	.200	4.900	.163	3.000	3.162
1960	26	.175	1.175	.175	4.375	.175	2.875	3.050
1959	27	.075	1.575	.250	3.650	.162	2.612	2.775
1958	28	.100	1.075	.200	3.900	.150	2.487	2.637
1957	29	.075	1.025	.225	2.025	.150	1.525	1.675
1956	30	.200	2.400	.250	2.850	.225	2.625	2.850
1955	31	.125	1.275	.250	3.100	.188	2.188	2.375
1954	32	.250	1.050	.125	4.050	.188	2.550	2.737
1953	33	.150	.950	.125	1.250	.137	1.100	1.237
1952	34	.125	1.000	.075	1.775	.100	1.387	1.487
1951	35	.075	1.025	.150	.825	.112	.925	1.037
1950	36	.075	.250	.150	1.025	.112	.637	.750
1949	37	.150	1.275	.075	.950	.112	1.112	1.225
1948	38	.250	1.775	.175	1.525	.212	1.650	1.862

Red Oak Tree # 17 (Slab # 10) Radius # 1 and Radius # 2
All measurements in millimeters

Year	Ring No.	1 Early	1 Late	2 Early	2 Late	Early Mean	Late Mean	Annual Mean
1985	1							
1984	2							
1983	3	.350	.525	.150	.500	.250	.512	.762
1982	4	.275	.600	.100	.525	.187	.563	.750
1981	5	.300	.750	.250	.575	.275	.662	.937
1980	6	.250	1.550	.225	1.350	.237	1.450	1.687
1979	7	.375	.750	.200	.725	.287	.737	1.025
1978	8	.225	1.025	.275	1.050	.250	1.037	1.287
1977	9	.200	.175	.175	.150	.188	.162	.350
1976	10	.275	.525	.050	.225	.162	.375	.537
1975	11	.375	1.025	.225	.950	.300	.987	1.287
1974	12	.250	1.125	.225	.475	.237	.800	1.037
1973	13	.225	1.050	.225	.500	.225	.775	1.000
1972	14	.350	1.700	.125	1.050	.237	1.375	1.612
1971	15	.125	1.800	.175	1.075	.150	1.438	1.587
1970	16	.175	1.550	.275	.725	.225	1.137	1.362
1969	17	.200	3.925	.150	1.600	.175	2.762	2.937
1968	18	.175	1.825	.200	1.100	.188	1.462	1.650
1967	19	.250	2.025	.150	1.125	.200	1.575	1.775
1966	20	.350	1.900	.150	1.150	.250	1.525	1.775
1965	21	.250	3.525	.425	2.425	.337	2.975	3.312
1964	22	.400	2.450	.400	1.025	.400	1.737	2.137
1963	23	.450	2.850	.150	1.900	.300	2.375	2.675
1962	24	.350	1.975	.100	1.700	.225	1.837	2.062
1961	25	.200	1.150	.075	.525	.137	.837	.975
1960	26	.200	1.150	.200	.650	.200	.900	1.100
1959	27	.150	1.300	.275	.775	.212	1.037	1.250
1958	28	.250	1.375	.175	.800	.212	1.087	1.300
1957	29	.325	1.050	.200	.875	.263	.938	1.200
1956	30	.400	1.200	.125	.825	.263	1.012	1.275
1955	31	.275	1.900	.250	1.450	.262	1.675	1.937
1954	32	.500	1.500	.275	1.300	.387	1.400	1.787
1953	33	.275	2.125	.100	1.950	.187	2.037	2.225
1952	34	.300	1.700	.225	1.700	.262	1.700	1.962
1951	35	.325	1.925	.100	1.325	.212	1.625	1.837
1950	36	.250	1.650	.175	1.525	.212	1.587	1.800
1949	37	.200	1.900	.175	2.025	.188	1.962	2.150
1948	38	.225	.675	.250	2.400	.237	1.537	1.775
1947	39	.275	1.600	.125	1.475	.200	1.537	1.737
1946	40	.300	1.725	.150	1.100	.225	1.412	1.637
1945	41	.225	1.175	.175	1.600	.200	1.387	1.587
1944	42	.275	1.975	.200	.825	.237	1.400	1.637
1943	43	.150	1.175	.075	1.800	.112	1.488	1.600

1942	44	.375	2.450	.100	1.100	.237	1.775	2.012
1941	45	.275	1.525	.100	1.200	.187	1.362	1.550
1940	46	.425	1.775	.125	2.050	.275	1.912	2.187
1939	47	.325	1.950	.100	2.000	.212	1.975	2.187
1938	48	.500	2.350	.050	1.125	.275	1.738	2.012
1937	49	.225	1.300	.050	.850	.137	1.075	1.212
1936	50	.100	.775	.050	.975	.075	.875	.950
1935	51	.175	.800	.050	.675	.112	.737	.850
1934	52	.200	1.100	.075	.900	.137	1.000	1.137
1933	53	.125	1.075	.025	1.225	.075	1.150	1.225
1932	54	.100	.550	.025	.275	.063	.412	.475
1931	55	.150	.650	.025	.600	.087	.625	.712
1930	56	.075	.325	.025	.275	.050	.300	.350

APPENDIX B
Ring-Width and Ring-Area Series' with Expected Growth From the Best-Fit Curve for the Sixteen Red Oak Trees

FIGURE (B1)
RING-WIDTH SERIES WITH EXPECTED GROWTH FROM QUADRATIC SMOOTHING FOR RED OAK TREE ONE

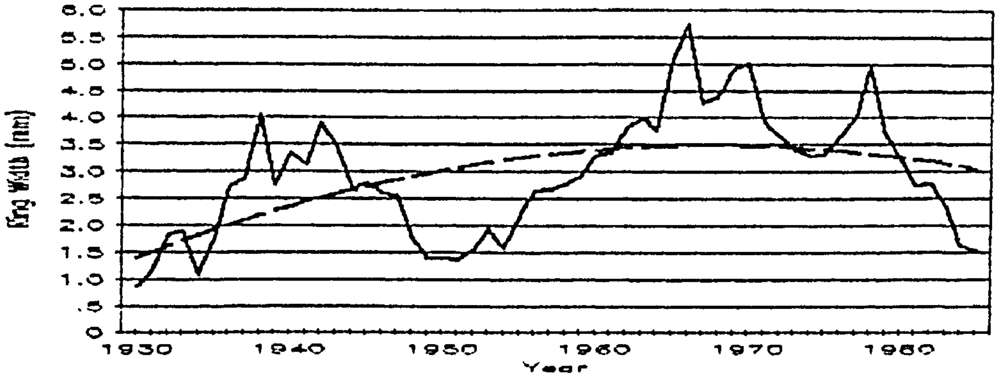


FIGURE (B2)
RING-WIDTH SERIES WITH EXPECTED GROWTH FROM QUADRATIC SMOOTHING FOR RED OAK TREE TWO

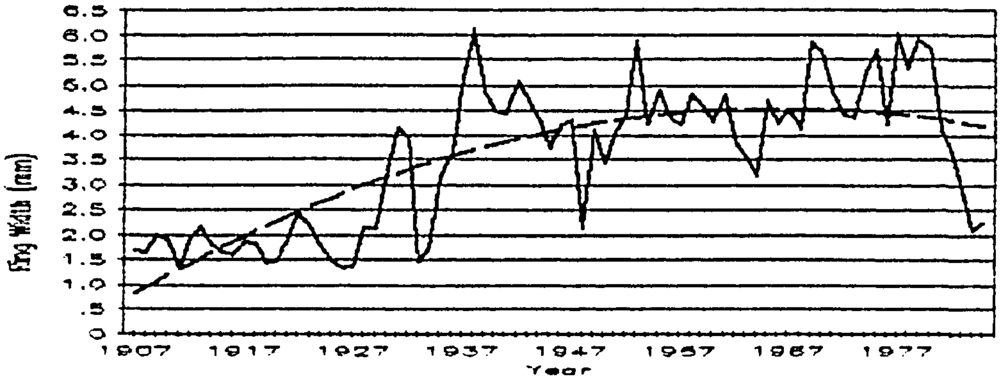


FIGURE (B3)
RING-WIDTH SERIES WITH EXPECTED GROWTH FROM QUADRATIC SMOOTHING FOR RED OAK TREE THREE

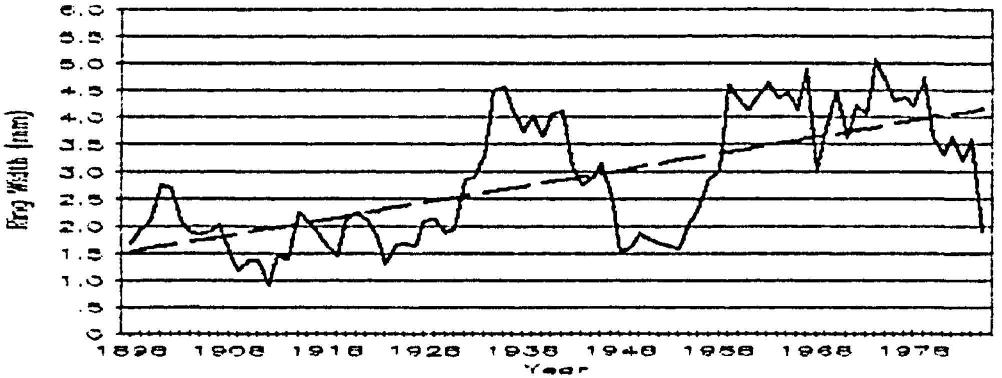


FIGURE (B4)
RING-WIDTH SERIES WITH EXPECTED GROWTH FROM QUADRATIC SMOOTHING FOR RED OAK TREE FOUR

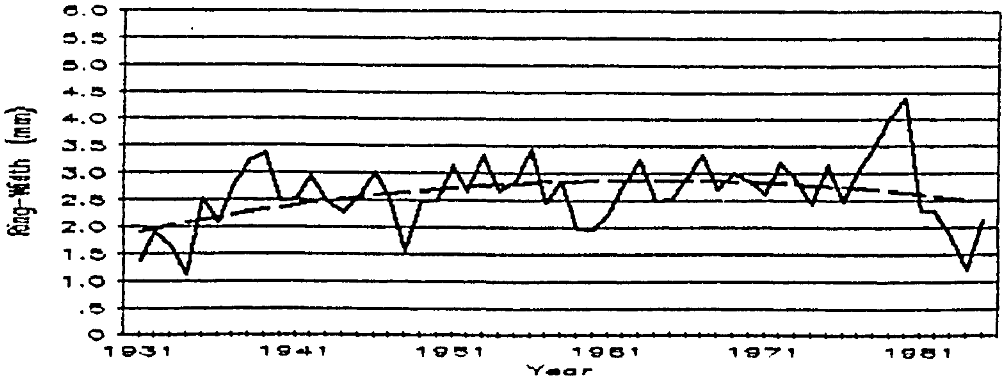


FIGURE (B5)
RING-WIDTH SERIES WITH EXPECTED GROWTH FROM EXPONENTIAL SMOOTHING FOR RED OAK TREE FIVE

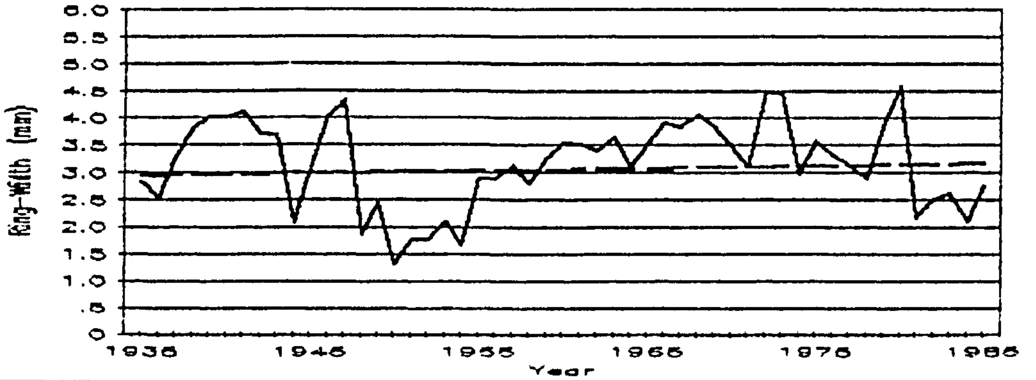


FIGURE (B6)
RING-WIDTH SERIES WITH EXPECTED GROWTH FROM QUADRATIC SMOOTHING FOR RED OAK TREE SIX

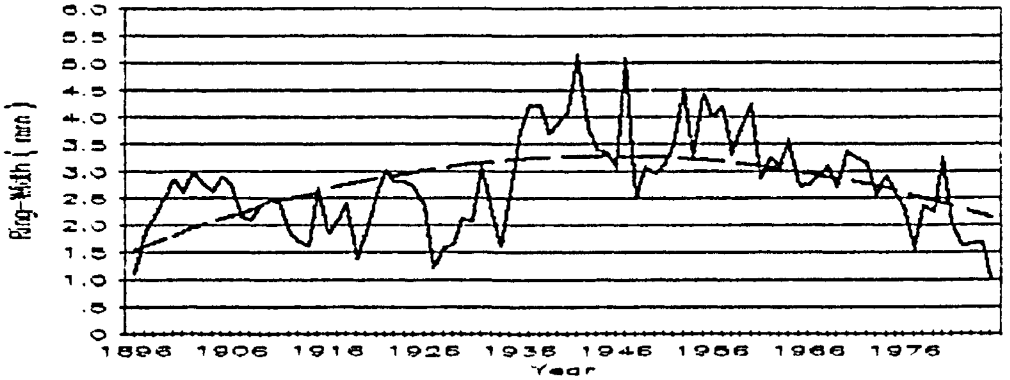


FIGURE (B7)
RING-WIDTH SERIES WITH EXPECTED
GROWTH FROM QUADRATIC SMOOTHING
FOR RED OAK TREE SEVEN

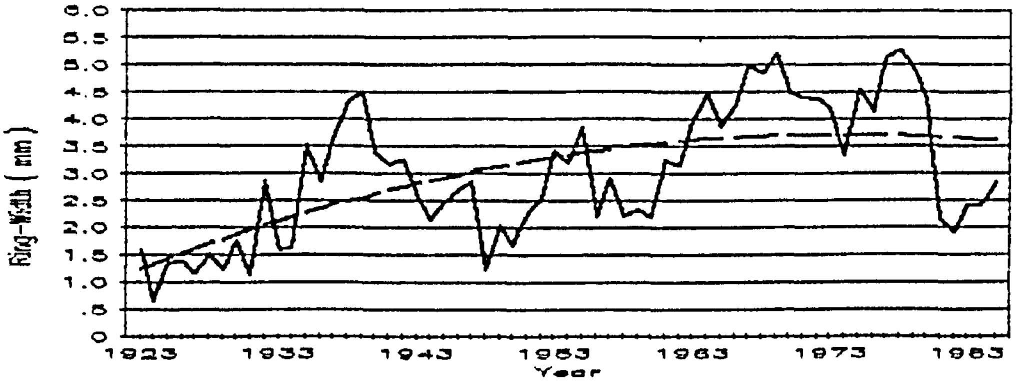


FIGURE (B8)
RING-WIDTH SERIES WITH EXPECTED
GROWTH FROM QUADRATIC SMOOTHING
FOR RED OAK TREE EIGHT

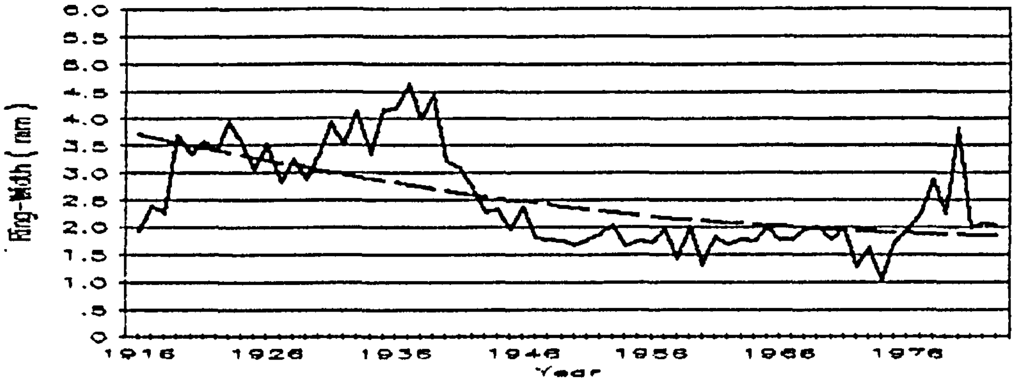


FIGURE (B9)
RING-WIDTH SERIES WITH EXPECTED
GROWTH FROM EXPONENTIAL SMOOTHING
FOR RED OAK TREE NINE

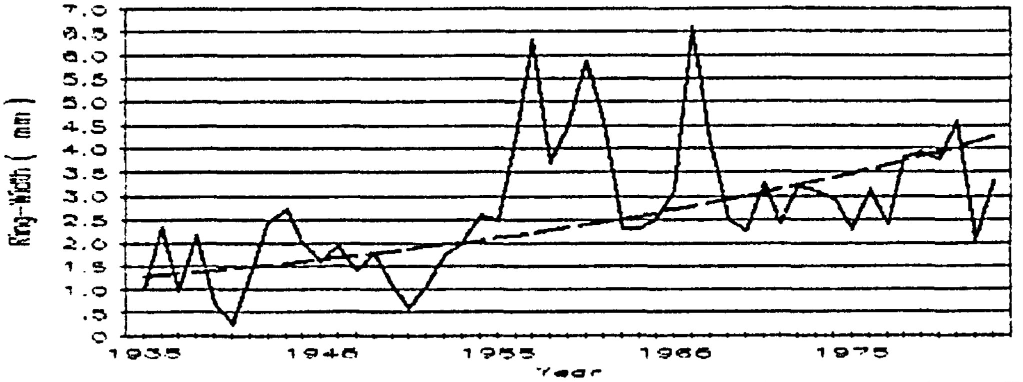


FIGURE (B10)
RING-WIDTH SERIES WITH EXPECTED GROWTH FROM QUADRATIC SMOOTHING FOR RED OAK TREE TEN

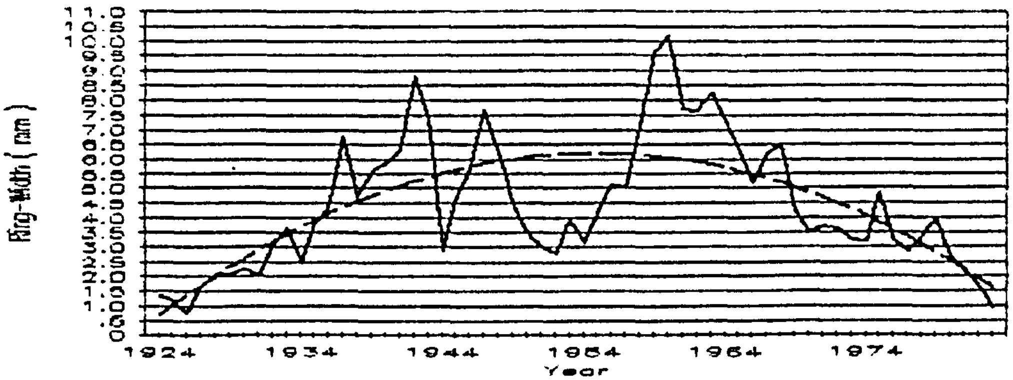


FIGURE (B11)
RING-WIDTH SERIES WITH EXPECTED GROWTH FROM QUADRATIC SMOOTHING FOR RED OAK TREE ELEVEN

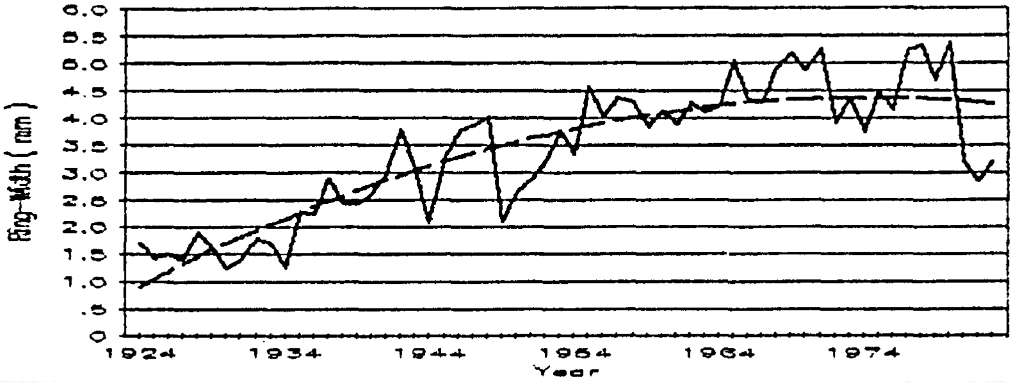


FIGURE (B12)
RING-WIDTH SERIES WITH EXPECTED GROWTH FROM EXPONENTIAL SMOOTHING FOR RED OAK TREE TWELVE

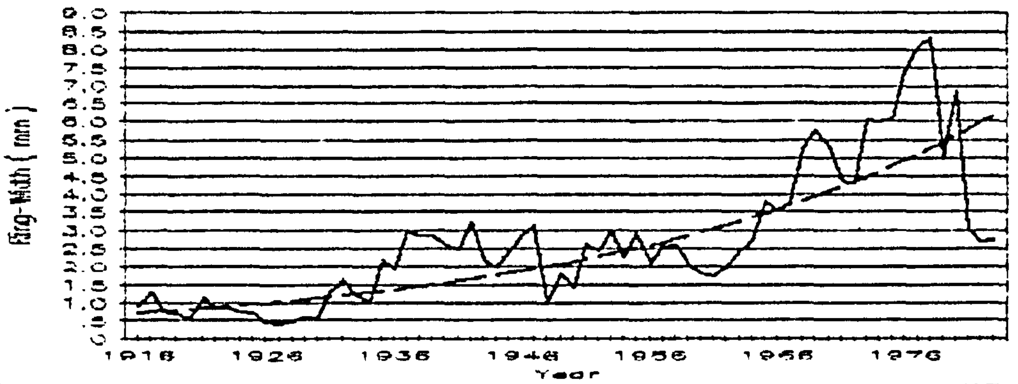


FIGURE (B13)
RING-WIDTH SERIES WITH EXPECTED GROWTH FROM QUADRATIC SMOOTHING FOR RED OAK TREE THIRTEEN

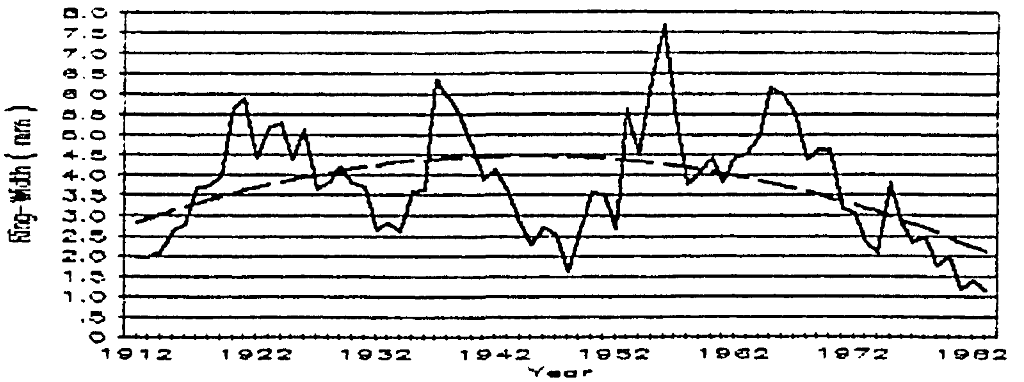


FIGURE (B14)
RING-WIDTH SERIES WITH EXPECTED GROWTH FROM QUADRATIC SMOOTHING FOR RED OAK TREE FOURTEEN

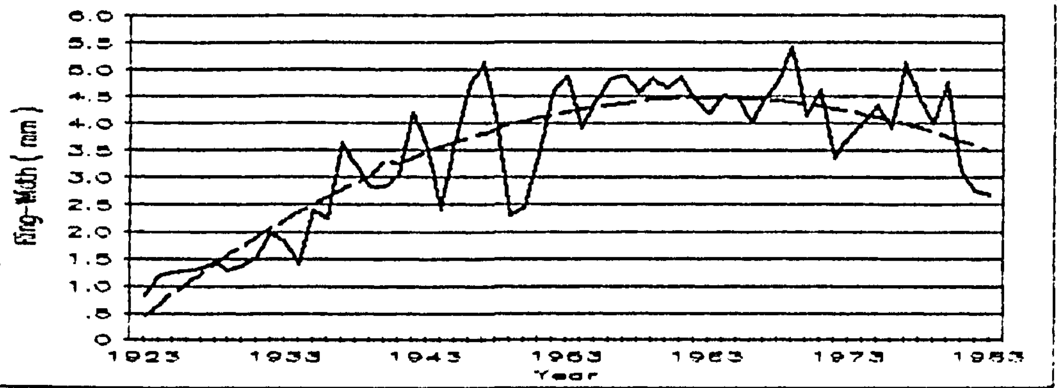


FIGURE (B15)
RING-WIDTH SERIES WITH EXPECTED GROWTH FROM QUADRATIC SMOOTHING FOR RED OAK TREE FIFTEEN

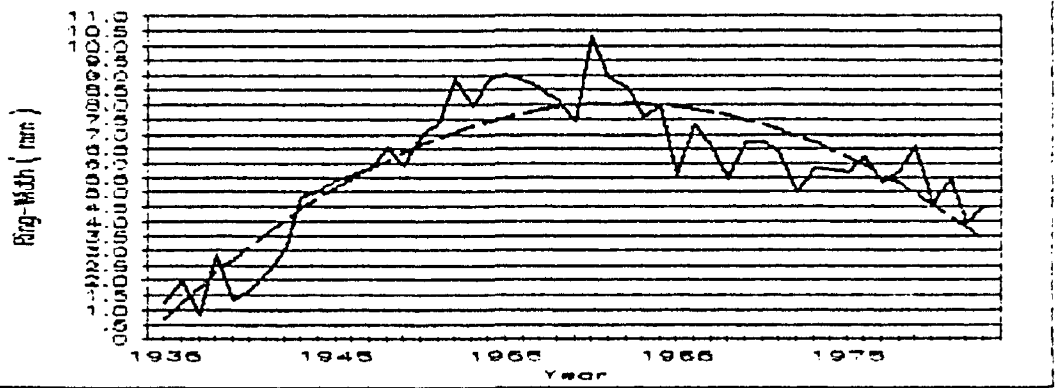


FIGURE (B16)
RING-WIDTH SERIES WITH EXPECTED GROWTH FROM QUADRATIC SMOOTHING FOR RED OAK TREE SEVENTEEN

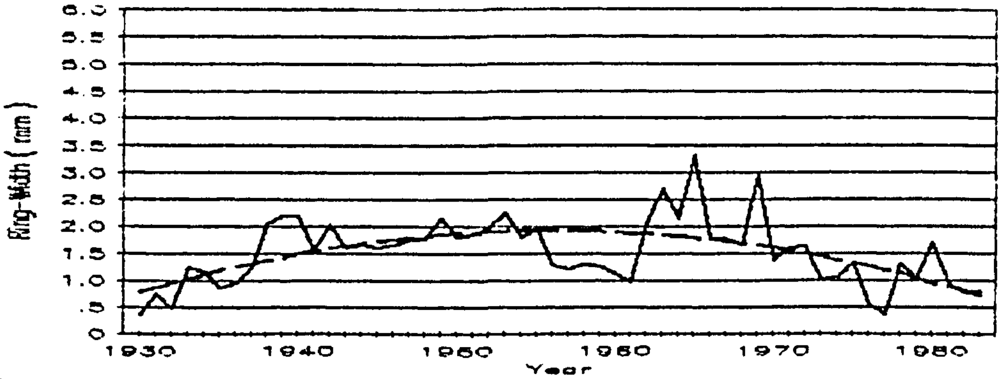


FIGURE (B17)
AREA OF ANNULUS SERIES WITH EXPECTED GROWTH FROM FOURIER SMOOTHING FOR RED OAK TREE ONE

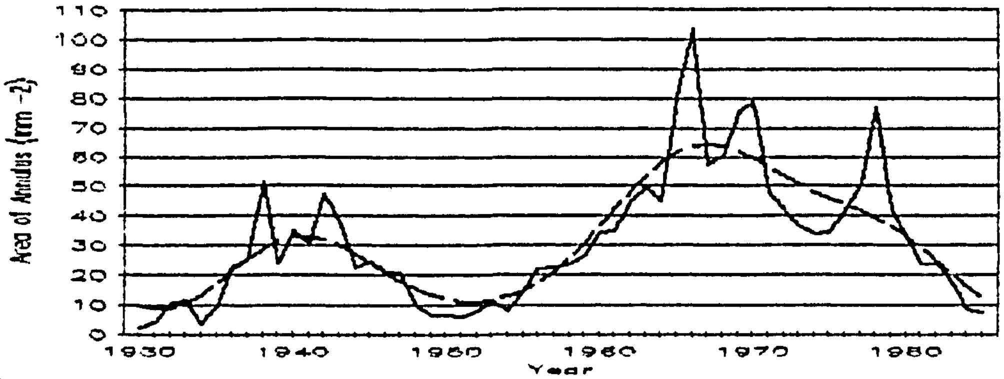


FIGURE (B18)
AREA OF ANNULUS SERIES WITH EXPECTED GROWTH FROM FOURIER SMOOTHING FOR RED OAK TREE TWO

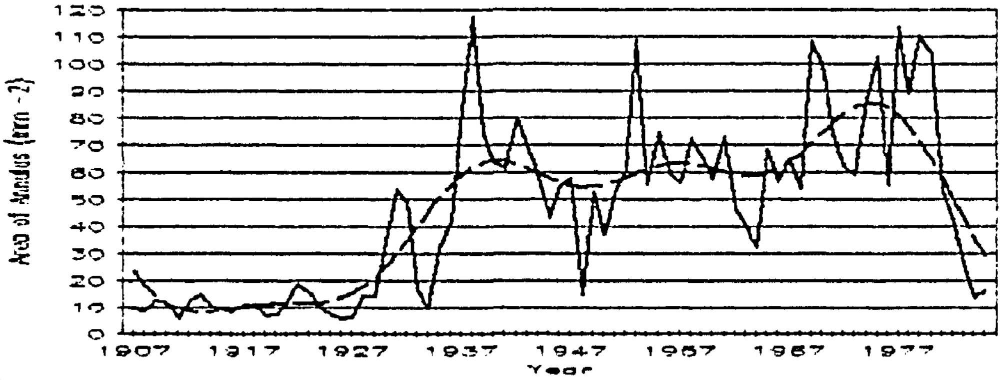


FIGURE (B19)
AREA OF ANNULUS SERIES WITH EXPECTED GROWTH FROM FOURIER SMOOTHING FOR RED OAK TREE THREE

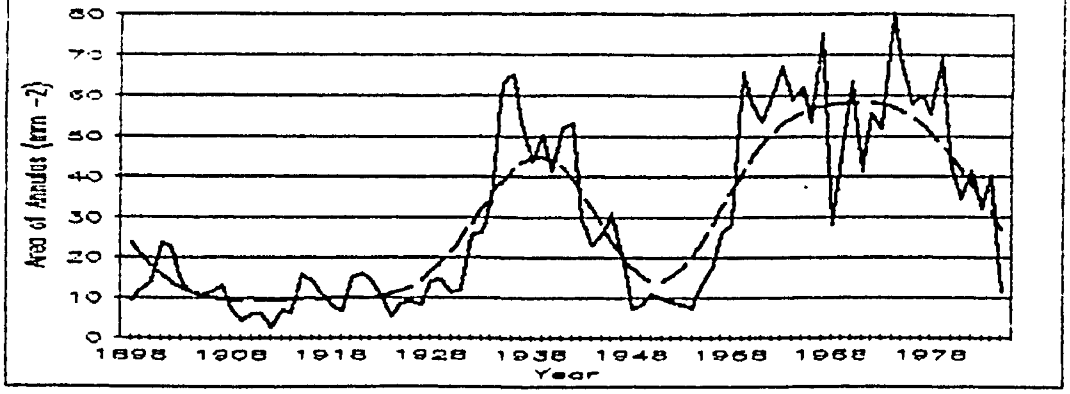


FIGURE (B20)
AREA OF ANNULUS SERIES WITH EXPECTED GROWTH FROM FOURIER SMOOTHING FOR RED OAK TREE FOUR

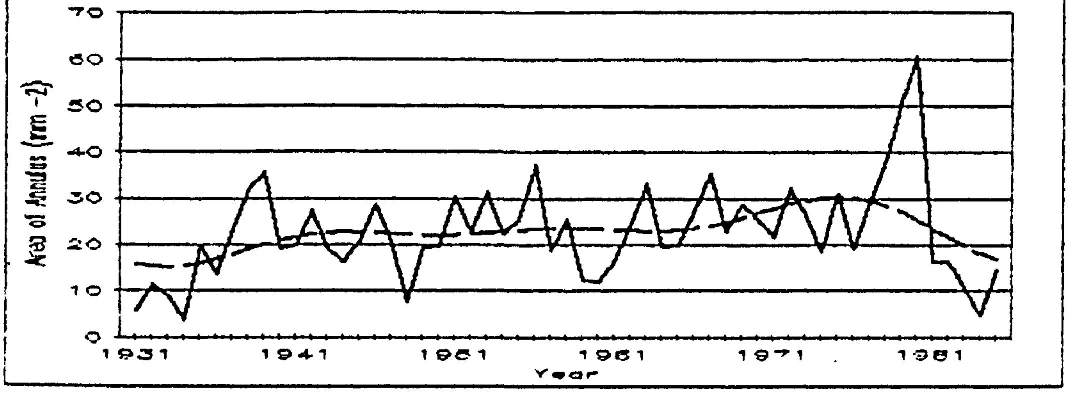


FIGURE (B21)
AREA OF ANNULUS SERIES WITH EXPECTED GROWTH FROM FOURIER SMOOTHING FOR RED OAK TREE FIVE

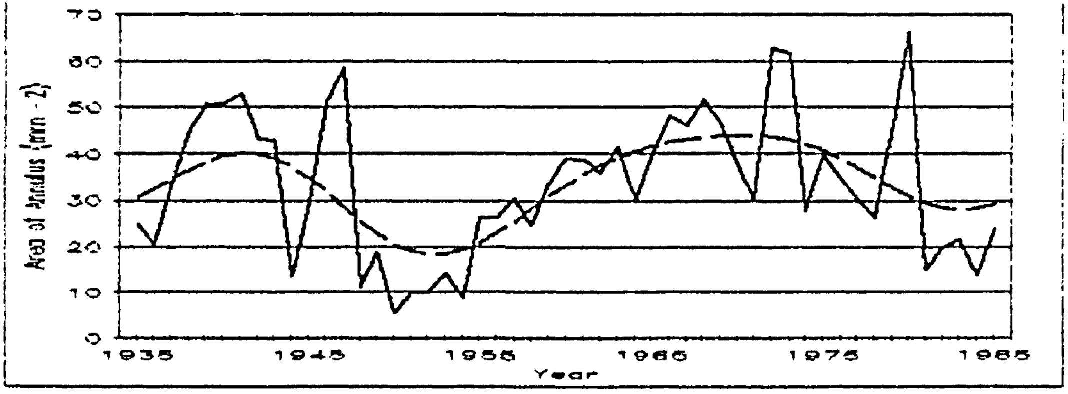


FIGURE (B22)
AREA OF ANNULUS SERIES WITH EXPECTED GROWTH FROM FOURIER SMOOTHING FOR RED OAK TREE SIX

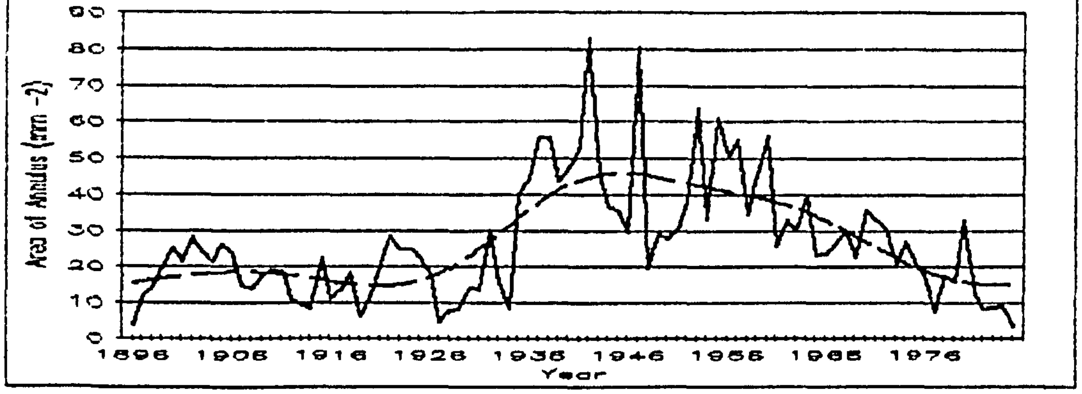


FIGURE (B23)
AREA OF ANNULUS SERIES WITH EXPECTED GROWTH FROM FOURIER SMOOTHING FOR RED OAK TREE SEVEN

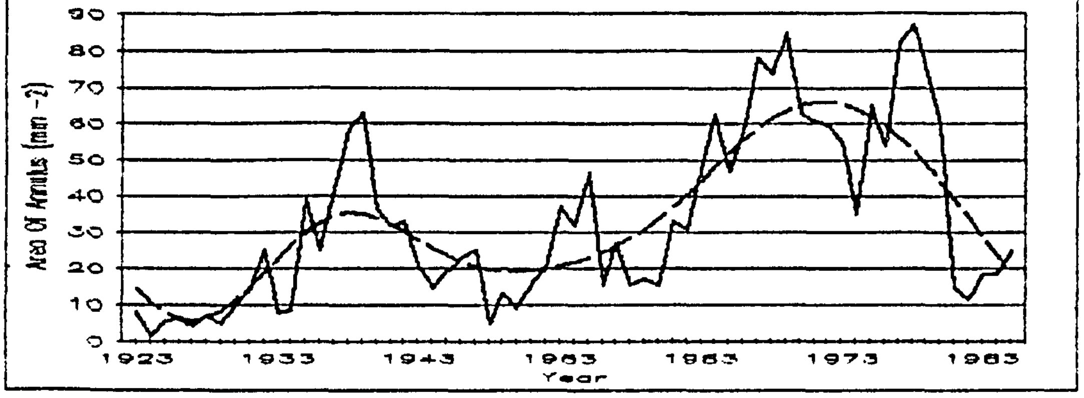


FIGURE (B24)
AREA OF ANNULUS SERIES WITH EXPECTED GROWTH FROM FOURIER SMOOTHING FOR RED OAK TREE EIGHT

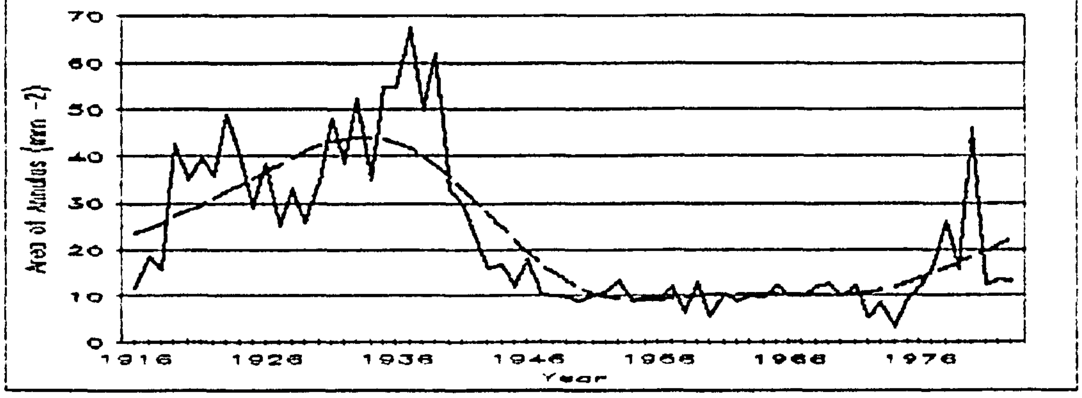


FIGURE (B25)
AREA OF ANNULUS SERIES WITH EXPECTED
GROWTH FROM FOURIER SMOOTHING
FOR RED OAK TREE NINE

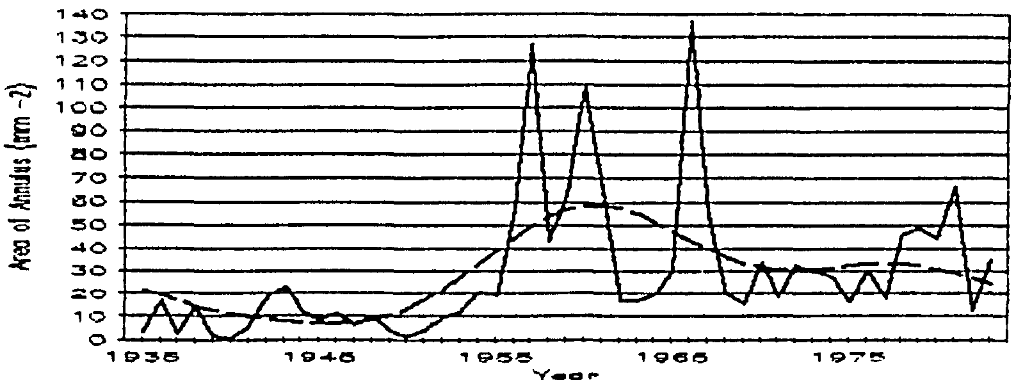


FIGURE (B26)
AREA OF ANNULUS SERIES WITH EXPECTED
GROWTH FROM FOURIER SMOOTHING
FOR RED OAK TREE TEN

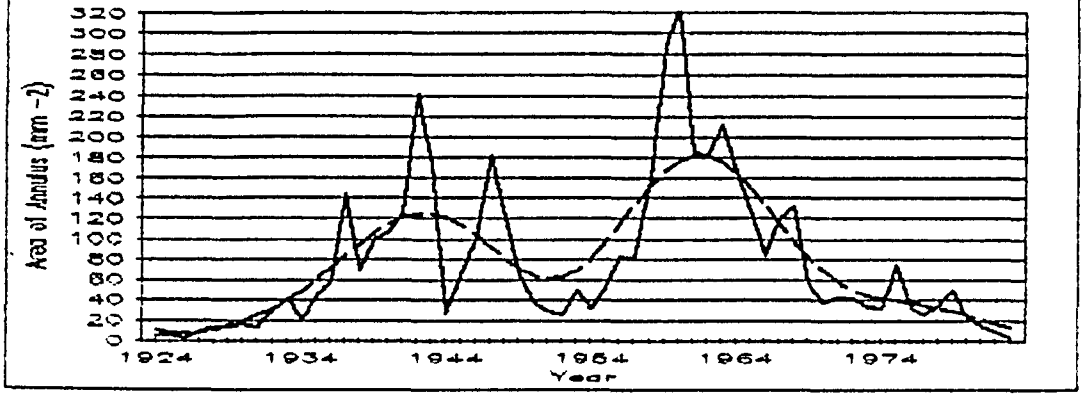


FIGURE (B27)
AREA OF ANNULUS SERIES WITH EXPECTED
GROWTH FROM FOURIER SMOOTHING
FOR RED OAK TREE ELEVEN

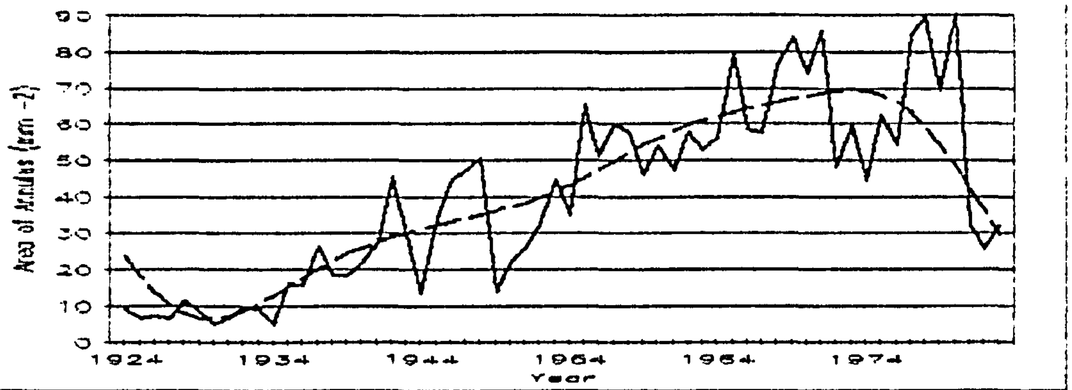


FIGURE (B28)
AREA OF ANNULUS SERIES WITH EXPECTED GROWTH FROM FOURIER SMOOTHING FOR RED OAK TREE TWELVE

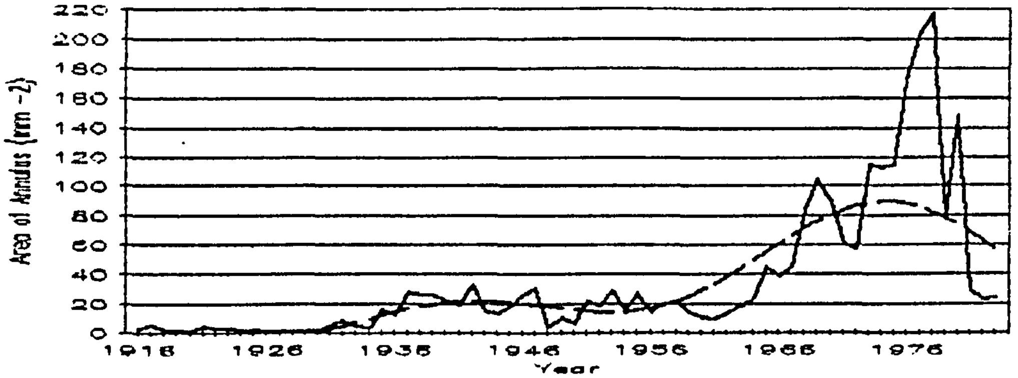


FIGURE (B29)
AREA OF ANNULUS SERIES WITH EXPECTED GROWTH FROM FOURIER SMOOTHING FOR RED OAK TREE THIRTEEN

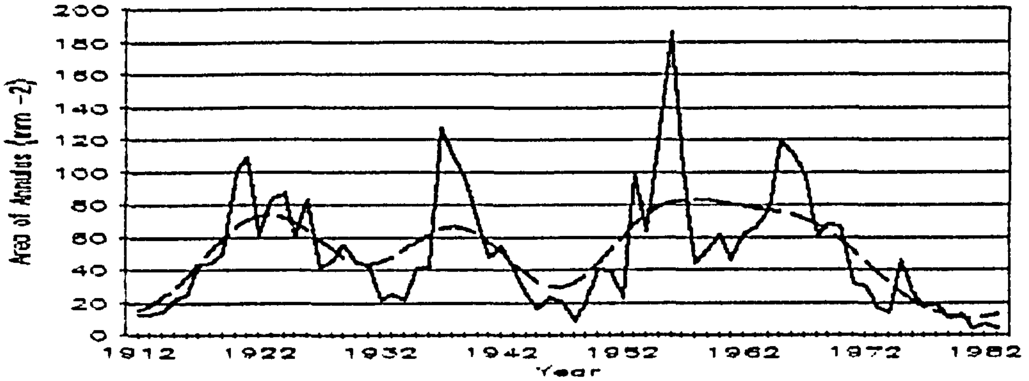
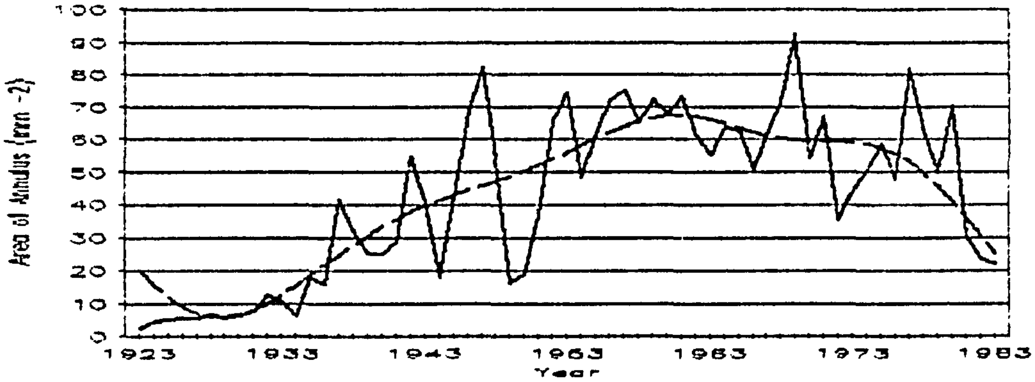


FIGURE (B30)
AREA OF ANNULUS SERIES WITH EXPECTED GROWTH FROM FOURIER SMOOTHING FOR RED OAK TREE FOURTEEN



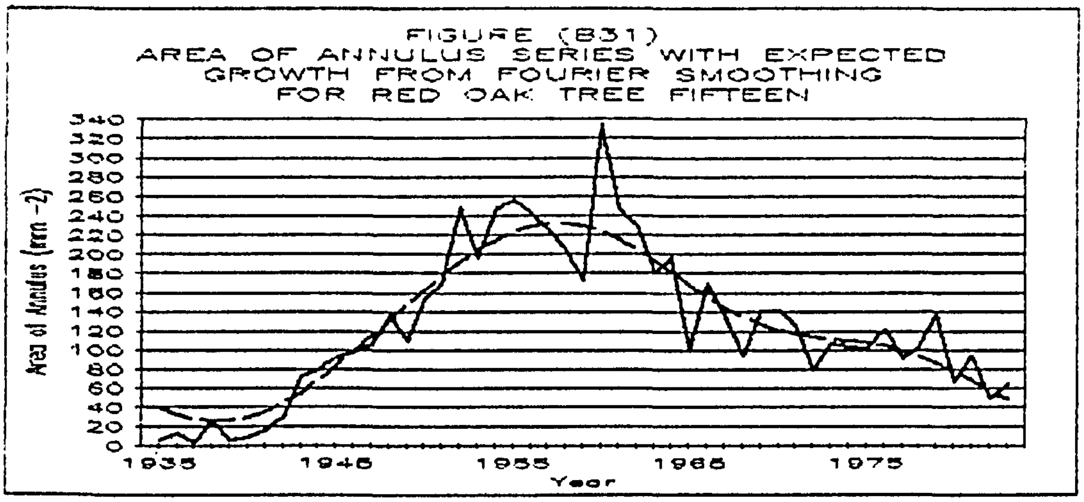


FIGURE (B31)
AREA OF ANNULUS SERIES WITH EXPECTED
GROWTH FROM FOURIER SMOOTHING
FOR RED OAK TREE FIFTEEN

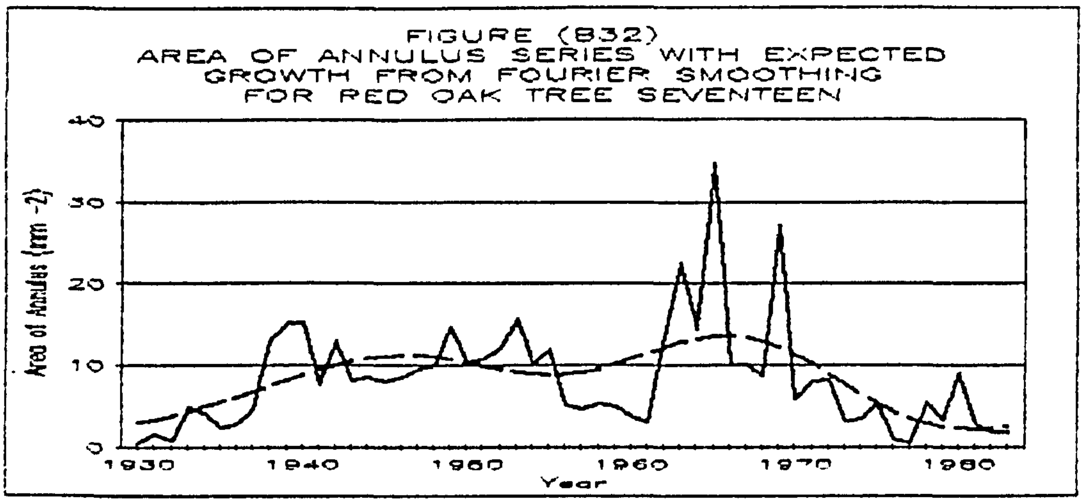


FIGURE (B32)
AREA OF ANNULUS SERIES WITH EXPECTED
GROWTH FROM FOURIER SMOOTHING
FOR RED OAK TREE SEVENTEEN

APPENDIX C

BASIC Computer Programs Used to Calculate the Response Functions and Their Confidence Limits

```
10  '   Program "STD" - Standardize Climatic Data
20 '
30 CLS
40 INPUT "Enter Name of File "; N$
50 INPUT "Enter Number of Data Points";N
60 DIM W(N), X(N), Y(N), Y1(N), Z(N)
70 OPEN "I", #1, N$
80 WHILE NOT EOF(1)
90 FOR I=1 TO N
100 INPUT #1, X(I)
110 NEXT I
120 WEND
130 CLOSE #1
140 ' Calculate mean, variance and standard deviation
150 '
160 SUM=0
170 FOR I=1 TO N
180 Y(I)=X(I)
190 SUM=SUM+Y(I)
200 NEXT I
210 MEAN=SUM/N
220 SUM=0
230 FOR I=1 TO N
240 Y1(I)=(Y(I)-MEAN)^2
250 SUM=SUM+Y1(I)
260 NEXT I
270 VAR=SUM/(N-1)
280 STD=SQR(VAR)
290 ' Standardize each element
300 '
310 FOR I=1 TO N
320 Z(I)=(Y(I)-MEAN)/STD
330 NEXT I
340 YR=1984
350 FOR I=1 TO N
360 W(I)=YR
370 YR=YR-1
380 NEXT I
390 ' Print Routine
400 '
410 PRINT "St. Anne's Monthly Data as Calculated From ",N$
420 PRINT
430 PRINT " Year         Actual        Standardized"
440 PRINT "              Value         Value"
450 PRINT
```

```
460 FOR I=1 TO N
470 PRINT W(I),Y(I),Z(I)
480 NEXT I
490 PRINT
500 PRINT "Mean = ";MEAN
510 PRINT "Variance = ";VAR
520 PRINT "Standard Deviation = ";STD
530 INPUT "Name of Standardized File to be Saved";F1$
540 ' Save standardized file
550 '
560 OPEN "O", #1, F1$
570 FOR I=1 TO N
580 PRINT #1, Z(I)
590 NEXT I
600 CLOSE #1
610 END
```

```
1  '               Program "ANNULUS"
2  ' Calculates mean area of each annulus from two
3  ' ring-width series' from opposite sides of a tree
10 CLEAR
20 CLS
30 DIM X(100), Y(100), Z(100), SUMSQ(100), AR(100)
40 INPUT "Enter Number of Years";N
45 INPUT "First Year in Time Series";YR
50 PRINT
60 INPUT "Enter Name of First File to be Used"; N1$
70 OPEN "I", #1, N1$
80 WHILE NOT EOF(1)
90 FOR I=1 TO N
100 INPUT #1, X(I)
110 NEXT I
120 WEND
130 CLOSE #1
140 PRINT
150 INPUT "Enter Name of Second File to be Used"; N2$
160 OPEN "I", #1, N2$
170 WHILE NOT EOF(1)
180 FOR I=1 TO N
190 INPUT #1, Y(I)
200 NEXT I
210 WEND
220 CLOSE #1
230 PRINT
240 ' Find average ring-width and reverse time series
250 J=N
260 FOR I=1 TO N
270 Z(I)=(X(J)+Y(J))/2
280 J=J-1
290 NEXT I
300 PRINT "Average Annual Growth (mm) beginning with first ring formed:"
310 PRINT
320 FOR I=1 TO N
330 PRINT Z(I)
340 NEXT I
350 PRINT: PRINT
360 ' Calculate Area of each Annulus
370 PI=3.141592654#
380 FOR I=1 TO N
390 FOR J=I TO N
400 SUMSQ(I)=SUMSQ(I)+Z(J)^2
410 NEXT J
420 NEXT I
430 PRINT "Sum of Radius Squared Values Beginning with first ring formed:"
440 PRINT
450 FOR I=1 TO N
460 PRINT SUMSQ(I)
470 NEXT I
500 ' Calculate Annular Radii Beginning with first ring formed
```

```
510 FOR I=1 TO N
520 AR(I)=(SUMSQ(I)-SUMSQ(I+1))*PI
530 NEXT I
535 ' Print Area of each Annulus
550 LPRINT "Area of Annulus:"
560 LPRINT
570 FOR I=1 TO N
580 LPRINT YR, AR(I)
585 YR=YR+1
590 NEXT I
600 ' Save Area File
610 INPUT "Name of Area File to be Saved";N$
620 OPEN "O", #1, N$
630 FOR I=1 TO N
640 PRINT #1, AR(I)
650 NEXT I
660 CLOSE #1
700 END
```

```
1  '              Program "MSX"
2  ' Calculates the mean sensitivity statistic (Fritts, 1976)
3 '  for a ring-width (or ring-area) series.
5 CLS
10 INPUT "Enter the number of cases";N
15 INPUT "Enter name of mean annual width file to be analyzed";F$
16 INPUT "Enter name of mean annual sensitivity file to be saved";F1$
20 DIM T(N), ASX(N-1)
30 OPEN "I", #1, F$
40 WHILE NOT EOF(1)
50 FOR X=1 TO N
60 INPUT #1, T(X)
70 NEXT X
80 WEND
90 CLOSE #1
100 SUM=0
150 FOR X=1 TO N-1
160 DEN=T(X+1)+T(X)
170 NUM=2*(T(X+1)-T(X))
180 ASX(X)=ABS(NUM/DEN)
190 SUM=SUM+ASX(X)
200 NEXT X
210 MSX=SUM/(N-1)
220 PRINT "Mean sensitivity for  ";F$;" is",MSX
230 OPEN "O", #1, F1$
240 FOR X=1 TO N-1
250 WRITE #1, ASX(X)
260 NEXT X
300 END
```

```
4  '  Program "FOURIER"
5  '  Fourier Smoothing Without the Fast Fourier Transform
6  '  Source:  Aubanel and Oldham (1985)
10 CLS
20 INPUT "Enter Name of File to be Used"; N$
30 INPUT "Enter Number of Data Points";N
40 N2 = INT((N+1)/2+1): DIM X(N), X1(N), X2(I), U(N2), V(N2)
50 OPEN "I", #1, N$
60 WHILE NOT EOF(1)
70 FOR I=0 TO N-1
80 INPUT #1, X(I)
90 PRINT "X(";I;") = ";X(I)
100 NEXT I
110 WEND
120 CLOSE #1
130 GOSUB 320
140 LPRINT: LPRINT "When Degree of Smoothing = ";E
145 LPRINT "On File ";N$
150 LPRINT
160 INPUT "Enter First Year of Record";YR
170 LPRINT " Year          Actual         Expected      Indice"
175 LPRINT "               Area           Area            A/E":LPRINT
180 FOR I=0 TO N-1
190 LPRINT YR, X(I), X1(I), X(I)/X1(I)
200 YR=YR+1
210 NEXT I
220 INPUT "If You Want to Try a Different E, Enter 1 Else Enter 0";MORE
230 IF MORE=1 THEN GOSUB 320 ELSE IF MORE<>0 THEN 220 ELSE 250
240 GOTO 150
250 INPUT "Name of Standardized File to be Saved";N$
260 OPEN "O", #1, N$
270 FOR I=0 TO N-1
280 PRINT #1, X(I)/X1(I)
290 NEXT I
300 CLOSE #1
310 END
320 PI=3.141593
330 PRINT"Number of Transform Points to be Kept";
340 INPUT E
350 IF E>INT((N+1)/2) THEN PRINT "E Too Large": GOTO 330
360 IF E<>INT(E) OR E<=1 THEN GOTO 330
370 IF E<=Q THEN 1020
380 '
390 IF Q<>0 THEN 480
400 ' Calculate R(0)
410 G=0
420 FOR J=0 TO N-1
430 G=G+X(J)
440 NEXT J
450 R(0)=G/N
460 Q=1
470 '
```

```
480 PRINT "Working on R(K) Transform Calculations"
490 J2=INT((N-1)/2)
500 P1=INT(LOG(2*J2-1)/LOG(2))
510 FOR K=Q TO E-1
520 J1=J2
530 S=PI*K*2/N
540 C=COS(S): S=SIN(S)
550 FOR J=1 TO J1
560 L=2*J-1
570 U(J)=X(L)*C+X(L+1)
580 V(J)=X(L)*S
590 NEXT J
600 S=2*S*C: C=2*C*C-1
610 FOR P=1 TO P1
620 U(J1+1)=0: V(J1+1)=0
630 J1=INT((J1+1)/2)
640 FOR J=1 TO J1
650 L=2*J-1
660 U=U(L)*C-V(L)*S+U(L+1)
670 V(J)=U(L)*S+V(L)*C+V(L+1)
680 U(J)=U
690 NEXT J
700 S=2*S*C: C=2*C*C-1
710 NEXT P
720 R(K)=(X(0)+(U(1)*C+V(1)*S))/N
730 NEXT K
740 '
750 PRINT "Working on I(K) Transform Calculations"
760 FOR K=Q TO E-1
770 J1=J2
780 S=2*PI*K/N
790 C=COS(S): S=SIN(S)
800 FOR J=1 TO J1
810 L=2*J-1
820 U(J)=-(X(L)*S)
830 V(J)=X(L)*C+X(L+1)
840 NEXT J
850 S=2*S*C: C=2*C*C-1
860 FOR P=1 TO P1
870 U(J1+1)=0: V(J1+1)=0
880 J1=INT((J1+1)/2)
890 FOR J=1 TO J1
900 L=2*J-1
910 U=U(L)*C-V(L)*S+U(L+1)
920 V(J)=U(L)*S+V(L)*C+V(L+1)
930 U(J)=U
940 NEXT J
950 S=2*S*C: C=2*C*C-1
960 NEXT P
970 I(K)=-((U(1)*C+V(1)*S)/N)
980 NEXT K
990 '
```

```
1000 IF E>Q THEN Q=E
1010 '
1020 PRINT "Working on Inverse Transform"
1030 '
1040 'Calculate X1(0)
1050 F1=0: F2=0
1060 FOR K=1 TO E-1
1070 T=R(K)
1080 F1=F1+T
1090 F2=F2+K*K*T
1100 NEXT K
1110 X1(0)=R(0)+2*(F1-F2*(1/E/E))
1120 '
1130 P1=INT(LOG(2*E-3)/LOG(2))
1140 FOR J=1 TO N-1
1150 T2=E*E
1160 FOR K=1 TO E-1
1170 F=1-K*K/T2
1180 U(K)=R(K)*F: V(K)=-(I(K)*F)
1190 NEXT K
1200 K1=E-1
1210 S=2*PI*J/N
1220 C=COS(S): S=SIN(S)
1230 FOR P=1 TO P1
1240 U(K1+1)=0: V(K1+1)=0
1250 K1=INT((K1+1)/2)
1260 FOR K=1 TO K1
1270 L=2*K-1
1280 U=U(L)*C-V(L)*S+U(L+1)
1290 V(K)=U(L)*S+V(L)*C+V(L+1)
1300 U(K)=U
1310 NEXT K
1320 S=2*S*C: C=2*C*C-1
1330 NEXT P
1340 X1(J)=R(0)+2*(U(1)*C+V(1)*S)
1350 NEXT J
1360 RETURN 140
```

```
1  '      Program "PCA"
2  ' Principal Components Analysis
3 '  Source:  Alonso (1981)
5 CLEAR
10 CLS
15 DIM MATDATA(50,50), MAT1(50,50), MEANS(50), CORRMAT(50,50)
20 DIM COMPS(50,50)
25 INPUT"Enter number of climatic Variables";N
30 INPUT"Enter number of years";M
35 FOR J=1 TO N
40 INPUT"Enter name of file ";N$
45 OPEN "I", #1, N$
50 WHILE NOT EOF(1)
55 FOR I=1 TO M
60 INPUT #1, MEANS(I)
65 NEXT I
70 WEND
75 CLOSE #1
80 FOR K=1 TO M
85 MATDATA(K,J)=MEANS(K)
90 NEXT K
95 NEXT J
200 '
205 FOR I=1 TO N
210 MEANS(I)=0
215 FOR J=1 TO M
220 MAT1(I,J)=MATDATA(J,I)
225 MEANS(I)=MEANS(I)+MAT1(I,J)
230 NEXT J
235 MEANS(I)=MEANS(I)/M
240 NEXT I
245 PRINT: PRINT
250 INPUT"Do you want the observation matrix printed";A$
255 IF A$="N" OR A$="n" THEN 300
260 PRINT: PRINT
265 PRINT "Number of Variables = ";N
266 PRINT "Number of Observations = ";M
267 PRINT
270 PRINT "The Observation Matrix is:"
271 PRINT
275 FOR I=1 TO M
276 FOR J=1 TO N
280 PRINT USING "####.####  "; MATDATA(I,J)
282 NEXT J
284 PRINT
285 NEXT I
286 PRINT: PRINT
300 '
305 FOR I=1 TO N
306 FOR J=1 TO N
310 CORRMAT(I,J)=0
312 FOR K=1 TO M
315 CORRMAT(I,J)=CORRMAT(I,J)+(MAT1(I,K)-MEANS(I))*(MAT1(J,K)-MEANS(J))
316 NEXT K
```

```
318 CORRMAT(I,J)=CORRMAT(I,J)/(M-1)
320 NEXT J
322 NEXT I
325 INPUT"Do you want Means and S.D.'s printed";A$
326 IF A$="N" OR A$="n" THEN GOTO 350
327 PRINT: PRINT
328 PRINT"The Means are:
330 FOR I=1 TO N
332 PRINT USING "####.####  ";MEANS(I)
333 NEXT I
335 PRINT: PRINT:PRINT
337 PRINT"The Standard Deviations are:"
338 FOR I=1 TO N
340 PRINT USING "####.####  ";SQR(CORRMAT(I,I))
341 NEXT I
342 PRINT: PRINT: PRINT
350 '
352 INPUT "Do you want the covariance matrix printed ";A$
353 IF A$="N" OR A$="n" THEN GOTO 400
354 PRINT: PRINT
355 PRINT"The Covariance Matrix is:"
360 PRINT
365 FOR I=1 TO N
370 FOR J=1 TO N
375 PRINT USING "####.####  ";CORRMAT(I,J)
380 NEXT J
385 PRINT
390 NEXT I
400 '
405 FOR I=1 TO N
408 FOR J=N TO I STEP -1
410 CORRMAT(I,J)=CORRMAT(I,J)/SQR(CORRMAT(I,I)*CORRMAT(J,J))
412 NEXT J
415 NEXT I
420 INPUT "Do you want the correlation matrix printed ";A$
423 IF A$="N" OR A$="n" THEN GOTO 500
425 PRINT: PRINT
430 PRINT "The Correlation Matrix is:"
435 PRINT
440 FOR I=1 TO N
445 FOR J=1 TO N
450 PRINT USING "####.####  ";CORRMAT(I,J)
455 NEXT J
460 PRINT
465 NEXT I
470 INPUT "Name of Correlation Matrix to be saved";N$
475 OPEN "O", #1, N$
480 FOR I=1 TO N
482 FOR J=1 TO N
485 PRINT #1, CORRMAT(I,J)
490 NEXT J
492 NEXT I
495 CLOSE #1
500 '
```

```
525 EPS-.00001
530 GOSUB 2000
620 PRINT "Actual Amounts of Variance Contributed by each Variable"
625 LPRINT "Actual Amounts of Variance Contributed by each Variable"
630 PRINT "(Followed by Percentage of Total Variance and then by"
635 LPRINT "(Followed by Percentage of Total Variance and then by"
640 PRINT "the Cumulative Percentages are :"
645 LPRINT "the Cumulative Percentages are :"
650 PRINT
655 LPRINT
670 SUM-0
680 FOR I-1 TO N
690 PRINT USING "####.####  "; CORRMAT(I,I)
695 LPRINT USING "####.####  "; CORRMAT(I,I)
700 SUM-SUM+CORRMAT(I,I)
710 NEXT I
720 PRINT
725 LPRINT
730 FOR I-1 TO N
740 PRINT USING " (##.###) ";(CORRMAT(I,I)/SUM*100)
745 LPRINT USING " (##.###) ";(CORRMAT(I,I)/SUM*100)
750 NEXT I
760 PRINT
765 LPRINT
770 TEMP-0
780 FOR I-1 TO N
790 TEMP-TEMP+CORRMAT(I,I)/SUM*100
800 PRINT USING "(###.###) ";TEMP
805 LPRINT USING "(###.###) ";TEMP
810 NEXT I
820 PRINT: PRINT: PRINT
825 LPRINT: LPRINT: LPRINT
830 PRINT "The Principal Components are :"
832 LPRINT "The Principal Components are :"
835 PRINT
836 LPRINT
840 FOR I-1 TO N
850 FOR J-1 TO N
855 PRINT USING "####.####  ";COMPS(I,J)
857 LPRINT USING "####.####  ";COMPS(I,J)
860 NEXT J
865 PRINT
866 LPRINT
870 NEXT I
880 PRINT: PRINT
890 INPUT "Do you want the Principal Components saved";A$
900 IF A$-"Y" OR A$-"y" THEN GOTO 5000
1000 END
2000 '
2020 FOR I-1 TO N
2025 FOR J-1 TO N
2030 COMPS(I,J)-0
2035 NEXT J
2040 NEXT I
```

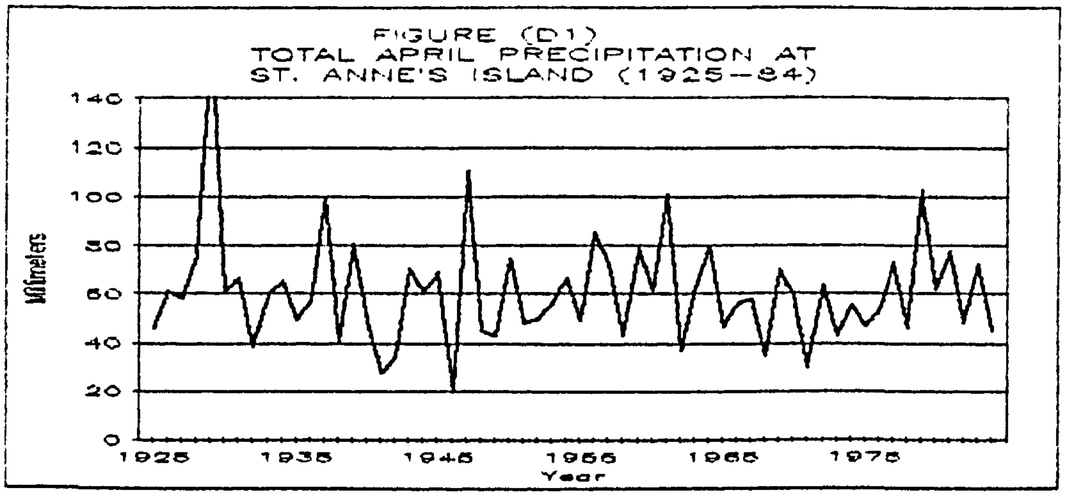
```
2050 FOR I=1 TO N
2060 COMPS(I,I)=1
2065 NEXT I
2080 SUMSQ=CORRMAT(N,N)^2
2090 FOR I=1 TO N-1
2100 SUMSQ=SUMSQ+CORRMAT(I,I)^2
2110 FOR J=I+1 TO N
2115 SUMSQ=SUMSQ+CORRMAT(I,J)^2*2
2120 CORRMAT(J,I)=CORRMAT(I,J)
2125 NEXT J
2130 NEXT I
2135 ITERNUM=0
2150 '
2155 ITERNUM=ITERNUM+1
2160 FOR I=1 TO N-1
2165 FOR J=I+1 TO N
2170 IF ABS(CORRMAT(I,J))<1E-09 THEN GOTO 2250
2172 COSALPH=SQR(.5)
2173 SINALPH=COSALPH
2175 IF ABS(CORRMAT(I,I)-CORRMAT(J,J))>1E-09 THEN
     ALPH=ATN(CORRMAT(I,J)/(CORRMAT(I,I)-CORRMAT(J,J))): GOSUB 4000
2200 FOR K=1 TO N
2205 TEMP=CORRMAT(I,K)
2210 CORRMAT(I,K)=TEMP*COSALPH+CORRMAT(J,K)*SINALPH
2215 CORRMAT(J,K)=TEMP*SINALPH-CORRMAT(J,K)*COSALPH
2220 NEXT K
2225 FOR K=1 TO N
2230 TEMP=CORRMAT(K,I)
2232 CORRMAT(K,I)=TEMP*COSALPH+CORRMAT(K,J)*SINALPH
2233 CORRMAT(K,J)=TEMP*SINALPH-CORRMAT(K,J)*COSALPH
2235 TEMP=COMPS(K,I)
2237 COMPS(K,I)=TEMP*COSALPH+COMPS(K,J)*SINALPH
2238 COMPS(K,J)=TEMP*SINALPH-COMPS(K,J)*COSALPH
2240 NEXT K
2250 '
2260 NEXT J
2265 NEXT I
2270 TEMP=0
2280 FOR I=1 TO N
2285 TEMP=TEMP+CORRMAT(I,I)^2
2290 NEXT I
2300 IF ABS(TEMP-SUMSQ)<EPS THEN RETURN
2305 PRINT ITERNUM
2310 IF ITERNUM<10 THEN GOTO 2150
2320 PRINT "Function has not converged after 10 iterations"
2325 STOP
2330 RETURN 620
4000 '
4010 COSALPH=COS(ALPH/2)
4020 SINALPH=SIN(ALPH/2)
4030 RETURN
5000 INPUT "Name of Principal Component file to be saved";N$
5010 OPEN "O", #1, N$
5020 FOR I=1 TO N
```

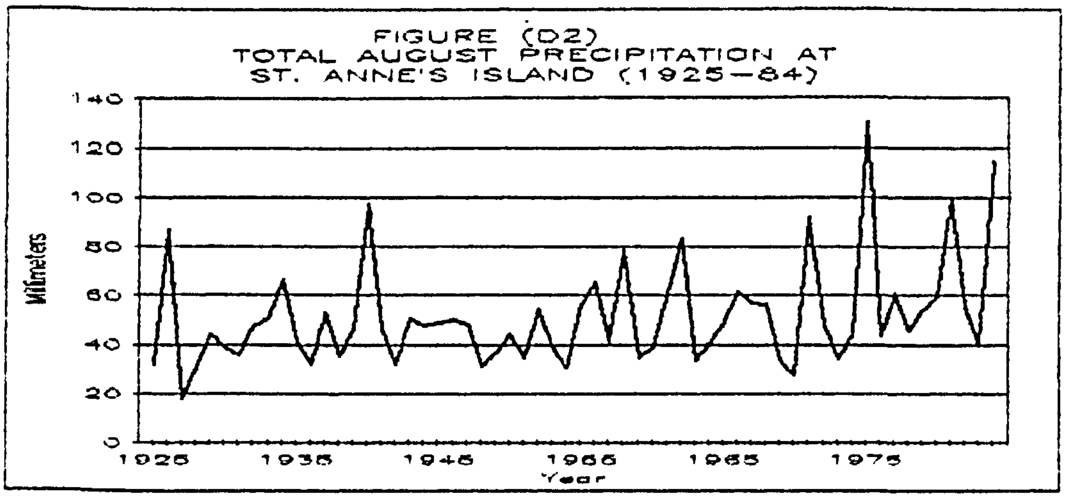
```
5030 FOR J-1 TO N
5040 PRINT #1, COMPS(I,J)
5050 NEXT J
5060 NEXT I
5070 CLOSE #1
5100 END
```

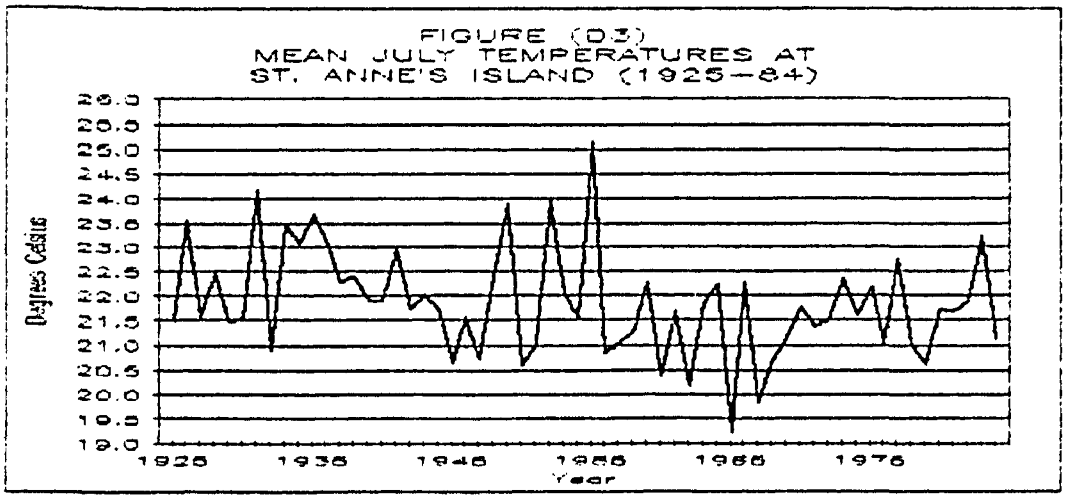
```
1  '              Program  "RF"
10 ' Compute Response Function, Predicted Ring-Widths (Areas)
20 ' and LIST onfidence Limits of Response Function
30 CLEAR
40 CLS
50 DIM B(48,48), COEF(48), T(60), P(60)
60 INPUT "Number of Climatic Variables";N
235 DIM E(48,48), EE(48,48)
240 ' Input Principal Components (48 rows x 48 cols)
250 PRINT"Inputting Principal Components.........."
260 OPEN "I", #1, "COMP60"
270 WHILE NOT EOF(1)
280 FOR I=1 TO N
290 FOR J=1 TO N
300 INPUT #1, B(I,J)
310 NEXT J
320 NEXT I
330 WEND
340 CLOSE #1
345 PRINT: PRINT
350 ' Fill Principal Component Matrix (E) with Zeros
360 FOR I=1 TO N
370 FOR J=1 TO N
380 E(I,J)=0
390 NEXT J
400 NEXT I
410 ' Input First 26 Principal Components in Descending Order into E
414 PRINT " Input First 26 Principal Components in Descending Order"
415 PRINT
420 FOR I=1 TO 26
430 INPUT "Which column to access"; N1
440 FOR J=1 TO N
450 E(J,I)=B(J,N1)
455 EE(J,I)=B(J,N1)
460 NEXT J
470 NEXT I
471 ERASE B
475 DIM ET(48,48), ET1(48,48), SE(48), E1(48)
476 DIM S(48), CONF(48)
480 ' Create ET and ET1 as Transpose of E
490 FOR I=1 TO N
500 FOR J=1 TO N
510 ET(J,I)=E(I,J)
515 ET1(J,I)=EE(I,J)
520 NEXT J
530 NEXT I
540 PRINT: PRINT
550 FOR L=1 TO 6
560 ' Fill T, E1 and S and SE with Zeros
570 FOR I=1 TO N
580 T(I)=0
590 E1(I)=0
```

```
600 S(I)=0
605 SE(I)=0
610 NEXT I
620 ' Input Regression Coefficients and Their Standard Errors
625 INPUT "Name of This Chronology "; CN$
630 FOR I=1 TO 26
640 PRINT
650 PRINT "Amplitude No. ";I
660 INPUT "Coefficient ="; C
670 INPUT "Standard Deviation ="; CC
680 COEF(I)=C
690 SE(I)=CC/48
700 NEXT I
710 PRINT: PRINT: PRINT
720 ' Calculate Transfer Function (T)
730 FOR I=1 TO N
740 FOR J=1 TO N
750 T(I)=T(I)+COEF(J)*ET1(J,I)
760 NEXT J
770 NEXT I
1000 ' Calculate 95% Condidence Limits of Response Function T
1010 ' Multiply SE by Principal Component Matrix E
1020 FOR I=1 TO N
1030 FOR J=1 TO N
1040 E1(I)=E1(I)+SE(J)*E(J,I)
1050 NEXT J
1060 NEXT I
1070 ' Multiply Product E1 by ET
1080 FOR I=1 TO N
1090 FOR J=1 TO N
1100 S(I)=S(I)+E1(J)*ET(J,I)
1110 NEXT J
1120 NEXT I
1130 ' Calculate 95% Confidence Limits
1150 ' F Value for V1(1) and V2(46) Degrees of Freedom = 4.06
1160 FOR I=1 TO N
1170 CONF(I)=SQR(ABS(S(I))*4.06)
1180 NEXT I
1200 ' Print Results
1210 LPRINT
1220 LPRINT CN$
1230 LPRINT
1240 LPRINT "Coefficient        Plus/Minus Confidence Interval"
1250 LPRINT
1260 FOR I=1 TO N
1270 LPRINT USING "#.#####             "; T(I),T(I)+CONF(I),T(I)-CONF(I)
1280 NEXT I
1300 NEXT L
1500 END
```

APPENDIX D
Environmental Variables Which were Significantly Different in Their Variances or Means







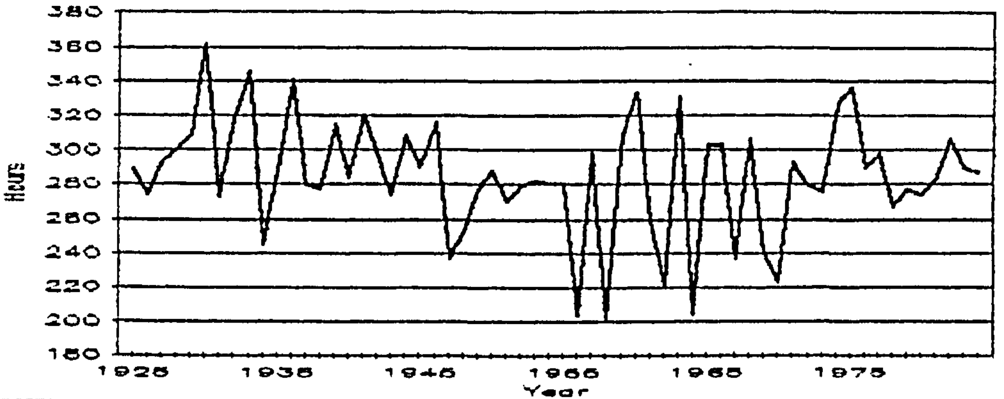


FIGURE (D4)
TOTAL BRIGHT JULY SUNSHINE HOURS
AT ST. ANNE'S ISLAND (1925–84)

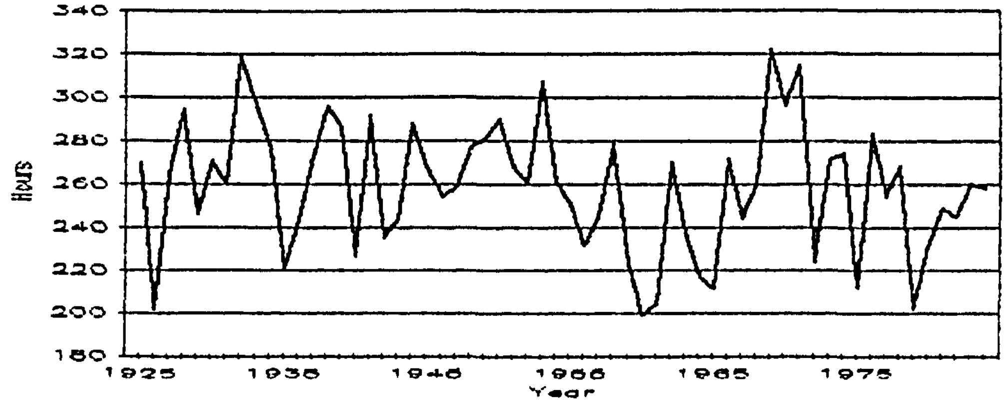


FIGURE (D5)
TOTAL BRIGHT AUGUST SUNSHINE HOURS
AT ST. ANNE'S ISLAND (1925–84)

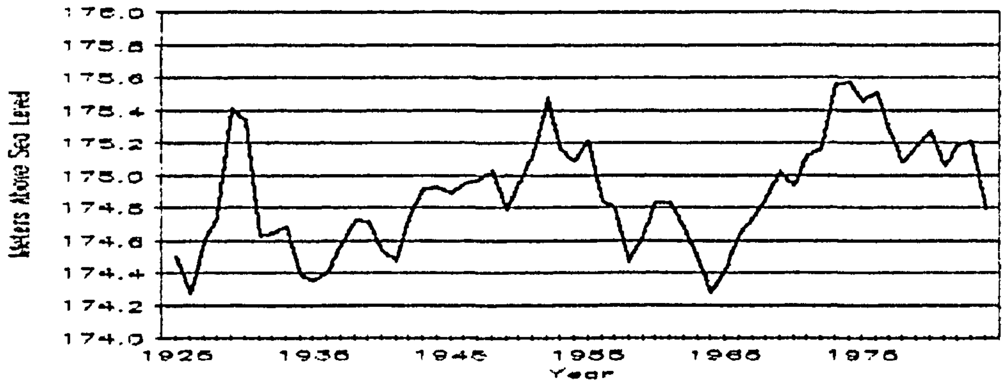


FIGURE (D6)
MEAN APRIL LAKE ST. CLAIR LEVELS
MEASURED AT BELLE RIVER, ONTARIO
FOR THE PERIOD 1925 TO 1984

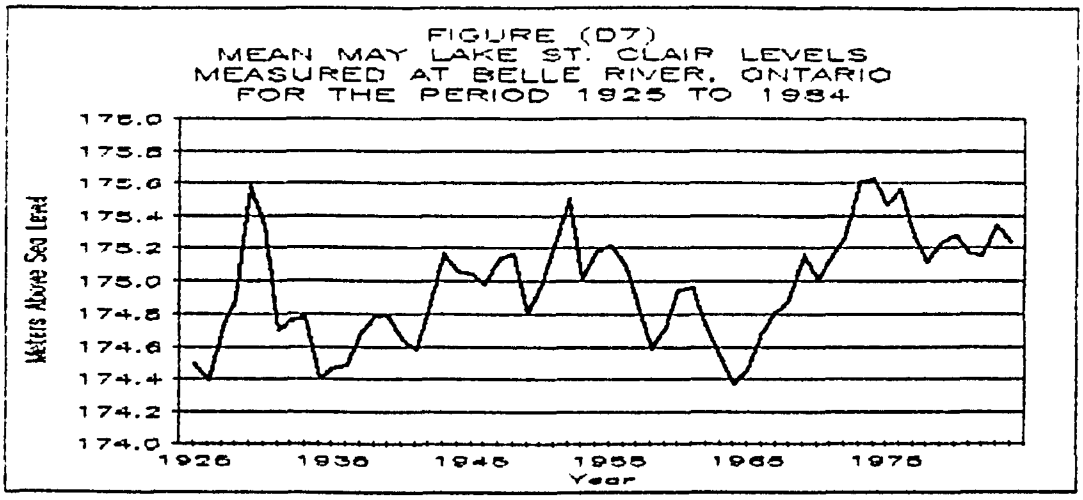


FIGURE (D7)
MEAN MAY LAKE ST. CLAIR LEVELS
MEASURED AT BELLE RIVER, ONTARIO
FOR THE PERIOD 1925 TO 1984

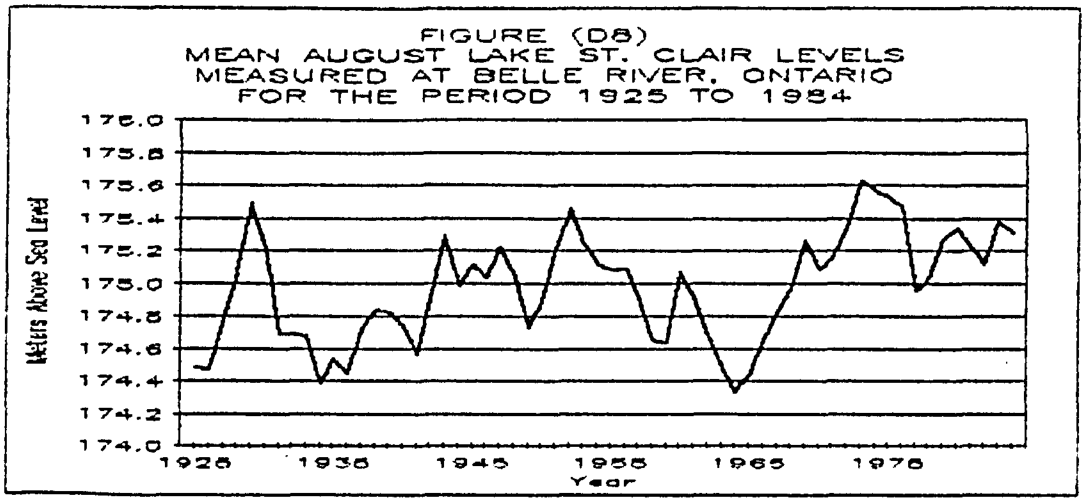


FIGURE (D8)
MEAN AUGUST LAKE ST. CLAIR LEVELS
MEASURED AT BELLE RIVER, ONTARIO
FOR THE PERIOD 1925 TO 1984

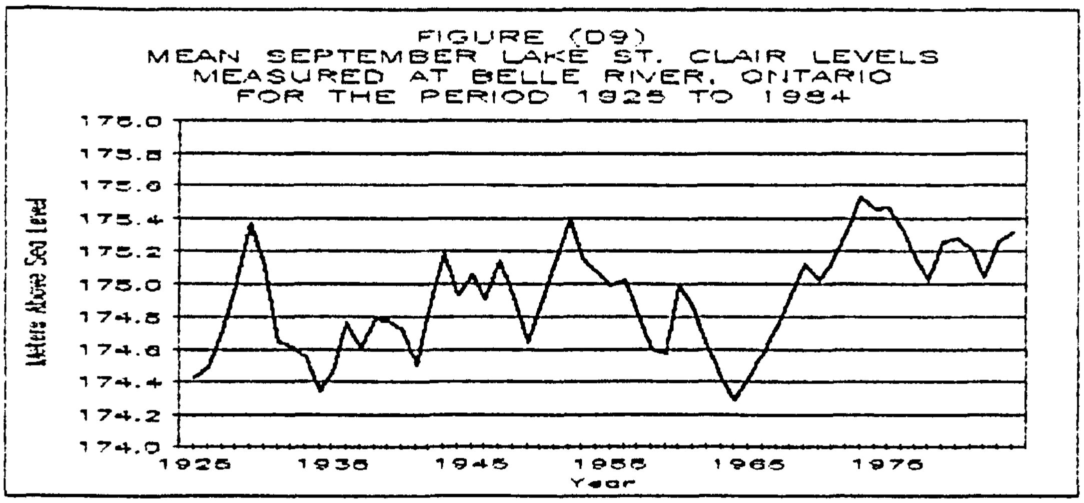


FIGURE (D9)
MEAN SEPTEMBER LAKE ST. CLAIR LEVELS
MEASURED AT BELLE RIVER, ONTARIO
FOR THE PERIOD 1925 TO 1984

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