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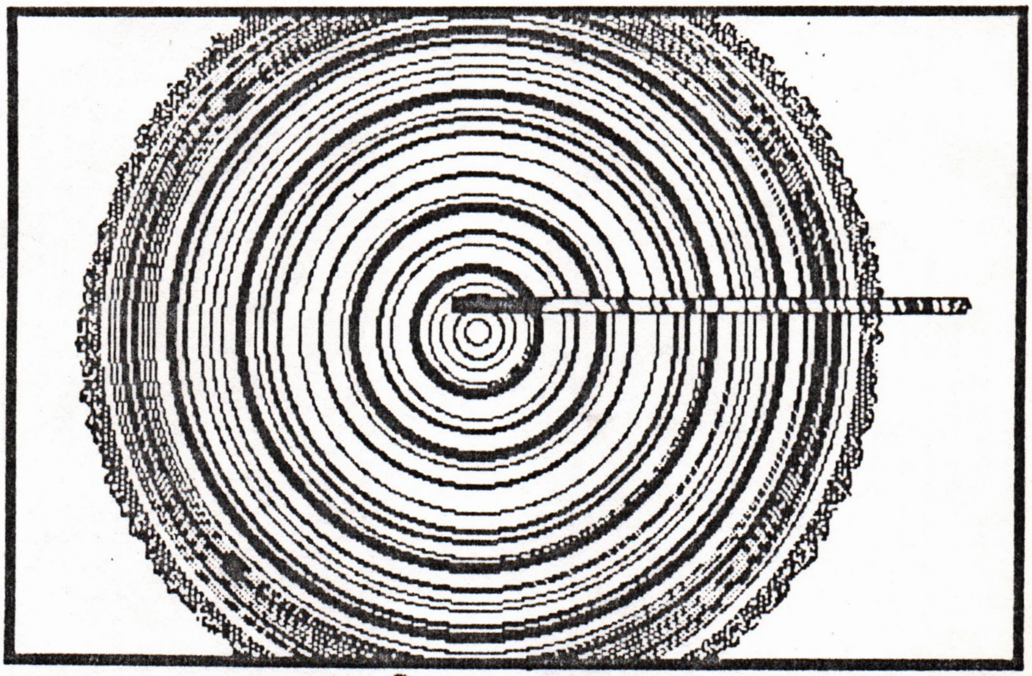

Factors Affecting the Growth and Distribution of Pitch Pine on Bog Soils

A Field Naturalist Final Project Proposal

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Abstract

Maquam Bog is an extensive lakeside wetland on the Missisquoi Delta, Lake Champlain, Vermont. It supports one of the largest populations of pitch pine (*Pinus rigida*) in the state, and several other plant and animal species that are rare or threatened in Vermont. Preliminary studies indicate that the present trophic status and plant community composition are controlled by processes of peat accumulation, annual flooding, and fire. Information on the ecology of pitch pine on this site may be useful in making management decisons for Missisquoi National Wildlife Refuge and the Lake Champlain Basin.

The proposed study will use dendroecological methods to examine the influences of fire, drought and lake level on a population of pitch pine in Maquam Bog. Ring width, lake level and climatic data will be used to develop growth response functions for trees from five stands in the bog. The direction and magnitude of the regression coefficients will be used to make inferences about the ecological effects of changes in lake level on pitch pine growth. Fire history will be determined by examination of fire scarred trees and stumps and from historical records. Population age structure will be determined from a random sample of trees in each site to determine if reproductive age classes corrrelate with the occurrence of fire. Results of these studies will be integrated into existing knowledge of the ecology of pitch pine and of the hydrology and geomorphology of Maquam Bog.

Introduction

Maquam Bog is an 800-hectare wetland occupying much of the southern portion of Missisquoi National Wildlife Refuge in Swanton, Vermont (Fig. 1). It is one of three stations in Vermont for Virginia chain fern (*Woodwardia virginica*), regarded as threatened in the state. It also supports a large, intact population of pitch pine (*Pinus resinosa*), perhaps the largest population in Vermont. Marsh hawk and short-eared owl, both species of special concern in the state, have been sighted at Maquam Bog, and the area has a good potential as breeding habitat for both species. Because of its value as habitat for these and other plant and animal species, and because it represents an extensive area of undisturbed wetland, the site is of state and perhaps regional significance.

Preliminary investigation indicates that the present trophic status and plant community composition of the bog are regulated by three interacting processes: 1) Annual flooding by Lake Champlain; 2) Plant successsional processes and peat accumulation; and 3) The regular occurrence of natural fires. Any management plans for Missisquoi National Wildlife Refuge or for Lake Champlain which affect these factors may potentially affect Maquam Bog and its rare and endangered species.

The proposed study will use dendroecological methods to determine how lake level and fire affect the growth and reproduction of pitch pine in the bog. This project is intended to fulfill requirements for the final project of the Field Naturalist Program at the University of Vermont, a non-thesis master's degree program in integrative field science. A cardinal requirement of the final project is that it be integrative, that is, the project should draw on knowledge of different natural sciences in developing an understanding of a natural system. Implicit in the development of hypotheses about pitch pine at Maquam Bog is some understanding of the bog's geomorpholgy, hydrology, and developmental history, as well as a knowledge of plant physiology and ecology. These subjects will be integrated in the final report.

The results of this project will be of interest and use to the managers of the Missisquoi National Wildlife Refuge, to persons interested in resource conservation in the Lake Champlain Basin, in Vermont, and in the New England region. I also hope that the results will be of sufficient general interest for journal publication.

Study Area

Maquam Bog is bounded by the uplands of Hog Island to the west, abandoned distributaries of the Missisquoi River to the north and east, and a low berm along Maquam Bay to the south (Fig. 1). Peats in the bog range from less than 1 m to nearly 3 m deep; these overlie fine to medium deltaic sands (Fillon, 1970). Subsidence in these sediments and a long term relative rise in lake level drive the continued accumulation of peat in the bog.

The vegetation of Maquam Bog has been described and mapped by Lind (1975) and Bogucki and Gruendling (1978). The most abundant species on the bog is leatherleaf (*Chamaedaphne calyculata*) which forms large clumps less than 1 m high over much of the bog. Several other low shrub species are found in the central area of the bog, as well as turf areas of the few-seeded sedge (*Carex oligosperma*); these give way to taller shrubs and trees toward the bog edges.

Maquam Bog is flooded nearly every year, primarily by water from

Lake Champlain entering by way of Charcoal and Maquam Creeks. The presence and distribution of several minerotrophic peatland plant species (e.g. sweet gale, *Myrica gale*) suggest that this annual flooding delivers nutrients and flushes acids from the bog, with this effect strongest in areas adjacent to Maquam and Charcoal Creeks. The bog is highest (over 99 feet asl). in the central and western areas; these are the areas least affected by flooding. Towards Maquam and Charcoal Creeks the bog falls away to elevations of approximately 96-97 ft.

Charcoal on the bark of living trees, on dead wood, and in peat deposits gives evidence of a long history of fire disturbance. Scars on the trunks and lower branches of pitch pines from a number of sites in the bog all date to about 20 years ago. Some trees show multiple scars, spaced only 4-5 years apart. This suggests that Maquam Bog was swept by at least one fire during the early 1960's. This is coincident with a period of prolonged drought in the Northeastern United States (Cook and Jacoby,1977), and a period of record low lake levels.

Pitch Pine occurs in Maquam Bog in several closed-canopy stands, mainly near the bog margins, and as individual trees scattered over much of the central open area of the bog. The closed canopy stands vary in character, some having only the low shrubs and sedges characteristic of the bog center as understory species, others having a well-developed shrub layer of rhodora (*Rhododendron canedense*), sheep laurel (*Kalmia angustifolia*), and highbush blueberry (*Vaccinium corymbosum*). In some of the latter stands, red maples (*Acer rubrum*) are growing up through the canopy.

The oldest pitch pine found to date is about 120 years old, occurring in the closed canopy stand in the south-central area of the bog.

Reproductive age individuals from a few to 20 or more years old are found in abundance within 50 m of parent trees, except in the closed stands, where there is not enough light for seedling germination or establishment. Where there is sufficient light, the seeds apparently germinate and establish well in *Sphagnum* moss; young trees may be found with the roots growing entirely in the top few inches of a *Sphagnum* hummock.

Pitch pine is presently regarded as a species of special concern in the state of Vermont (Gallegos, personal communication). Most other locations in the state are small stands on sandy uplands. On many of these sites, there is little or no reproduction taking place, apparently because of the absence of fire, on which pitch pine is largely dependent for seed germination and establishment on dry sites (Fowells, 1965; Ledig and Little, 1979). A few pitch pines are found in Colchester Bog near Burlington, but these are being crowded out by swamp maple and various shrub species. By contrast, the pitch pine at Maquam Bog is a large and vigorously reproducing population, probably the largest in the state.

Other tree species occuring in the bog include a stand of black spruce (*Picea mariana*), west of the south-central pitch pine stand; tamarack (*Larix laricina*), occurring with the black spruce and along the western margin of the bog; and numerous small, multi-stemmed gray birch (*Betula populifolia*), rarely more than 3 m tall, occurring over much of the bog. Lagg areas and areas adjacent to Charcoal and Maquam Creeks support more varied tree and shrub populations, but these are not relevant to the proposed study.

Literature Review

Past studies on the ecology of pitch pine have focused on populations on upland sites, particularly the fire-dominated ecosystems of the New Jersey Pine Barrens and other sandy coastal plain areas (e.g. Ledig and Little, 1979, Buchholz and Good, 1982). While pitch pine is recognized as occurring on saturated soils throughout its range, there appears to be little information in the literature about the ecology of the species on these soils. The common denominator seems to be acid, nutrient-poor soils where competition from other species is limited (Ledig and Little 1979). Fire also plays a role in reducing competition from other shrub and tree species on both dry and wet sites (Little, 1979).

McCormick (1979), in a description of the vegetation of the New Jersey Pine Barrens describes a 'pitch pine lowland forest', occurring in poorly drained areas. He notes that leatherleaf is the predominant understory species in pitch pine stands on frequently inundated sites; other important shrubs in these stands include sheep laurel (*Kalmia angustifolia*) and huckleberries (*Gaylussacia* spp.). Judging by this description, Maquam Bog is generally similar in character to these areas. Lowlands in the pine barrens occur where the topography dips below the water table. Due to annual fluctuations in the water table (Rhodehamel, 1979) , these areas are subject to a regime of spring flooding similar to that in Maquam Bog. The pitch pine community at Maquam appears to be a northern outlier of this community type, which is more abundant on the coastal plain areas further south.

Fire is the key factor in perpetuating pitch pine populations on upland sites (Ledig and Little, 1979). By killing off less fire resistant species and exposing mineral soil for seed germination (Little and Moore, 1949), fire ensures the continued presence of the species on these sites. Age structures of tree populations in fire-dominated ecosystems commonly reflect the fire history, with the modal age class occurring within a few years after a fire. This has been demonstrated for Pine Barrens pitch pine (Buccholz and Good, 1982), red pine in Vermont (B. Engstrom, unpublished data), black spruce in boreal regions (Lieffers, 1986; Black and Bliss, 1980), and probably other coniferous species as well.

Ecological effects of fire are varied and often dependent on specific site characters (Ahlgren and Ahlgren, 1960). In fire-dominated ecosystems fire plays a critical role in nutrient cycling, by releasing nutrients bound in litter (Viro, 1974). Fire may vary in intensity in a given site, depending on vegetation biomass and height, wind speed, speed of fire front, and moisture content of litter (Sparling and Smith, 1966). Fires of different intensity differ in their effects on nutrient release (Boerner and Forman, 1982) and vegetation (Boerner, 1981; Armour and Bunting, 1984).

Flooding for more than a few weeks during the growing season generally has adverse effects on the growth of woody plants (Kozlowski, 1984), primarily by causing depletion of oxygen in the rooting zone, which limits root growth and metabolism, and may cause root mortalty. Flooding also reduces soil temperature (Ponnamperuma, 1984), which may also slow root metabolism. However, particularly for flood tolerant species, shorter periods of inundation may stimulate growth (Kozlowski and Pallardy, 1984) presumably by delivering nutrients where these are limiting.

Dendrochronological studies of dry site pitch pine (Johnson et al., 1981; Puckett, 1982; Cook and Jacoby 1977) show correlations of radial growth with various environmental variables. The most consistent predictor is the July Palmer Drought Severity Index (PDSI; Palmer, 1965), which shows a positive correlation with growth (PDSI is negative for dry years and poistive for wet years) in pitch pines from Pine Barrens sites (Johnson et al. 1981) and from Mohonk Lake, N.Y. (Cook and Jacoby, 1977). In the latter study, about 30% of the variance in ring width indices was accounted for by July PDSI alone. Cook and Jacoby (1977) also found negative correlations with summer temperature and positive correlations with summer precipitation, reinforcing the hypothesis that dry site pitch pine growth is limited by water availabilty. These correlations may well not apply to bog grown pitch pine; no dendrochronological studies to date have focused on bog populations.

Stockton and Fritts (1973) used radial growth response of white spruce to develop a long term chronology of water level changes for Lake Athabasca, BC. Variations in annual ring widths of trees from six sites accounted for 80% of the variance in July lake level. Because they used trees from different sites located on rivers near the lake, which were affected differently by lake level changes, the responses of the trees are varied. Other than some very broad conjectures, the authors do not specifically discuss the growth responses of trees from any one site. However, the success of their study is encouraging, and their methods may be applicable in this study.

The few physiological studies of pitch pine (e.g. Ledig, 1976, 1977) deal with rates of photosynthesis and respiration in seedlings under controlled conditions, and shed little light on questions concerning the phsysiology of bog-grown pitch pine, particularly the problems of water relations and nutrient absorption. As with other conifers, mycorrhizal associations ocur in pitch pine roots and may play a role in nutrient absorption (Buccholz and Motto, 1981). In saturated soils, mycorrhizae occur only near the soil surface and are poorly developed (Marks and Kozlowski, 1973). They have been reported on roots of pitch pine growing on wet sites (McQuilkin, 1935), but whether or not they are as important to normal growth in pitch pine as they are to other conifers has not been studied. Mycorrhizae could act as an intermediary in the growth response of pitch pine to environmental variables that affect soil conditions.

Objectives

Preliminary observations conducted in May 1987 raise a number of questions and hypotheses concerning the ecology of pitch pine at Maquam Bog (Table 1). This project will focus primarily on hypotheses concerning effects of lake level and fire on tree growth, and address other questions as time and budget allow. In past years, water management plans for Missisquoi National Wildlife Refuge (Gallegos, personal communication) and Lake Champlain (ICREB, 1973) have been proposed which would drastically affect the current regime of flooding in Maquam Bog. Information about pitch pine response to lake level changes may be critical in making decisions about these or other management plans. Lake level changes may also affect the bog's suitability as habitat for the other rare species found there; to the extent that pitch pine growth reflects growth conditions for other plant species, results of this study may be valuable in making impact assessments for these species as well. Similarly, a better understanding of the role of fire in Maquam Bog may be helpful in making management decisions for the area.

The primary objective of this study is to determine if lake level affects pitch pine growth. This will be achieved by statistical analysis of tree ring width and lake level data. The second priority is a reconstruction of the recent fire history for Maquam Bog, and a qualitative assessment of the effects of fire on pitch pine growth, population age structure, and distribution. This will be achieved by determining an age structure for pitch pine stands on different sites, dating fire scars on living trees, sectioning and crossdating stumps, and corroboration with historical records. Other hypotheses concerning effects of environmental gradients on pitch pine distribution (Table 1) will be tested as time allows.

Hypotheses

Tree Growth

While it is entirely reasonable that flooding of Maquam Bog by Lake Champlain should have measurable effects on pitch pine growth, the relationship is probably not a simple one, and may be complicated by other factors. Annual flooding of the bog by the lake and river flushes out acids and delivers some nutrients, and may serve to stimulate growth of pitch pine and other plants. However, years of prolonged high water could cause depletion of oxygen in the rooting zone, thereby affecting rates of root growth and nutrient absorption, and the growth of the tree as a whole. Low water years might allow late summer drying out of the bog, and limit tree growth by drought stress. In the latter case, some interaction with summer precipitation and temperature may be expected. Thus, hypotheses about tree response to lake level are "two-tailed". The working hypothesis is that lake level in some way affects pitch pine growth; the null is that there is no significant correlation. While the very general ideas outlined above suggest some possible growth response mechanisms, no prior assumptions will be made about the direction of growth response to lake level.

Fire may affect the growth rate of pitch pine by at least three mechanisms: 1) It may cause a mobilization of nutrients in the soil, stimulating growth; 2) It may reduce competition by killing off less fire-resistant species; and 3) A severe fire may temporarily defoliate trees, resulting in a reduction in incremental growth while new foliage is established. These hypotheses would best be tested by experimentally burning sections of the bog, but some evidence may be gained by examining incremental growth before and after known fire years.

Other climatic factors may also affect tree growth. As outlined above, drought limits growth in upland pitch pine, and it is possible that the bog pitch pine may be drought-stressed in dry years. Consideration may be given to climatic factors in analysis of the ring width data.

Spatial Distribution

The present spatial distribution of pitch pine in the bog is patchy. Contrasting hypotheses suggest that it may be controlled by environmental gradients related to the geomorphology and hydrology of the bog, or to variations in fire intensity. Fillon (1970) suggests that the distribution of pitch pine reflects the peat depth overlying old deltaic channels and levees which underlie the bog. Preliminary data on pH and electrical conductivity show decreases in pH and nutrient availiabilty away from Maquam and Charcoal Creeks; these conditions may affect the establishment and growth of pitch pine. These hypotheses may be tested by correlating pitch pine frequency or basal area with peat depth, pH, or electrical conductivity along a transect from bog edge to center.

The occurrence of a tall shrub layer in some pitch pine stands which is lacking elsewhere in the bog suggests that these areas may have escaped the most recent fire, or that it was less intense in these sites. While it is difficult to test this hypothesis directly, examination of fire scars and age structure in different stands may provide some evidence.

Population Age Structure

It is a working hypothesis of this project that the fire history of Maquam Bog will be reflected in the population age structure of pitch pines. While the pitch pine can reproduce in peat, they need sunlight, therefore reproduction in a given stand should be concentrated in a period of twenty years or so following fire, before shrubs and trees create too much shade. This can be tested by developing a population age structure and comparing it with the fire history developed from fire scars and historical records.

Lake level may also affect population age structure; establishment and survivorship may be affected by drought or oxygen stress. Unless it is very pronounced this may be hard to detect in the age structure and to differentiate from the effects of fire, since its effect would be to kill off individuals in a restricted range of age classes corresponding to years of stress caused by high or low lake level. Similarly, drought may kill off some age classes, but would be hard to detect, although the recent drought of the early 60's may provide a unique opportunity to examine this hypothesis.

Preliminary Results

Preliminary examination of tree cores from 3 stands shows periods of low growth for the years 1910 and 1948-50 ocurring in trees from three different stands. Other patterns may exist, but are not as readily apparent. Lake level data are available beginning in 1871, but have been compiled only for the period 1939-1970 (Fig. 2). 1947 was a year of high lake level through much of the summer; the low growth in succeeding years could be accounted for by a lagged response to drowning of roots. Alternatively, 1949 was a year of below average lake levels for much of the growing season, and this may explain low growth in 1949-50. Growth responses to lake level are not clear from a cursory inspection of the data.

The early 1960's were a time of drought for New England; this is reflected in the lake level and precipiation records in Figure 2. In 1965 and possibly 1964, lake levels wre not high enough to flood the bog. There is no clear growth response to this drought period in the ring series examined so far. Response to this particular drought may be complicated by a probable fire sometime during this period. Fire may slow growth in some trees by injury or defoliation; other trees may be stimulated by the release of nutrients associated with fire. Larger, site-specific samples may show more consistent responses to drought and fire.

Preliminary coring and sectioning of fire scarred trees indicates that a fire affected at least two stands in the bog about twenty years ago. A cursory examination of age structure of the pitch pines supports this and suggests another fire between 50 and 75 years ago. Most of the smaller trees in the central area of the bog are twenty years or less in age. While some older trees in the closed stands exceed 100 years in age, most fall in an age class of 50-75 years. More detailed analysis of age structure in individual stands should help clarify this picture. The fire about twenty years ago is roughly coincident with a period of drought (Cook, 1982) and low lake level (Fig. 2), which was most pronounced in 1964-65.

Examination of climatic records may reveal other periods with increased likelihood of fire.

Materials and Methods

The scheme outlined below is designed to obtain a representative sample of trees and cores for determining population age distribution and ring width chronologies for each of five stands in Maquam Bog. Sampling for growth response analysis will include only trees >10 cm dbh to ensure enough replication of yearly ring widths to develop a response function. Random sampling across age groups within this restriction is necessary if inferences are to be drawn regarding the ecology of the pitch pine population as a whole. It is possible that the ring width series of younger trees from closed stands may be dominated by the effects of competition rather than environmental variables. If this is so, it may be necessary to depart from the strictly random sampling scheme in order to develop more responsive site chronologies.

Data Collection

Four closed canopy pitch pine stands, (Fig. 1) have been selected for sampling; a fifth sample will come from the pitch pines scattered over the central bog area. Stands 1, 3 and 4 all have a well developed shrub uunderstory; stands 1 and 4 ar closer to Charcoal and Maquam Creeks and are probably less acid and somewhat lower in elevation than stand 1. Stand 2 is thinner, somewaht higher in elevation than the other three, and has an understory consisting of scattered small (<1 m) rhodora and sedges. The central area is dominated by leatherleaf, lowbush blueberry, and few-seeded sedge. The five sites represent the full range of conditions in which pitch pine is found growing in the bog.

In each of the four closed canopy stands, five10 m x 10 m quadrats will be located 50 m apart on a transect line located on the long axis of each stand. All pitch pine in each quadrat will be measured and aged, either by coring individuals >10 cm. dbh, or by node counts on individuals <10 cm. Dbh will be recorded for the larger size class; diameter 10 cm above ground level will be recorded for the smaller trees. Age corrections for node counts will be determined by counting nodes and then coring or sectioning a set of smaller trees, and calculating a mean difference between ages determined by the two methods. Trees will be cored 50 cm above the base, on the south side. This should result in a sample of 100-200 aged individuals from each stand, sufficient to develop a fairly accurate picture of population age structure and basal area in each stand.

Four trees >10 cm dbh, located nearest the corners of each quadrat will be cored a second time, on the east side. The two cores from these trees will be used for the growth response analysis. This will result in a random sample of 20 trees and 40 cores from each stand, generally considered an adequate sample for developing a site chronology (Fritts, 1976).

Sampling procedures in the central bog will differ from those above because the trees are widely scattered. Five points 100 m apart will be located along a north-south transect line through the bog center. All trees within a 50 m radius of the center point will be measured as above. There may be some points with few or no trees within 50 m; if this results in a sample of less than 100 trees, the transect may be extended, or repeated 200 m to the east or west. The four trees > 10cm dbh closest to each center point will be cored twice for growth response analysis.

All cores will be given a unique number and stored in soda straws. Only those selected for growth response analysis or for which age determination is difficult will be mounted on blocks. Any dead trees or stumps in the sample areas will be measured and recorded. A qualitative description of understory vegetation, incidence of squirrel middens, deer browse, etc., will be recorded for each quadrat or sample point.

Sampling for fire history will not necessarily be random. All trees in the quadrats will be inspected for fire scars; any scarred trees encountered in the bog outside the quadrats will also be included. Partial cores adjacent to scars will be used to age fires. A bow saw may be used to section a few small fire scarred individuals for more accurate age determination. Sectioning and crossdating of large stumps may help extend the fire history into the 1800's.

This intensive phase of data collection will be accomplished in the first few weeks of June. Following this period, the bog will be visited weekly through the summer season for observations on water level changes and further collection of fire scar data. Two relative water level measuring stations (marks on tree trunks) have been established in stands 2 and 3. As groundwater level drops, it may be necessary to dig pits to extend water level observations through the summer. These measurements will be used to get some idea of the response of the bog water table to changes in lake level; this information may be helpful in interpreting growth response results.

Cores for growth response analysis will be air-dried, mounted on wood blocks and sanded. Cores will be crossdated using skeleton plots (Stokes and Smiley, 1968). Ring widths will be measured using a dendrometer, available in the Acid Rain Lab at the University of Vermont. This allows measurement of ring widths to within .01 mm, and direct recording of measured widths on computer.

Data Analysis

The focus of the statistical analysis will be on tree growth response to lake level. At present, consideration of the effects of fire is planned to be largely qualititative. As the data base is developed and examined, some opportunities for statistically examining growth response to fire may emerge.

Water levels of Lake Champlain have been continuosly recorded since 1871; these data are available from the UVM library or from the USGS office in Boston, and will be entered on the mainframe computer. Climatic data, including monthly temparature and precipitation data and Palmer Drought Severity Index are already on the computer.

The ring-width series for each tree will be standardized by exponential or polynomial curve fitting (Fritts, 1976). Programs for this procedure are available on the UVM computer. This step serves both to remove growth trends unique to individual trees and to obtain uniform variance over time.

Analysis of variance on the ring width indices will be used to partition the variance due to differences between stands, age classes, trees and cores. Because of autocorrelation in ring width series, it is not possible to evaluate the significance of these differences exactly. However, a reduction of degrees of freedom based on the degree of autocorrelation may be used to estimate significance (Fritts, 1976); there may still be some subjective judgement involved. If stands are not significantly different, the data may be grouped in a single chronology for further analysis. If stands are significantly different, they may be analyzed separately using canonical correlation analysis as applied in Stockton and Fritts (1973), which is used to relate a set of dependent variables to a set of predictors. The pattern of differences, in combination with observations on the elevation, hydrology, associated vegetation, or other factors for each site, may reveal much about the ecology of the trees.

A lake level response function will be developed using stepwise regression analysis. The direction and magnitude of growth responses to lake levels at different times of year may then be used to make inferences about the physiological responses of the trees to inundation and drying out. WIth this goal in mind it is desirable to keep the statistical model as simple as possible to allow clear interpretation of the results. Development of the lake level response function will begin with simple models using as few variables as possible so as to minimize intercorrelation between predictor variables and to keep the model simple. Variables currently being considered are 1) Spring maximum lake level for the year of and the year preceding growth; 2) Mean July lake level for the year of and the year preceding growth 3) Minimum lake level for the year preceding growth and 4) July Palmer Drought Severity Index fo the year of and the year preceding growth. The first variable is intended to be an indicator of the extent of flooding, the second of growing season water levels, the third of winter water levels. July PDSI, which was used by Cook and Jacoby (1977) to develop a relatively simple climatic response function for pitch pine and other species at Mohonk Lake, integrates temperature and precipitation data. Because ring widths are usually significantly autocorrelated over lags of a few years (Fritts, 1976), ring widths of the preceding 3 years will also be included as predictor variables in the analysis.

Alternative approaches are partial correlation analysis or principal components analysis of a large set of predictor variables which may include monthly mean lake levels, mean temperature and total precipitation. The goals of this approach are to objectively collapse the lake level data set into a smaller set of variables representing seasonal environmental changes and determine which of these variables correlate most highly with ring width.

Because the goal of the analysis is to test the hypothesis that tree growth is correlated with changes in lake level, the entire random sample of cores will be used. In dendroclimatic analysis, in which the goal is to develop a predictive relationship between tree growth and climate, so that climatic records may be extended back in time, tree stands and cores are subjectively selected (Fritts, 1976). Cores from the overall sample may be selected as particularly responsive, and these augmented with other cores from selected trees. It is possible that this approach may ultimately be more fruitful in developing a predictive relationship, but inferences regarding the ecology of pitch pine may be more limited.

If time allows, hypothese regarding correlation of pitch pine distribution with pH, electrical conductivity and peat depth may be tested by making one or more transects of the bog and measuring these variables as well as tree frequency, density, or basal area.

Timetable

Sampling of stands will begin the first week of June, and will be completed by June 15. Stands will be sampled as numbered in Fig. 1. If the overall scheme is too ambitious, it may be modified. Field assistance may be obtained from volunteers. Cores will be mounted and sanded by June 21. Measurement will follow the same stand priority, but will start with half the total sample to ensure that at least ten trees from each site are measured by July 10. Statistical analysis will begin by July 10. Writing of the report will begin by August 1, and a preliminary draft will be available for review by August 15. The final draft is targeted for September 1. Some data analysis may continue following completion of the report. If results warrant it, a paper may be prepared for publication.

Budget

The total budget for the project stands at $975.00. (Table 2). The majority of these expenses will be offset by funding and services available at UVM; other expenses will be covered out-of-pocket or with assistance from the field naturalist program. Computer time for unfunded graduate projects is supplied by Academic Computing Services at UVM. The flight is optional, but may be instrumental in developing a more complete picture of the distribution of pitch pine and other plants on the bog. Some aerial photos are available on loan from the Geographic Information Service at UVM, however the 1980 photos are not availble there, and copies of these may be useful in the field and in mapping. Travel expenses are given for 17 round trips from my home to the Wildlife Refuge, a distance of 60 miles, at $.20 a mile for gas, oil, and maintenance.

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Table 1. Questions, Hypotheses, and Methods.

A. What factors control the radial growth of pitch pine at Maquam Bog?

1. Lake level. Method: Correlation or regression analysis of ring width on lake level.
2. Fire. Method: Reconstruct fire history and compare with ring width record.
3. Drought. Method: Correlation or regression analysis of ring width on drought indices or temperature and precipitation data.

B. What factors control the spatial distribution of pitch pine at Maquam Bog?

1. Spatial variations in fire frequency and intensity. Method: Reconstruct fire history for different sites and compare with pitch pine distribution (iffy).
2. Peat depth. Method: Correlation analysis of peat depth with tree frequency and density.
3. pH and nutrient gradients. Method: Correlation analysis of pH and electrical conductivity with tree frequency and density.

C. What factors control the age distribution of pitch pine at Maquam Bog?

1. Fire frequency. Method: Reconstruct fire history and compare with age structure.
2. Lake level. Method: Compare age structure with lake level record and growth response functions developed in A1 (above).
3. Drought. Method: Compare population age structure with drought record and growth response functions developed in A3.

Table 2. Budget.

Materials	
(Wood, sandpaper, insect repellent, etc.)	$20.00
Aerial photos	25.00
Film and processing	25.00
Computer time	400.00
Travel	
(17 trips @ 120 miles/trip, $.20/mi.)	405.00
Small plane flight	100.00
Total	975.00

Fig. 1. Study site location and approximate location of sample stands.
— — — Study area boundary ⬭ Closed-canopy stands
- - - - - Central area of scattered pines.

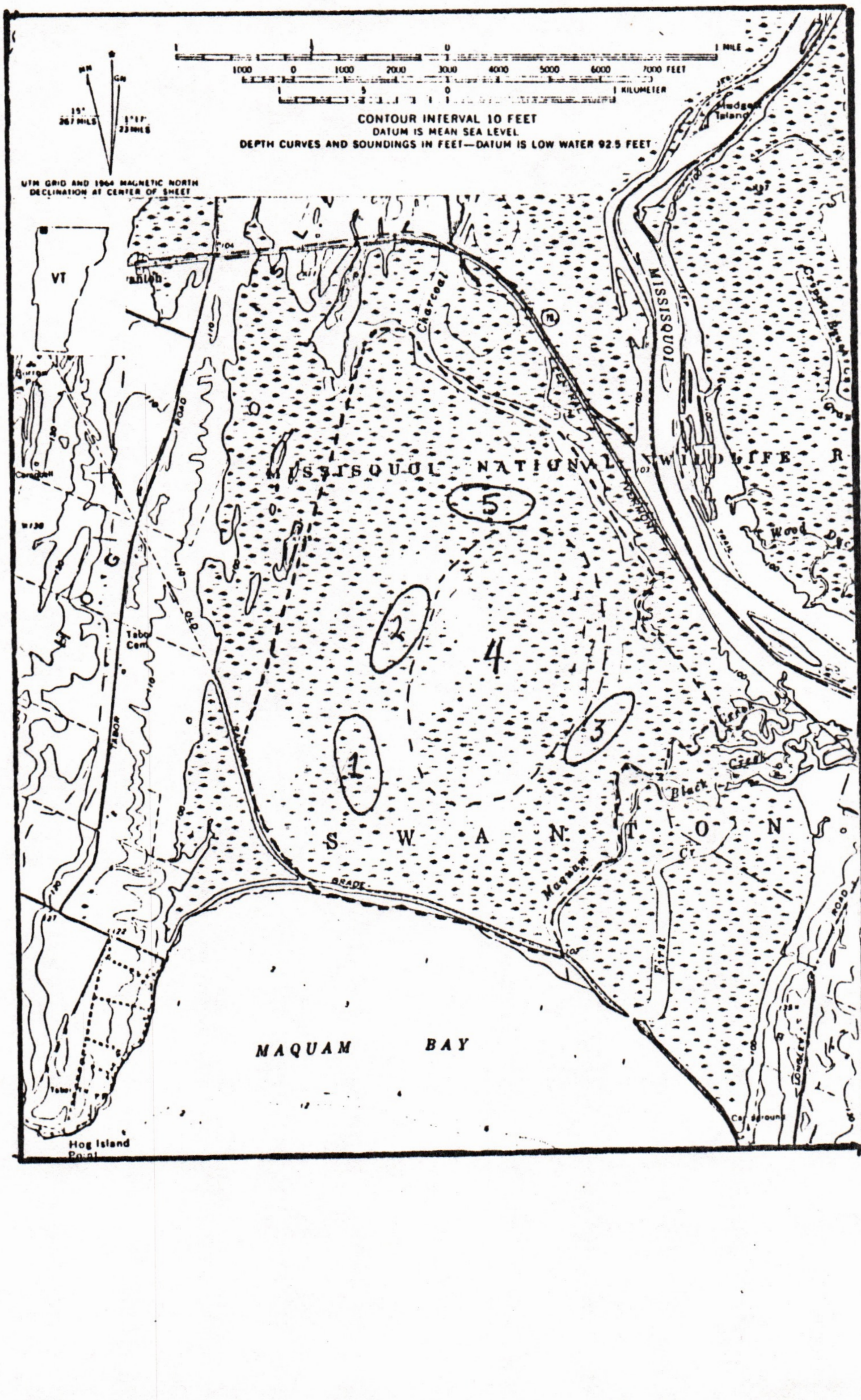

Fig. 2. Lake level, temperature, and precipitation records, and ring width series for the period 1939-1970.