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INTERACTIONS OF WETLANDS WITH THE PHOSPHATE INDUSTRY

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INTERACTION OF WETLANDS WITH THE PHOSPHATE INDUSTRY

FINAL REPORT

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1. PROJECT SUMMARY

Howard T. Odum and G. Ronnie Best

Field studies of 13 little-disturbed (control) wetland sites and of others influenced by nearby mining through changes in water quantities, qualities, silting, and drainage showed dominant tree species with even age-class distributions. Apparently, self-organizational processes were maintaining considerable variety and forest canopy.

Whether even age mode of growth was the natural one in Florida wetlands or whether the present wetlands are even aged because of past episodes of lumbering is not yet evident and will remain unknown until historical records can be correlated with tree rings. The vegetation first developing on floodplain wetlands whose hydrologic functions are adequately restored after mining may be expected to be similar with regard to an even age-class distribution of dominant trees.

Using cypress tree ring analysis as a general site index and as a standard measure, growth on the study sites was found to be similar to that on undisturbed sites of similar type. Growth was sometimes more rapid, as if the sites were fertilized. Computer programs were developed for generating basal area growth rate graphs and statistics of growth. Mean curves of basal area increment by year defined characteristic growth rates for trees of each age. Growth was usually in pulses of several years separated by periods of lesser growth.

Tree growth measurements at undisturbed sites and comparative data of other investigators provided baselines for evaluating future impacts and the success of reclamation. Growth of cypress on stream banks with roots reaching the main stream was usually more rapid than that of those on floodplains away from the channels. One area of former phosphatic clay deposition had lesser growth rate.

The considerable amount of data on cypress tree rings assembled by other investigators working on other sites needs to be converted to these standard measures and graphs using the new computer programs in order to strengthen the confidence with which characteristic growth rates are assigned as typical of the various kinds of undisturbed and disturbed sites.

Study of case histories of natural succession on wet clay settling areas following mining identified some sites with rapid re-establishment of wetlands vegetation comparable to succession on disturbed soils without mining. In some sites with long hydroperiods, succession to willows was fast, but further succession was arrested apparently for lack of adequate seeding of cypress, gum, or other species adapted to the long flooding regimes.

Where the accidental distribution of dikes, spoils, and clays had developed in low places with a short hydroperiod of a few weeks or less with the balance of water draining in or percolating out, typical wetland hardwoods were found developing in 30 years.

A preliminary analysis of available theory and data on seed dispersal and germination of normal plant succession showed that the distances now involved between vegetated areas that serve as seed sources and the clay settling areas in Florida's mining areas may be limiting plant succession. Formerly when mined areas were smaller and dispersed within vegetated areas, the seeding was better. Preliminary experiments transplanting living soil blocks from areas in advanced succession to areas of early wetland succession following mining showed accelerated appearance of later successional species.

Concepts of hydroperiod and seeding as determinants of the type and rate of wetland rehabilitation were made quantitative by expressing as a computer model. Preliminary runs using assumed but plausible values for parameters suggest that when calibrated with real site data, a model of this class can generate nomograms for implementing, wetland rehabilitation after mining in Florida.

Ecological engineering of the restoration work of ecological succession, by improving seeding at appropriate stages, and controlling hydroperiod through initial landscaping may be the fastest way found so far to restore wetlands in Florida. The next step is proving these concepts with direct experimental tests.

Suggestions are made for experimental testing of the ecological engineering of wetland reclamation with natural succession by transplant seeding of the areas in arrested state. Also suggested is the experimental verification of the means of rapid hardwood restoration by control of drainage area and percolation of low-ground swales in the final landscaping after mining.

2. INTRODUCTION

Howard T. Odum and G. Ronnie Best

Among the alternatives for restoration of wetlands after phosphate mining in Florida is the maximum use of nature's work in its natural processes of succession along with some help from human management to eliminate any limitations. Many efforts to replant a wetland ecosystem as if it were a crop have given mediocre results, the planted vegetation being rapidly passed up by the natural succession appropriate for that site. The theory and progress in systems ecology is revealing more and more each year the mechanisms by which natural succession is so effective, but, at present, the understanding is still not sufficient to specify, a priori, the conditions for wetland succession. However, by study of case histories of nature's re-creation of wetlands in the past 70 years, conditions for generating the most rapid restoration may be identified.

Where mining is near wetlands there are numerous impacts such as changed hydroperiods, increased hardness and other substances in stream waters, silting from overburdens and slimes, lowering of water tables in wetlands, and other influences. Often in the past studies of effects on ecosystems have been made with short-term tests of influences, which are not very relevant to the sustained ecosystem response. Ecosystems are highly self-organizing and when species are affected with stress, the ecosystem often undergoes rapid adaptations through changes by the trees such as growing different kinds of roots and by substituting species that can profit by the new conditions rather than be stressed. This adaptation process cannot be observed adequately in short-term tests of 2 or 3 years, but it can be observed by study of case histories that have provided unintended test experiments over longer periods of time.

This is the report of a 2-year effort to document the interactions of wetland ecosystems and the phosphate mining industry, to identify conditions for maximum self-restoration, and to determine effects of nearby phosphate mining on wetlands over a long enough time scale to include the ecosystems' adaptations to the changed conditions. The crux of the problems of evaluating impact and restoration alternatives is in understanding how the self-organizational work of ecosystems is accomplished in order to be able to manipulate it towards goals of continuing or restoring wetland ecosystems.

Methodology for ecosystems study includes evaluating major driving functions (e.g., water regimes) and major components (e.g., dominant trees) and generating overview models that include the processes that control relationships. Preliminary models help guide planning of experiments. Aggregated models, when simulated, allow quantitative verification of the way the system works. Models are iteratively improved with successive calibration with observed data on the parts and observed patterns with time. The parallel development of field measurements and models helps focus investigations that start with a wide array of exploratory measurements.

In this project the initial study of sites and measurements with systems models narrowed. emphasis to tree growth and age-class distributions as best indices of long-range characteristics of floodplain ecosystems. Useful indices of natural restoration are leaf area index, diversity, stem density, and presence of mature species.

The important role of seeding and hydroperiod was demonstrated. Experimental tests may be included as part of future mining. Appropriate drainage area and percolation times can be arranged to restore wetland forest, and seeding of mature species can' be added after a period of early succession.

Questions and Research Objectives

Work was organized to answer questions that are pertinent to minimizing impacts of phosphate mining on wetlands and facilitating rapid restoration of wetlands after mining as follows:

1. What are the main characteristics of wetland ecosytems in mining areas of Florida and how have these been affected by nearby mining?

2. To what extent are the natural ecosystems developing adaptations that maintain productivity and diversity in response to mining influences? What is the nature of the self-organizational processes involved?

3. Which ecosystem indices are most useful for evaluating impacts and adaptation in these kinds of wetlands in the future?

4. What kinds of wetland ecosystems have developed naturally in the wet areas of formerly mined landscapes? How do these compare with wetland ecosystems undisturbed by mining?

5. What factors may be limiting the wetland's ecological succession following mining that may be eliminated at relatively small cost?

6. What guidelines for mining and reclamation may maximize rates of wetland restoration in the future using the natural reorganizational processes to the maximum?

7. How do energy analysis calculations evaluate the work contribution of nature in reclamation managed by ecological engineering? How does this work compare with that of traditional technological engineering with machinery?

Project Narrative

At the time this project was funded, studies were already under way on natural reclamation and energy analysis of phosphate mining with seed monies from the University of Florida College of Engineering and several phosphate mining companies (International Minerals and Chemical Corporation, Estech Chemical Corporation, and Amax). With help of Tom Oxford, formerly of Bromwell Associates of Lakeland, Florida, Pat Kangas studied upland succession on a number of postmining landscapes and conducted energy analysis of nature's work as compared to bulldozer work in reclamation. Successional surveys by J. R. Butner and R. Best of clay settling areas complemented some by others, further establishing the relatively rapid early succession of wetland plants. In contrast, slime settling ponds from kaolin mining at Jari, Brazil, where nutrients are very low show almost no plant growth for long periods. Models for the phosphate mining process as a whole were evaluated for perspectives on energy involvement by Betty Rushton. Scott Leibowitz simulated mining so as to suggest the way declining quality of reserves generated increased areas of disturbance and overburden, making mining uneconomic before all reserves were depleted. At the start of this current project, these previous studies were published in a report (Odum et al. 1981).

Willows and Restored Wetlands

A major question facing the phosphate industry and state officials is the feasibility of restoring wetlands on phosphate mined lands, replacing a mined wetland with a new wetland. Wetland ecosystems develop after mining in former clay settling ponds as they settle and dry over many years. Are these wetlands adequate to count as restored wetlands? Since these wetlands are dominated by willows, we organized one main phase of our work around the willow wetland and the conditions under which it continues in succession to more diverse wetland ecosystems with more substantial, long-lived trees. Betty Rushton studied this system and established study sites of various ages, including one on Lake Panasoffkee unaffected by mining. Whereas willow succession is normal for disturbed soils the world over, the arrested succession in which willows become aged, die, and are replaced by more willows is not normal.

Recognizing the arrested nature of the willow communities, factors of seeding access were examined. Whereas most disturbed wetlands in nature have access to seeds borne by wind, water, and animal vectors, the pattern of elevated and isolated clay settling ponds tends to interfere with transmission of the larger seeds that go with the later succession trees that follow willows.

Tim McClanahan joined the project to review the literature on energy of seedling transport, contributions of natural sources, and distances and barriers involved in relation to distances now involved between mined areas and forest plots that serve as seeding sources. Enough preliminary analysis is reported in Chapter 6 by T. McClanahan to establish that seeding is one of the limitations now inhibiting wetland succession beyond the willow stage.

While working on former clay settling areas, Betty Rushton discovered sites of rapid succession advanced past willows that have generated a wetland hardwood forest having the composition and appearance of floodplain forest, even though the site is perched above the surrounding landscape in swales in a settling area. She observed these areas being flooded for a few days from rainwater draining from the irregular surrounding area, but then percolating down through the clays through rootholes, cracks, and porosities in the sandy spots, etc., so that the standing water hydroperiod was only a week or two. This hydroperiod is the floodplain type of water regime. Even in this site, though, some hardwood species were missing and may be absent for lack of transport up and over the high dikes around the area.

These hydroperiods may be easily duplicated in future mining, and seeding may improve the diversity if the seeding is done some years after the start of succession. With some of the mystery surrounding the restoration process possibly eliminated, we how have hopes for low cost use of natural successional processes for rapid restoration of forested wetlands.

To verify these concepts, more careful documentation of the successful hydroperiod are needed next. Seeding of the areas of arrested succession will test the theory that seeding is limiting further succession both in the very wet willow areas and in the occasionally wet hardwood areas.

To organize our concepts a simulation model of these processes to include what is known of water level effects on species, seeding, hydroperiod and water budgets, and nutrients was generated. This defines the parameters we need to measure next. Calibration of the model may allow nomograms to be drawn relating the drainage areas and percolation rates to type of forest succession and timing. Work is now needed to improve the model by calibrating the coefficients with measured data until the graphs with time agree with observed performance.

Transects of Floodplains

To evaluate unaffected wetland forests and the response of wetland forests to influences of nearby mining, Michael Miller began transect studies of forested wetland sites, particularly the floodplains along streams receiving drainages from mining areas, receiving discharges from waters used in aspects of mining and processing, and in areas with slime spills and changed drainage patterns. Since the project emphasis was on longer ranged adaptation, indices were developed that represent longer term responses. General properties of vegetation such as species composition and diversity to some extent integrate influences and their adaptive responses. In particular, age-class distributions and tree rings were found useful.

Tree Rings of Cypress as Bioassay

A major, effort was launched to compare cypress tree rings using the two cypress varieties as field test organisms indicative of conditions favoring or inhibiting growth. Our studies at the Center for Wetlands have already established the slow growth rates of cypress in perched areas receiving only rainwater or with slight drainage in cypress ponds. Faster growth rates were in floodplains receiving nutrient rich waters. In this project Michael Miller developed computer programs that facilitated the conversion of data into basal area increment graphs, thus eliminating the effect of tree diameter on the ring width.

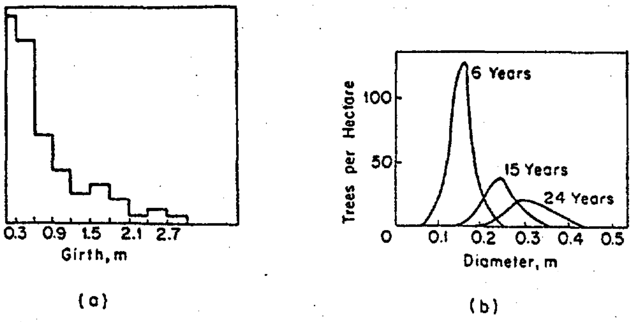
With the new methods, standardizing and facilitating statistics of floodplain areas of central Florida were studied for cypress growth rate with and without influences from phosphate industry. These measurements provide some measure of impact: stimulation, inhibition, or no effect. Now that these baselines have been set, we need to put all the other available data on cypress growth from other studies in Florida on the same graphs and statisitical form, further documenting standards in Florida wetlands. The methods and results of the cypress tree ring work are given in Chapter 3.

Age Distribution of Trees

A principal feature of a forest is the size distribution of the trees. A forest plantation has an even-age distribution, since all trees were planted at the same time and tend to be similar in size as time passes. As shown in Figure 1b, the age class passes from many small trees to a few large ones as a pulse. Trees become old together and the canopy may be opened up as the trees die or are cut. Such even aged tree regimes may occur in nature where catastrophic influences such as fire or floods decimate a forest so that there is a surge of new seedlings of the same age that grow up together.

In contrast is the forest with stable age distribution that has simultaneously many small trees and a few large ones so that there is a continuous process of replacement as one old tree falls and is replaced by clusters of competing saplings locally, but not in unison when the whole forest is considered. Figure 1a illustrates this pattern. The Amazon floodplain forest is an example.

The floodplain forests of central Florida now influenced by phosphate mining, including some coming back after mining, from studies in Chapter 4 by Michael Miller, appear to be mostly even aged. This may be in the nature of these wetlands that the conditions for massive reseeding occur infrequently. It may be due to earlier lumbering that opened the canopy. Whether hurricane, flood, fire, and other catastrophes have occasionally opened the canopy naturally in a similar way in Florida is not known. If wetland restoration formulae are successfully developed to rapidly restore forested wetlands, they are likely to be even aged at least initially. Whether this resembles virgin wetlands or not, the even aged restoration will resemble the present forests in this respect.



Examples of hierarchical age distribution in tropical forest from Whitmore (1975): *(a)* hierarchical pattern with many small trees and few large ones; *(b)* even-aged pulse of plantation trees passing up the hierarchy with remaining individuals accumulating embodied energy (*Anthocephalus chinensis* in Indonesia after Socharlan, 1967).

Figure 1. Types of age-class distribution in trees (Odum 1983). (a) Stable age distribution; (b) even-age distribution in successive years.

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H. T. Odum and G. R. Best are Principal Investigators. All participants in the project at various times mutually assisted all phases of work. Jay Allen and others at International Mineral and Chemicals Corporation (IMC) aided with historical records, in site selection, and provision of special vehicles for on-site inspections. Mr. C. L. Knight made available the Alderman Ford Ranch site. Alfonso Hernandez assisted with fieldwork; Bill Dunn helped with plant identification; Gordon Innes with particle size analysis; Darlene Johnson, Robert Tighe, Craig Diamond, and Kathleen Miller helped reading of tree cores; and Jon Barbour and Steve Roguski with diagrams. For use of data we thank Jim Butner, Roger Schnoes, and Stephen Humphrey.

Center for Wetlands Technical Report #37-2.

3. CYPRESS TREE RINGS FOR WETLANDS ASSAY

Michael A. Miller

Introduction

The growth rates of dominant, wide-spread tree species may be useful as an index of past and present conditions. Analysis of cypress tree rings may be used as a field assay for comparison of sites, for comparing year to year conditions, for study of impacts of disturbance, and for study of effects of normal processes such as crowding and succession. In this report, cypress growth rates from tree rings are compared in various sites, especially some influenced by phosphate mining.

Phosphate mining has influenced ecosystems in north and central Florida for many years. Some influences are similar to those of other industries, such as logging or lowering of the water table through drainage. Others are more intimately related to the activities of the phosphate industry, such as discharge of nutrient rich waters, spills of clay slimes, and large-scale watershed alteration through mining and construction of clay settling ponds. These landscape alterations affect forested wetland ecosystems through changes in water regimes, chemistry, and sediment loads.

Change in growth rates of dominant trees may reflect changes in nutrients, water, sediments, and canopy closure, depending on ecosystem type and other factors. Cypress are dominant, long-lived components in many wetland ecosystems, and changes in growth of their tree rings may reflect changes in the forest as a whole. By measuring growth rates of tree rings in bald cypress (Taxodium distichum) and pond cypress (T. ascendens) in various conditions and types of ecosystems, baselines are developed for field assay of impacts or lack of impacts. Positive and negative changes can be noted and related to mining influences, a standard index of growth conditions for wetlands can be developed, and a baseline can be provided for evaluation of growth in natural or human controlled succession (reclamation).

Study Sites

Sixteen representative study sites were chosen throughout north and central Florida. Seven had hydrologic alterations, three have been subjected to either clay slime spills or greatly increased sediment loads, five have had increased salt concentrations, three have been drained, and one was impounded (several sites had more than one impact). There were five little-disturbed sites. Locations of study sites by county and section are given in Table 1.

Table 1. Study site locations.

Site	County	Location
Alafia River	Hillsborough	S13, T30S, R21E
Clear Springs North, Peace River	Polk	S22, T30S, R25E
Clear Springs, Peace River	Polk	S22, T30S, R25E
Fort Meade, Peace River	Polk	S26, T31S, R25E
Sixmile Creek	Polk	S17, T30S, R25E
Swift Creek	Hamilton	S27, T1S, R15E
Prairie Creek	Alachua	S19, T10S, R21E
Swift Creek Swamp 1	Hamilton	S33, T1N, R14E
Swift Creek Swamp 2	Hamilton	S20, T1N, R14E
Swift Creek Swamp 3	Hamilton	S30, T1N, R14E
Cypress Creek Strand	Pasco	S28, T25S, R19E
Okefenokee Swamp	Charlton, Georgia	
Newnan's Lake	Alachua	S16, T10S, R21E
C-10 Dome	Pasco	S27, T25S, R19E
Oxy Dome	Hamilton	S10, T1S, R15E
K2 Dome	Polk	S7, T31S, R23E

Alafia River. This site is located about 2 miles downstream of Alderman's Ford Park on State Route 39, 1 mile north of Pinecrest in Hillsborough County. It is a backswamp and floodplain ecosystem that has received altered hydrologic regimes. Stream banks are fairly high here with only occasional flooding. The site is reached by canoeing downstream from the park about 1 mile, past the large sandbar on the right, and stopping at the group of cypress trees on the left. Floodplain cores were taken in this area, and bank cores were taken on both sides of the river for 1 mile downstream.

Clear Springs North, Peace River floodplain. This floodplain forest is approximately 3 miles north of the Clear Springs site on IMC property. There is less mining upstream than at the Clear Springs site, though the watershed has been greatly altered. The Clear Springs road south of Bartow on Route 17 is taken east. Past the IMC beneficiation plant, just before the bridge over the Peace River, one turns left, follows the dirt road about 50 meters, and descends into the floodplain forest. Cores were taken from bank and floodplain trees on the west side of the Peace River in this area.

Clear Springs, Peace River floodplain. This extensive floodplain forest is located near IMC's wetland reclamation project in Polk County. It has received hydrologic alterations and some wastes. The Clear Springs Road is taken going east from Route 17 south of Bartow and followed past the IMC beneficiation plant. After crossing the Peace River, turn right (south). The IMC-Florida Game and Fresh Water Fish Commission reclamation project is 1 mile south on the right. The road south of the project is followed to the west. The study site is reached by leaving this road where it turns and traveling due west to the Peace River . Cores were taken from the bank and floodplain on both sides of the river for approximately 50 meters upstream and downstream.

Fort Meade, Peace River floodplain. This site is located on the Peace River in Polk County. It is a bottomland hardwood ecosystem that has received phosphate influence, including slime spills. Cores were taken from the bank and floodplain on the east side of the river in an area approximately 100-200 meters downstream of the Route 98 bridge over the Peace River at Fort Meade.

Sixmile Creek floodplain. This is a floodplain forest in Polk County north of IMC's N-12 settling area and east of N-14. The creek has been channelized and bank vegetation has been removed. Uplands to the north have been mined and reclaimed. The access road is on Noralyn Mine Road one-half mile south of Bartow. One tree was cored between the road and canal-the only bank tree. The dirt road winds to the edge of the forest at the south end of the reclaimed pasture. The study site is located approximately 200 meters down the trail. Floodplain trees were cored.

Swift Creek floodplain. This site in Hamilton County in north Florida is a very narrow floodplain forest downstream of active phosphate mining. Increased sediment loads are present. It is located near the bridge over the creek, 1 mile north of the church camp off State Route 137, off U.S. 41, 3 miles northwest of White Springs.

Prairie Creek floodplain. This creek drains Newnan's Lake in Alachua County. Trees were cored in a small floodplain forest bordering the high banked creek. Phosphorus levels are relatively high (Brown 1978). The site is located

200-300 meters south of the bridge over Prairie Creek on State Route 20, east of Gainesville.

Swift Creek swamp 1. This swamp forms the headwaters of Swift Creek in Hamilton County. The site is adjacent to a large canal. There are some pockets of very large cypress present. This. site is reached via a series of private sand access roads from the main office of Occidental Mining Company, which is on State Route 137, off U.S. 41, 3 miles northwest of White Springs.

Swift Creek swamp 2. This is an area of Swift Creek swamp that receives process water from Occidental's Swift Creek chemical plant. A berm has been installed that holds water at a high level all year. To the south of the berm, water is not impounded, though there is increased flow. Impoundment is the primary change. This site is also reached via a series of private sand access roads from Occidental's main office north of White Springs.

Swift Creek swamp 3. This portion of Swift Creek swamp is also in Hamilton County. Sand tailings, with some clay and silts, have been disposed of for several years in a portion of the swamp that is surrounded by canals. The central area is a mound of sand. Around this mound the materials have separated out by weight, with the silts and clays traveling towards the canals. up to 2 feet of fine material is present on top of the original peat soil. Pond cypress trees are present. There is also increased water from the newly created watershed. This site is also reached via a series of private sand access roads from Occidental's main office north of White Springs. It is on an access road off State Route 137, 2 miles east of Occidental's main office.

Cypress Creek strand. This forest of bald cypress and other bottomland trees is located in the upper portion of a cypress strand in the Cypress Creek well field in Pasco County. The area is influenced by groundwater and aquifer drawdown due to the pumping. The site is not influenced by phosphate mining. The site is located 20-200 meters north of the bridge over Cypress Creek, one-half mile east of the Tampa wastewater treatment plant off State Route 583, 4 miles north of U.S. 41.

Okefenokee Swamp. This deepwater site in Charleton County, Georgia, has very low nutrient levels and a relatively constant environment. It was reached by boat and is located approximately 1 mile northeast of the Stephen Foster entrance, 100 meters north of the canoe trail.

Newnan's Lake, lake margin swamp. The site is in a cypress-hardwood swamp that fringes this lake in Alachua County. There are no phosphate mining related influences. Lake levels are controlled. The site is reached by a trail on the property of M. T. Brown. It is on the east side of the lake, 1 mile south of Windsor off State Road 234.

C-10 cypress dome. This dome in Pasco County is also in the Cypress Creek well field about 300 meters from an active well. The entire area has suffered groundwater drawdown. The dome had 0.5-10 meters of standing water during fieldwork in February following heavy rains. The dome is located 1 mile east, then one-half mile north of the Tampa wastewater treatment plant off State Route 583, 4 miles north of U.S. 41.

Oxy cypress dome. This cypress dome in Hamilton County has a lowered water table from drainage, and it has been logged. The surrounding flatwoods have been cleared for future mining. This site is also reached via private sand access roads starting 2 miles east of Occidental's main office north of White Springs on State Route 137.

K2 cypress dome. This is a stand of pond cypress adjacent to an active clay settling area in Polk County. It has been drained and may receive effluent, particularly during high rainfall. It is located 1 mile west of IMC's Kingsford plant, on the south side of the K2 settling pond.

Methods

Using cypress tree cores, a standard methodology was developed for collection, preparation, presentation, and comparison. Both bald and pond cypress cores were used.

By concentrating on these two closely related species we studied wetland growth conditions without sources of variation due to species differences. Cores were collected from 16 sites through north and central Florida. These included the phosphate-affected study sites as well as other types of sites and controls. Tree cores taken in the past as part of other Center for Wetlands projects were also examined. At all floodplain forests, 5 to 10 trees were sampled along the bank, and 5 to 10 trees were sampled away from the creek but within the annual floodplain.

Two cores were taken from each tree at breast height (or higher if buttresses were higher), the second at a 90° azimuth angle to the first. The use of two cores allows calculation of within tree variance. They were taken parallel to the ground and through the tree's center. Diameters were measured and sites briefly described. Trees from a variety of size classes were sampled, including any very large trees present. Cores were taken to the lab, mounted, and air dried for at least 5 days. They were sanded with increasingly fine paper to present as large and smooth a surface as possible for reading.

The increments were read using a dendrochronometer with a dissecting microscope. Values were recorded to the nearest one-hundredth of a millimeter from the bark inward (see Appendix A). A data base program (Appendix B) was developed on a DEC PDP 11/34 computer for entering, editing, storing, retrieving, and printing out these raw increment data. Increment data from previous projects (Appendix C) were entered in this data base. Since the same diameter increment represents considerably larger amounts of biomass increase as one moves from the center of the tree out, the increment data were converted to basal area growth rates with the following expression:

$$B_i = \pi r_i^2 - \pi r_j^2 \qquad (1)$$

where B = basal area increment in year i; r_i = radius of tree in year i; and r_j = radius of tree in previous year. These basal area increments (cm^2/yr) were then plotted over time. Due to false rings there is some uncertainty in the actual year involved. This error may be larger for long records (old trees). Although long records with trees over 200 years old are found occasionally in Florida, due to logging of cypress on the sites studied, most trees were less than 100 years old. Data were plotted beginning with 1880, though the data sets include all values from the center of each tree to the outermost ring. Values were plotted to the nearest square centimeter. Values over 70 cm^2 are noted as "+," though exact values were used in all calculations.

Five properties of the basal area data were studied. These were growth rates, variance, year to year trends, sudden changes, and cycles. The mean basal area increment was calculated for each core. Then the two cores for single trees were averaged to obtain a mean for the tree. Next, tree means of those trees growing together on the bank, away from the bank, or in some other category were averaged to obtain a category mean. Category means from the same site were then averaged. Finally means from the same type of sites were averaged to give ecosystem type means.

The basal area increments were also used to calculate means by year, again starting with two core values to give one tree mean. Category means, site means, and ecosystem type means were also obtained for these yearly values.

Mean values were also calculated by tree age, so that any intrinsic age-related behavior could be noted. One-year intervals were used for all trees up to the present time. Category, site, and ecosystem type means were also calculated.

Each type of standard error calculated is based on annual basal area increments for trees, which are means of two individual cores. Standard errors are used in all comparisons. The standard error obtained for each type of mean can be used as a rough confidence limit by inspection, where two groups with similar sample sizes might be regarded as significantly different if they differ by two standard errors or more (Steel and Torrie 1980).

Results

Data on basal area growth rates are summarized in Table 2. Long-term trends were not the rule, though perhaps 30% of the trees exhibited a slow increase in growth rates (Figure 2). This was common for the first few years of growth in most trees. Increase in solar capturing area of canopy may be part of the explanation.

Sudden changes are often found. Figure 3 shows cores from a tree in Swift Creek Swamp that had a major increase in growth rate starting in about 1975.

Cycles of various periods were apparent in many long-term records. Figure 4 illustrates the presence of both short- and long-term cycles in the same tree.

Different amounts of variance were present in different type ecosystems. Figure 5 shows growth rates in a tree in the Okefenokee Swamp, showing the typically low year to year variance of deepwater swamp trees. The growth rates plotted in Figure 6 are from a tree in the Sixmile Creek floodplain, exhibiting a much higher between year variance.

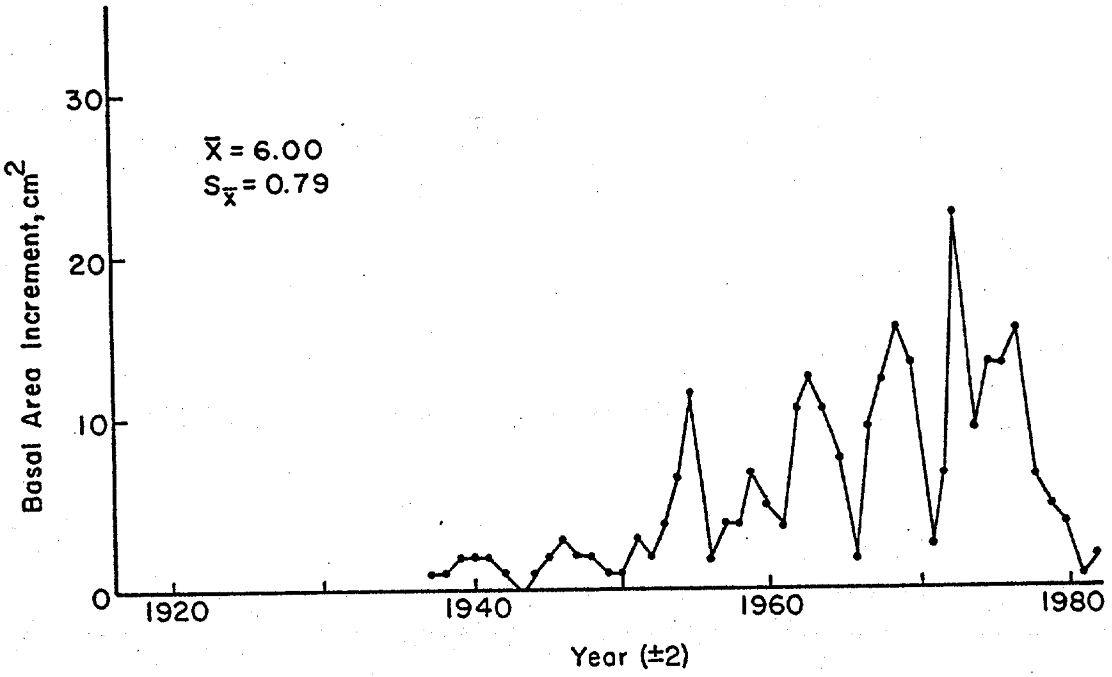
Table 2. Mean (± S.E.) growth rates (basal area increments; cm^2/yr).*

Site	Bank			Floodplain			Both		
	Mean	S.E.	n	Mean	S.E.	n	Mean	S.E.	n
SITES AFFECTED PRIMARILY BY MINING									
Floodplain Forests (mining in watershed)									
Alafia River	10.31	0.53	245(3)	7.15	0.27	758(5)	8.73	0.24	1012(8)
Clear Springs North, Peace River	13.40	0.74	242(5)	15.84	0.81	262(5)	14.62	0.55	504(10)
Clear Springs, Peace River	11.61	0.57	332(5)	17.72	0.74	460(10)	14.67	0.50	792(15)
Fort Meade, Peace River	15.25	0.72	276(5)	5.54	0.22	655(10)	10.40	0.29	931(15)
Sixmile Creek	23.23	2.91	31(1)	9.32	0.44	222(5)	16.28	0.57	253(6)
Swift Creek	11.29	0.78	182(5)	13.09	0.65	189(5)	12.19	0.51	371(10)
Seepage Swamps									
Swift Creek Swamp 2 (impounded versus nonimpounded)	8.91	0.45	196(5)	13.42	0.65	180(5)	11.17	0.41	376(10)
Swift Creek Swamp 3 (tailings pile)	----	----	----	----	----	----	11.37	0.98	224(5)
SITES NOT AFFECTED PRIMARILY BY MINING									
Floodplain Forests									
Prairie Creek	11.18	0.61	233(5)	11.01	0.46	205(5)	11.10	0.39	438(10)
Seepage Swamps									
Swift Creek Swamp 1	----	----	----	----	----	----	13.11	0.48	585(11)

Table 2. (continued.)

Site	Bank			Floodplain			Both		
	Mean	S.E.	n	Mean	S.E.	n	Mean	S.E.	n
<u>Cypress Strand</u>									
Cypress Creek	6.81	0.32	299(5)	7.79	0.31	213(4)	7.30	0.23	512(9)
<u>Low Nutrient Swamp</u>									
Okefenokee Swamp	----	----	----	----	----	----	5.24	0.17	597(5)
<u>Lake Fringe</u>									
Newnan's Lake	8.35	0.38	260(5)	8.42	0.43	278(5)	8.39	0.29	538(5)
<u>Cypress Domes</u>									
C-10 Pasco County	----	----	----	----	----	----	4.97	0.21	282(5)
Oxy Dome	----	----	----	----	----	----	6.47	0.25	388(5)
K2-IMC	----	----	----	----	----	----	5.33	0.39	253(5)

*Mean represents unweighted means of mean annual increments of all trees in the category from the center of the tree to the present. S.E. represents standard error, $S/\sqrt{n}$, where S is the standard deviation of all tree basal area increments in a category, and n is the number of increments. Numbers in parentheses represent the number of trees in a category (with 2 cores per tree).



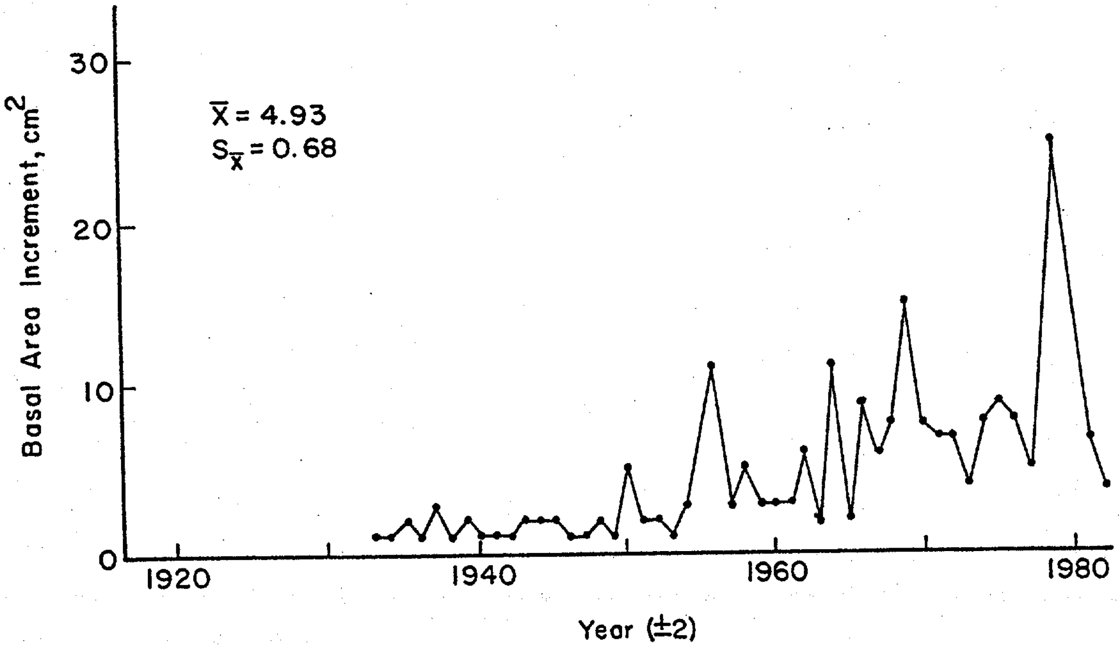


Figure 2. Growth rates for tree 5 (cores a and b), a pond cypress in cypress dome C10.

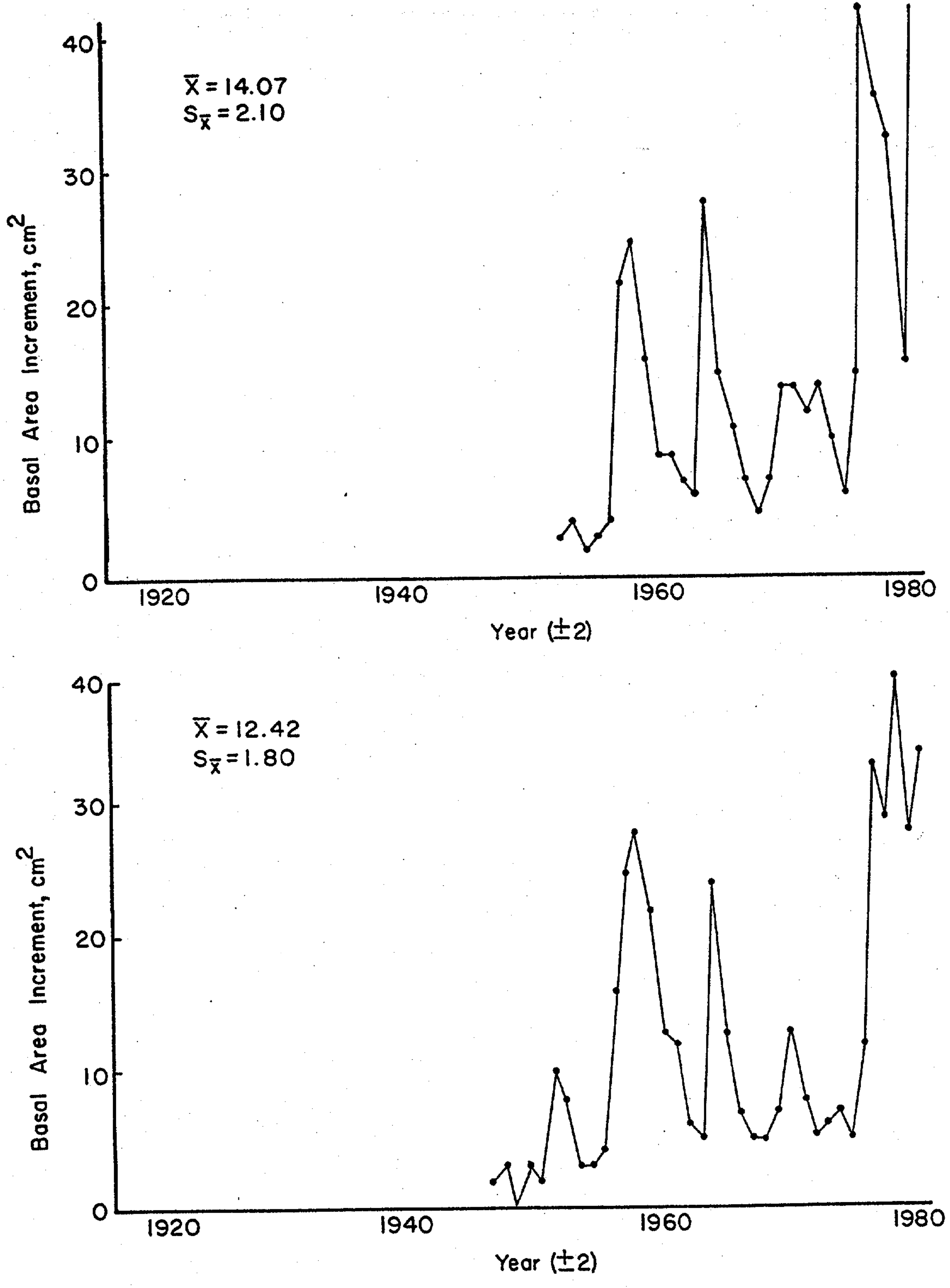


Figure 3. Growth rates for tree 3 (cores a and b), a pond cypress in Swift Creek Swamp 3.

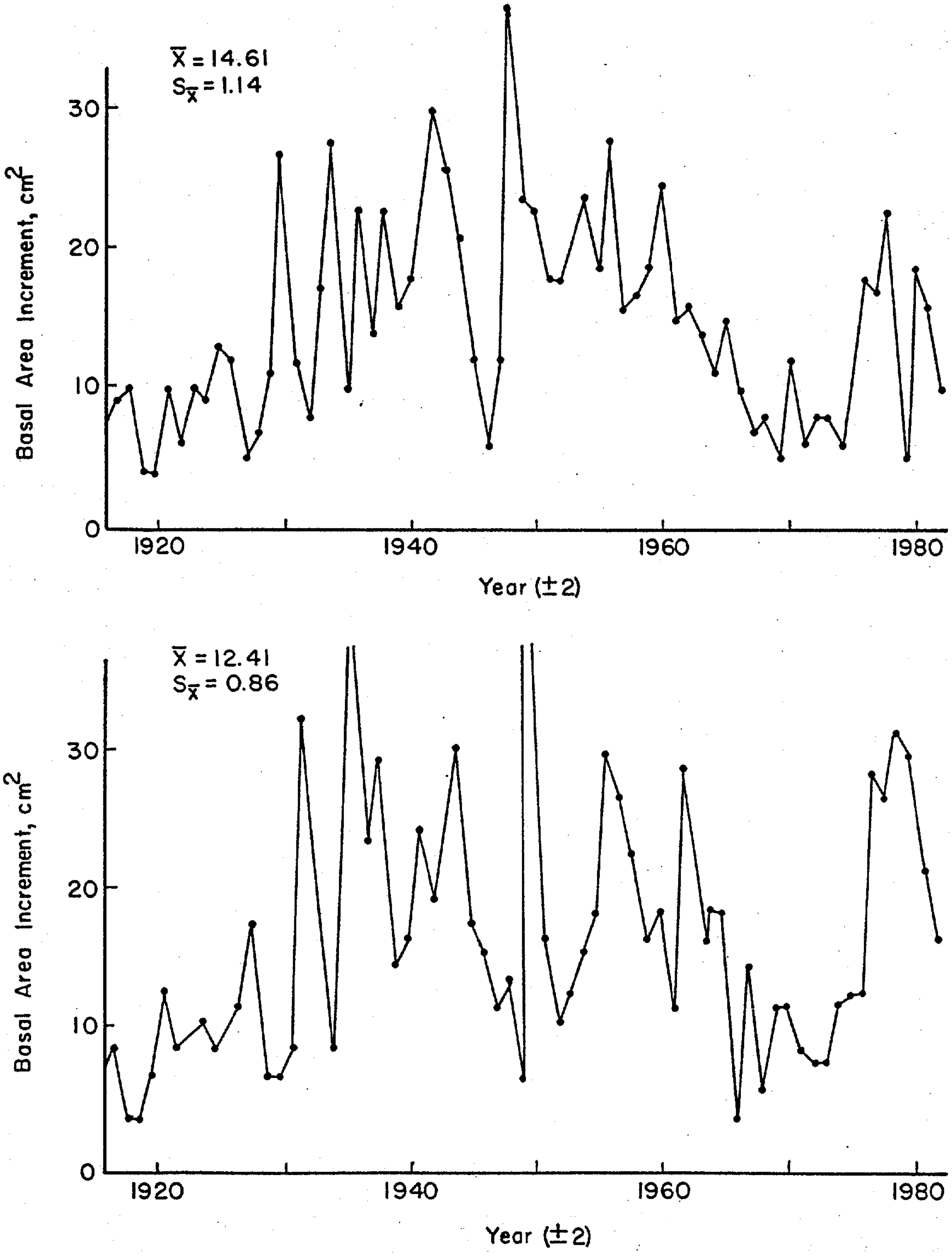


Figure 4. Growth rates for tree 5 (cores a and b), a bald cypress on the bank of Peace River, Clear Springs.

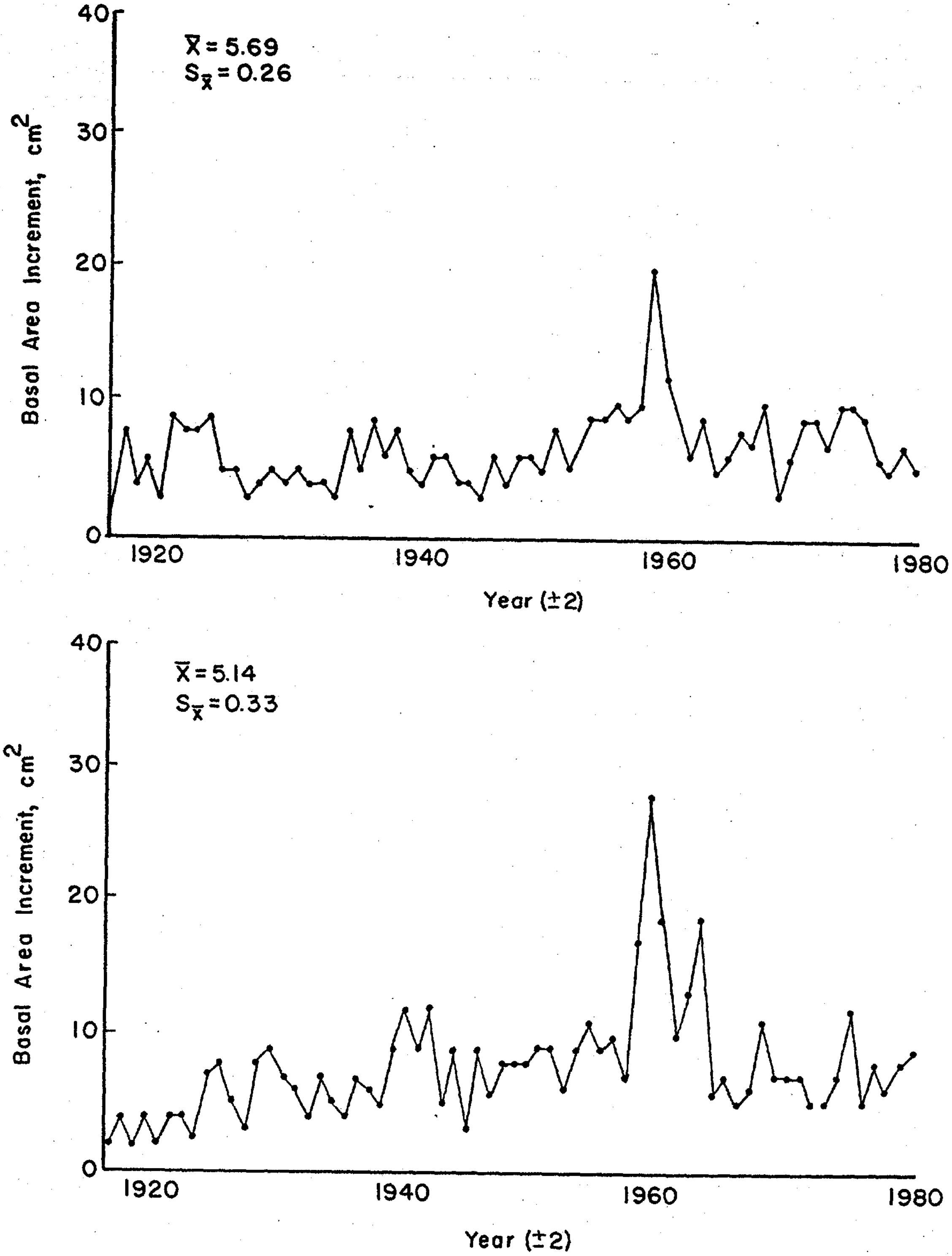


Figure 5. Growth rates for tree 5 (cores a and b), a pond cypress at a deepwater site in the Okefenokee Swamp.

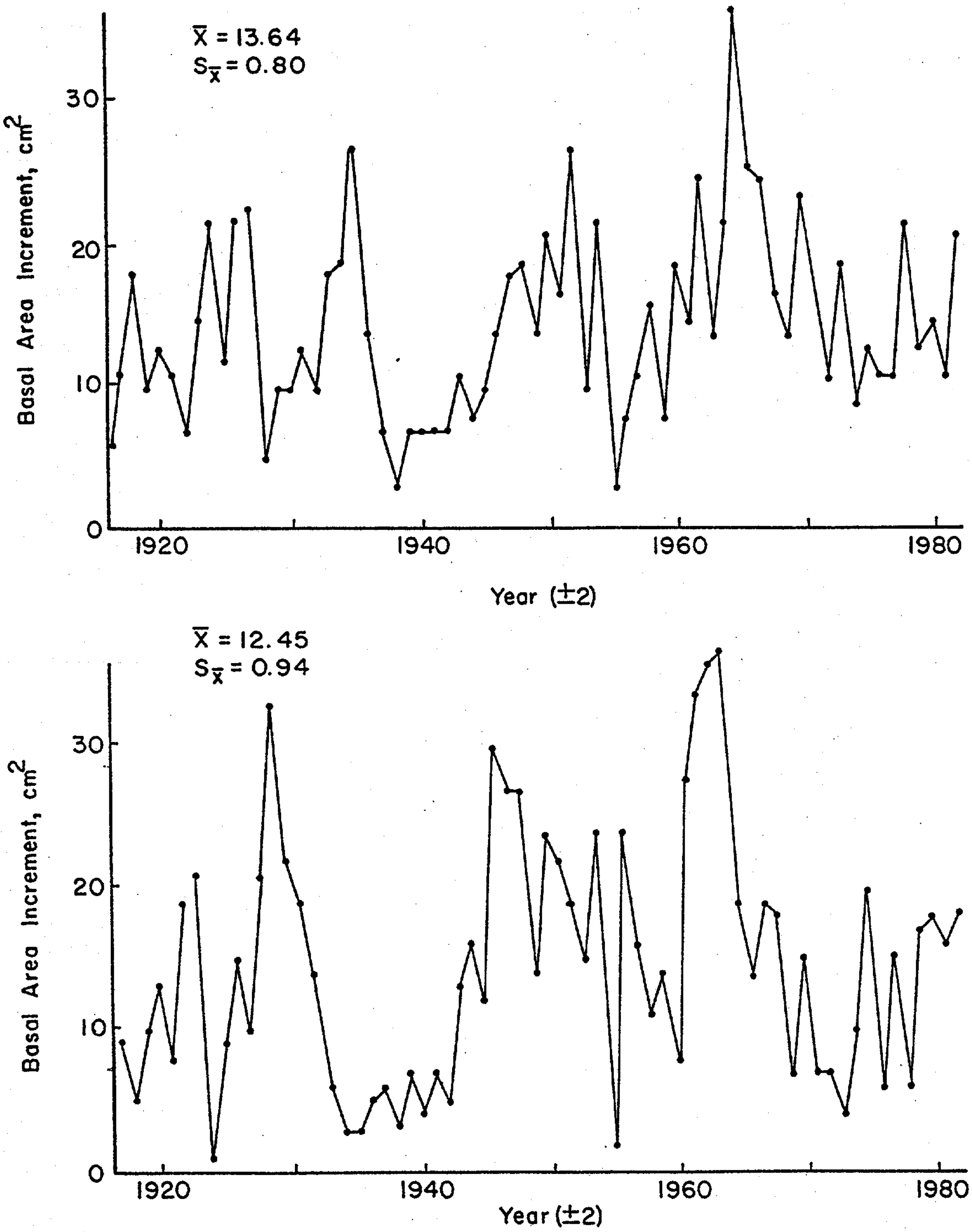


Figure 6. Growth rates for tree 6 (cores a and b), a bald cypress on the floodplain of Sixmile Creek.

In Table 2 are mean annual basal area increments for all study sites, by bank, floodplain, and total values. Mean growth was 8.7 to 16.3 cm^2/yr for all floodplain forests. The wetlands with upland water supply (swamps) had values ranging from 11.2 to 13.1 cm^2/yr. The Okefenokee Swamp mean was lower, 5.2 cm^2/yr. The lake fringe site was 8.4 cm^2/yr. Cypress dome values were lower still, from 5.0 to 6.5 cm^2/yr.

Means by ecosystem type are given in Table 3. Mean bank growth was higher than floodplain growth in floodplain forests. Growth in the low nutrient swamp (Okefenokee) was the lowest, 5.2 cm^2/yr. The highest mean growth was found in the Swift Creek swamp sites.

Means by age of tree in 10-year classes are listed in Table 4. Basal area increments started low and generally increased for the first 20-30 years, oscillating about some mean after that.

Discussion

Tree rings contain a record of growth (Fritts 1978). In most deciduous trees there is one ring per year, and in some species the rings are easily discernible. Even in the most suitable species there are occasional false rings, which tend to occur when growth slows down and then speeds up during one season. It is not always possible to tell these rings from the true ones. Also, new wood is not always laid down around the entire circumference of the tree, giving missing rings. Bald and pond cypress are common, long-lived deciduous wetland species. Rings are of decent quality, generally easily readable. In most specimens it was simple to tell true rings from false, though occasional errors and missing rings imparted some uncertainty into the results. Mean values of the two cores taken from each tree were used in all calculations. This tends to minimize the likelihood and impact of serious errors in interpretation. It also increases the confidence with which one can view apparent significant differences in various means.

Pattern of Growth Unaffected by Mining

Trees were cored at several sites where there have been no phosphate mining related influences. At some other sites near mining operations the only changes were those common to other industries and activities in Florida, such as various degrees of logging and drainage. Mean site values are given in Table 2, and ecosystem type means are given in Table 3. Ecosystem types are discussed in order of ascending growth rates.

The trees sampled in the Okefenokee Swamp were pond cypress growing in about 1 meter of standing water. The mean annual growth rate was 5.24 cm^2/yr, which was less than nearly all the other sites. The standard error was also least at this site (0.17 cm^2/yr). This may be due to the relatively unchanging conditions for growth in the low nutrient swamp.

The cypress dome trees sampled were all pond cypress. All three domes had been drained. Oxy dome in north Florida and K2 dome in central Florida had both

Table 3. Mean growth rates (basal area increments; cm^2/yr) by ecosystem type.

Site	Number of Sites	Bank	Flood-plain	Both
<u>Sites Affected Primarily by Mining</u>				
Floodplain Forests	6	14.18	11.44	12.81
Seepage Swamps	2	---	---	11.27
<u>Sites not Affected Primarily by Mining</u>				
Floodplain Forests	1	11.18	11.01	11.10
Seepage Swamps	1	---	---	13.11
Cypress Strands	1	---	---	7.30
Low Nutrient Swamps	1	---	---	5.24
Lake Fringes	1	---	---	8.39
Cypress Domes	3	---	---	5.59

Table 4. Growth rate by age class of tree.

	Age of Trees				
Site	1–10	10–20	20–30	30–40	40–50
Alafia River	2.0	3.7	4.6	5.1	6.0
Clear Springs North	5.3	11.9	20.0	17.4	16.4
Clear Springs, Peace River	8.2	14.4	16.6	17.3	16.2
Fort Meade, Peace River	4.5	8.1	9.9	10.0	9.1
Sixmile Creek	5.5	11.7	15.4	11.8	11.0
Swift Creek	3.4	12.5	18.4	19.2	12.6
Swift Creek Swamp 2	5.4	13.4	14.1	12.4	13.3
Swift Creek Swamp 3	3.4	6.2	10.1	18.3	16.0
Prairie Creek	5.1	9.1	12.7	14.9	16.8
Swift Creek Swamp 1	3.9	12.4	17.3	17.6	10.5
Cypress Creek	5.0	9.5	7.6	7.2	7.3
Okefenokee Swamp	1.0	2.1	3.4	3.4	4.3
Newnan's Lake	3.4	7.8	10.2	9.5	11.1
C-10 Cypress Dome	2.0	4.0	5.2	5.6	6.8
Oxy Cypress Dome	1.9	4.0	5.5	8.2	8.7
K2 Cypress Dome	2.0	2.9	2.8	7.2	8.2

been logged. The mean annual growth rate for the domes was 5.5 cm^2/yr, slightly higher than for Okefenokee Swamp. The mean standard error was 0.28 cm^2/yr. Growth conditions are also relatively constant in cypress domes. Cypress dome growth rates were less than those found by Brown (1981) in two small domes (8.4 cm^2/yr) and much less than a sewage enriched dome (20.2 cm^2/yr).

The bald cypress trees sampled at the Cypress Creek site in central Florida were in a cypress strand. Water flowed during periods of high groundwater level associated with rainfall. There was standing water throughout the site. Annual growth was 7.30 cm^2/yr, which was greater than the dome or Okefenokee sites. Trees were sampled along the central creek and away from this creek in the standing water areas. Growth in the trees away from the creek (listed under floodplain in Table 2) was significantly greater than in the trees on the bank, 7.79 cm^2/yr vs. 6.81 cm^2/yr. The standard error for the site was 0.23 cm^2/yr, again relatively low.

The mean annual growth rate in bald cypress trees in the lake fringe site at Newnan's Lake in north Florida was 8.39 cm^2/yr. Bank and floodplain growth were not significantly different. Water levels fluctuate in this lake, though they are controlled, so none of the trees are under water at all times, and none are exposed for long periods.

Trees at the Prairie Creek site had a mean annual basal area increment of 11.10 cm^2/yr. These were also bald cypress trees. Though the creek had high banks, bank and floodplain increments were not significantly different. Bank trees did exhibit a greater standard error, 0.61 vs. 0.46 cm^2/yr. In a site such as this with high banks that may seldom overflow, floodplain conditions would not be as variable as at creeks that did overflow regularly. This may account for the lower floodplain variance.

The trees sampled at the Swift Creek swamp 1 site in north Florida were pond cypress. This extensive swamp receives drainage from the surrounding uplands. There were large cypress trees present in some areas, with one tree cored being 200 years old. The mean annual basal area increment at this site was 13.11 cm^2/yr, with a standard error of 0.48 cm^2/yr. The site is flooded regularly, and the groundwater table is near the surface during much of the year. However, a canal located 50—100 meters to the west, the common network of old logging and hunting trails, along with the natural drainage-ways present combine to give some lateral movement of groundwater and surface water.

Mean annual basal area increments at these sites unaffected by phosphate mining varied from 5.24 cm^2/yr at Okefenokee Swamp to 13.11 cm^2/yr at Swift Creek swamp 1. The differences among these growth rates are not explained by tree species, since the least and greatest rates were found in pond cypress trees, while both bald and pond cypress made up sites with intermediate rates.

Sites with some movement of surface and/or surficial groundwater had greater rates if the Swift Creek swamp 1 site is included in this category. Total annual rainfall amounts for stations in central Florida (Bartow) are presented in Figure 7. Mean annual basal area increments for the Clear Springs site, plotted over the same time, are presented in Figure 8. The rainfall and growth means have varied in a similar manner. Though careful comparisons have not been made it is clear (and well known) that there is a positive relation

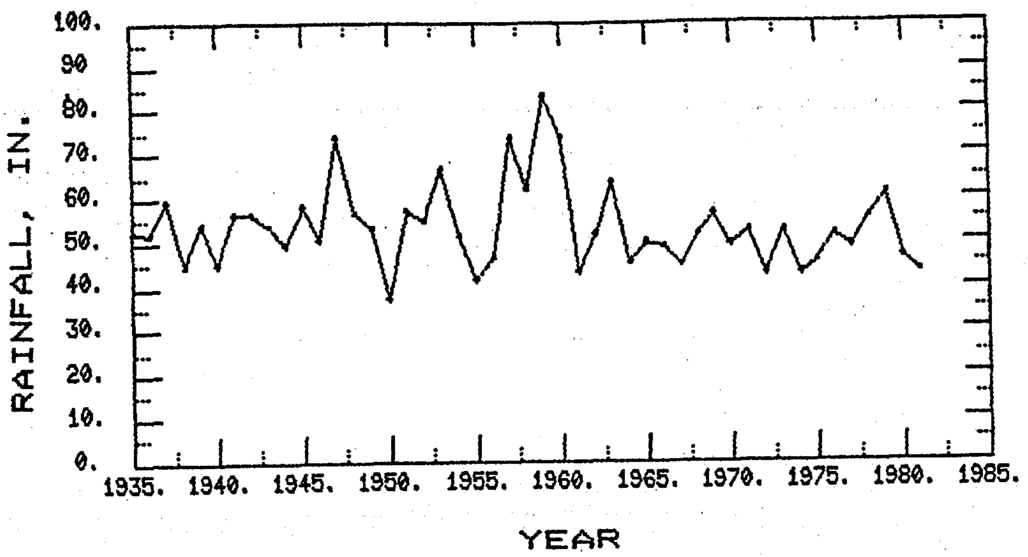


Figure 7. Annual rainfall, 1935—1981, Bartow, Florida (data from the U.S. Department of Commerce).

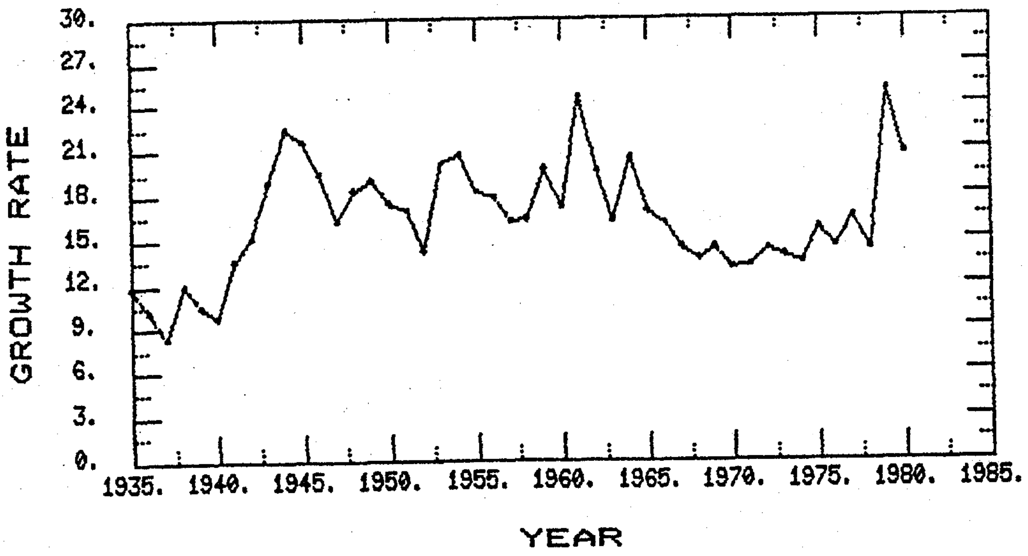


Figure 8. Mean annual basal area increments for bald cypress trees, Clear Springs, Peace River, 1935—1980 (in cm^2/yr).

between rainfall and tree growth. It is also probable that lags, thresholds, and other factors complicate the relation.

in most trees core graphs examined (note Figures 2-6) there is an obvious 2- to 6-year cycle in basal area increments. This is possibly related to the frequency of mast years, years of much greater seed production. Bald cypress has been noted to have intervals between mast years in this range (Detwiler 1916). With the commitment of resources to the production of massive amounts of seed, less wood growth would be possible in these years, giving lower basal area increments. It is not known whether these years of great seed production are triggered by environmental conditions, are intrinsic to the tree, or, as is the case in many biological cycles, are intrinsic rhythms that are set and calibrated by extrinsic signals. Populations with appropriate internal cycles could be expected to evolve in environments with regular environmental cycles.

Age related effects were apparent in many trees. This is discussed below.

Comparison of Banks and Locations Away from Banks

Differences were apparent in bank and floodplain growth at all mining related sites. Mean annual basal area increments were significantly greater for bank trees than floodplain trees at the Alafia River, Fort Meade, and Sixmile Creek sites. Floodplain growth was significantly greater at the Clear Springs North, Clear Springs, and Swift Creek sites. Highest bank growth was 23.23 cm^2/yr, though this was in the Sixmile Creek site, where only one bank tree remained, and the value may not be reliable. Mean annual basal area increments for bank trees in the other sites ranged from 10.31 to 15.25 cm^2/yr.

Floodplain site means were more variable from 5.54 cm^2/yr at Fort Meade to 17.72 cm^2/yr at Clear Springs, both on the Peace River floodplain. Particularly low growth rates were found at Fort Meade, the Alafia River site (7.15 cm^2/yr), and the Sixmile Creek site (9.32 cm^2/yr).

For the floodplain forest sites combined, bank growth was greater than floodplain, 14.18 cm^2/yr vs. 12.82 cm^2/yr. Bank trees might be expected to be less affected by occasional heavy silt and clay deposition, since the material might be washed away rapidly during the next high flow period. Bank trees might also be affected more positively by increased nutrient levels with their roots in direct contact with the stream water.

The low floodplain mean found at the Fort Meade site is discussed below. The floodplain at the Alafia River site was a poorly drained location with standing water. Poor drainage may be a partial explanation for the low growth rate. The Sixmile Creek floodplain site also had low mean annual basal area increment . The adjacent upland has been mined and reclaimed, and runoff waters might have affected growth. There was also evidence of possible sediment deposition in soil pits.

Growth in Sites Receiving Extra Sediment from Mining

The slowest mean growth rate was found in the floodplain trees at the Fort Meade site. Clay slime deposition was greatest at this site, which could account for this difference. A clay layer was apparent in the area where the tree cores were taken.

The site with the most obvious sediment deposition was Swift Creek swamp 3, part of the Swift Creek swamp system in north Florida. Pond cypress trees were present. The site bordered a sand tailings disposal area. Fine silt and clay size particles settled out of the tailings pile and inundated the surrounding forest. The deposit of fine particles was up to 2 feet thick on top of the original peat substrate. Here growth rates increased substantially following establishment of this pile (Figure 9). The increased water supply caused by the large new watershed area at this site may account for the increased growth here, as compared with the Fort Meade floodplain, which also received sediment. Also, the Fort Meade trees were bald cypress.

Effects of Impoundment

Occidental Mining Company discharged process water from its chemical plant in north Florida to a section of Swift Creek swamp. In 1979 a berm was placed across a channel in the swamp as part of a project to examine the effects of impoundment. There was standing water in the impounded area throughout the year, while the water supply was increased, though not as dramatically, downstream of the berm. Pond cypress trees were cored on both sides of the berm at the Swift Creek swamp 2 site. In Figure 10 are mean basal area increments for impounded trees (top), and unimpounded trees (bottom). In Figure 11 are means for trees at the Swift Creek swamp 1 site, which should not have been affected by the chemical plant discharges. Beginning in 1979, an increase in growth rate was apparent in both the impounded, and unimpounded sites, but not the other site. The increase was greater in the unimpounded location, from 10.9 cm^2/yr in 1979 to 22.1 cm^2/yr in 1981. Feiertag (1982) found low levels of dissolved oxygen (0.8-1.0 ppm) and high levels of hydrogen sulfide (1-2 ppm) on both sides of the berm. Sulfur bacteria were present. Growth increased at this Swift Creek swamp site in spite of the low DO and high H_2S in the surface water. In another cypress containing ecosystem in north Florida, Richardson et al. (1983) found hydrogen sulfide toxic to trees. Although low, the dissolved oxygen may be adequate for growth of pond cypress. Likewise, the hydrogen sulfide levels may be below the toxicity threshold.

Age Related Effects

There may be age related changes in basal area increments due to tree physiology, geometry, and changing canopy size. Mean annual basal area increment of trees vs. age of tree is given in Figure 12. These are means of all trees at all sites. The growth rate increased up to about 25 years of age, and then remained fairly constant after that. This indicates that, in the mean for these types of ecosystems, cypress trees reached their maximum net productivity (in terms of diameter increase) at approximately 25 years of age. No decrease was found after that, at least for the first 50 years. In old trees, such as the one shown in Figure 4 (138 years old), no decrease in growth rate is. seen with age.

In Figure 13 are mean annual basal area increments for bank trees (top) and floodplain trees (bottom) in floodplain forest ecosystems. Growth in diameter

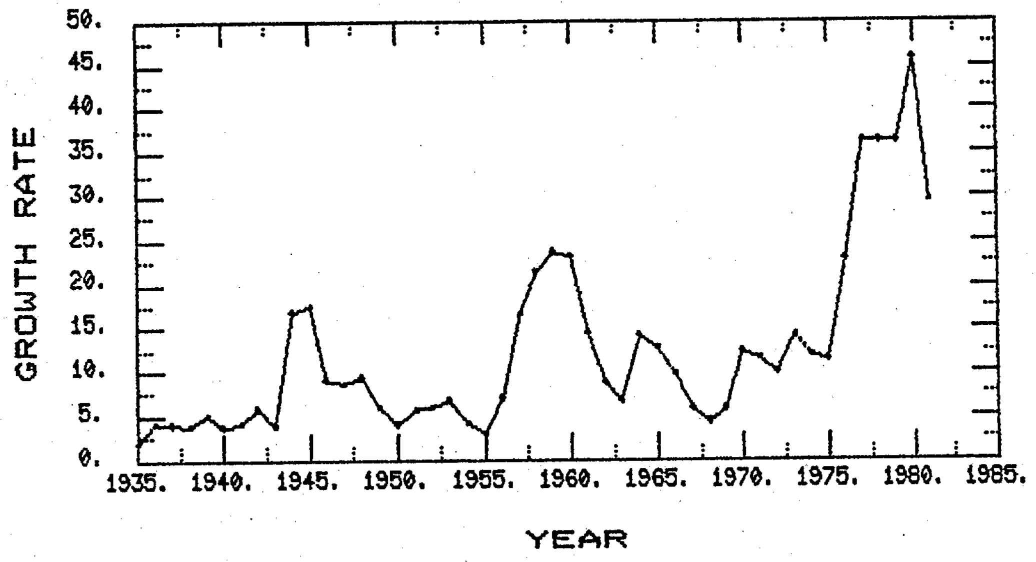
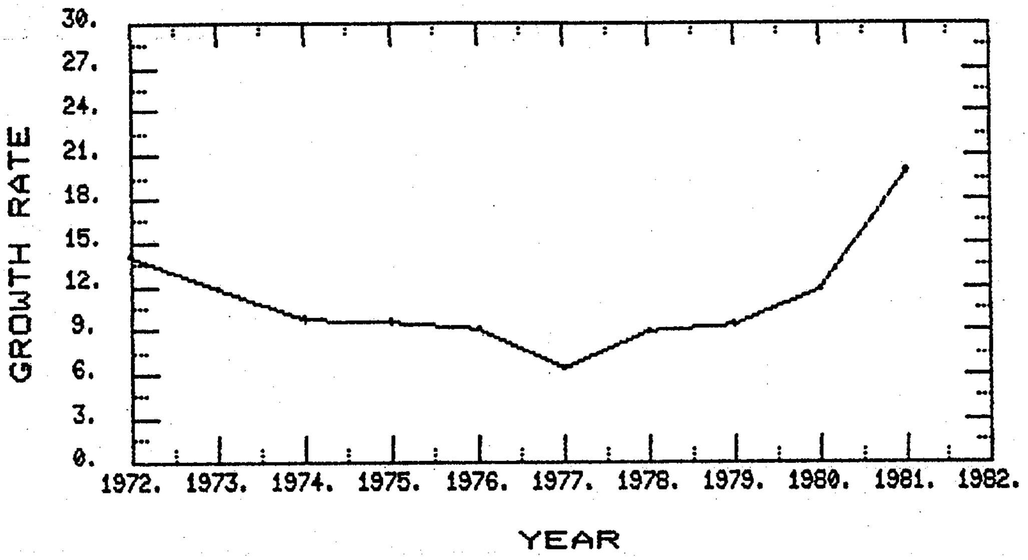


Figure 9. Mean annual basal area increments for pond cypress trees, Swift Creek Swamp 3, 1935–1981 (in cm^2/yr).



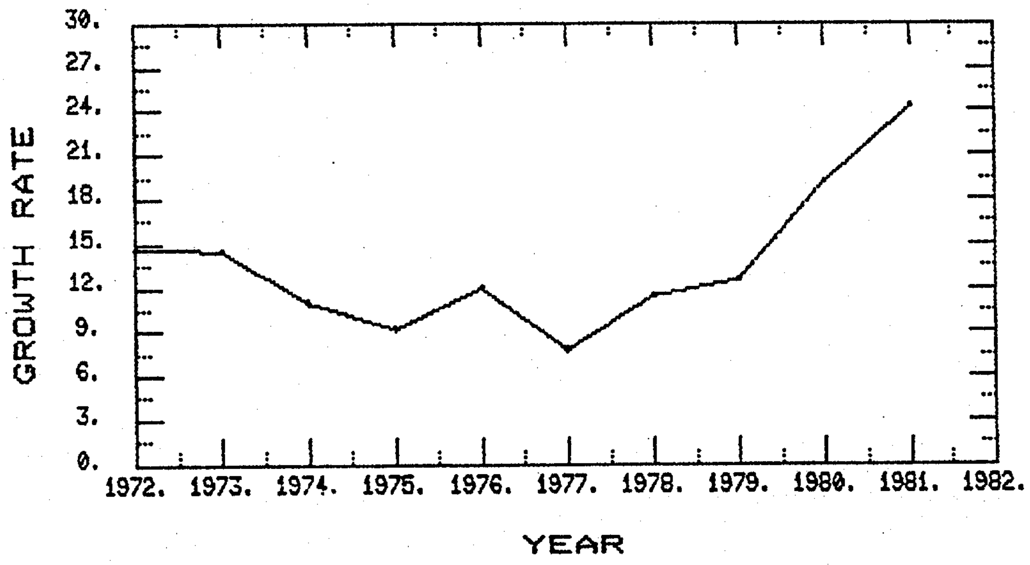


Figure 10. Mean annual basal area increments for pond cypress trees, Swift Creek Swamp 2, impounded (top) and unimpounded (bottom), 1972–1981 (in cm^2/yr).

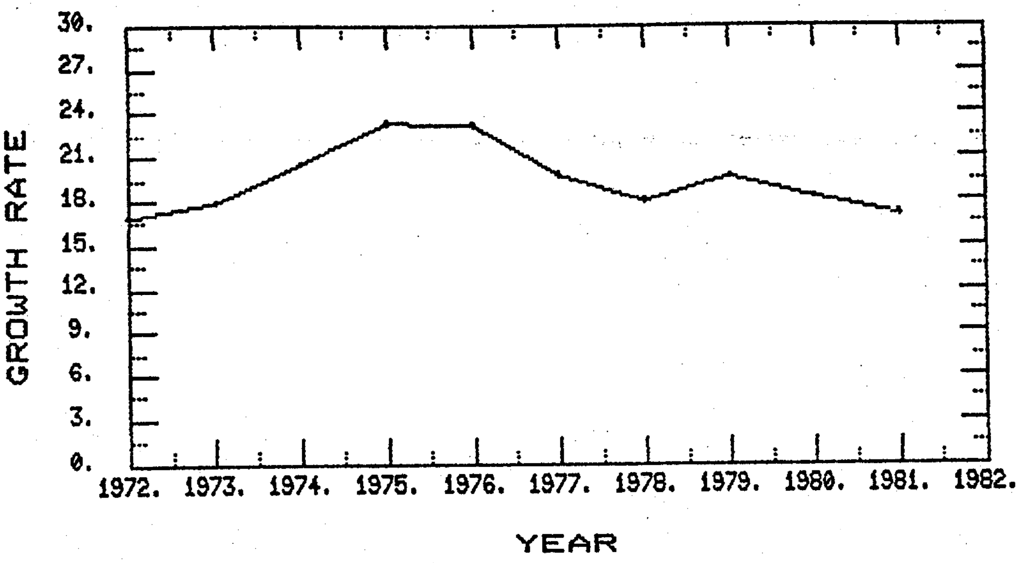


Figure 11. Mean annual basal area increments for pond cypress trees, Swift Creek Swamp 1, 1972–1981 (in cm^2/yr).

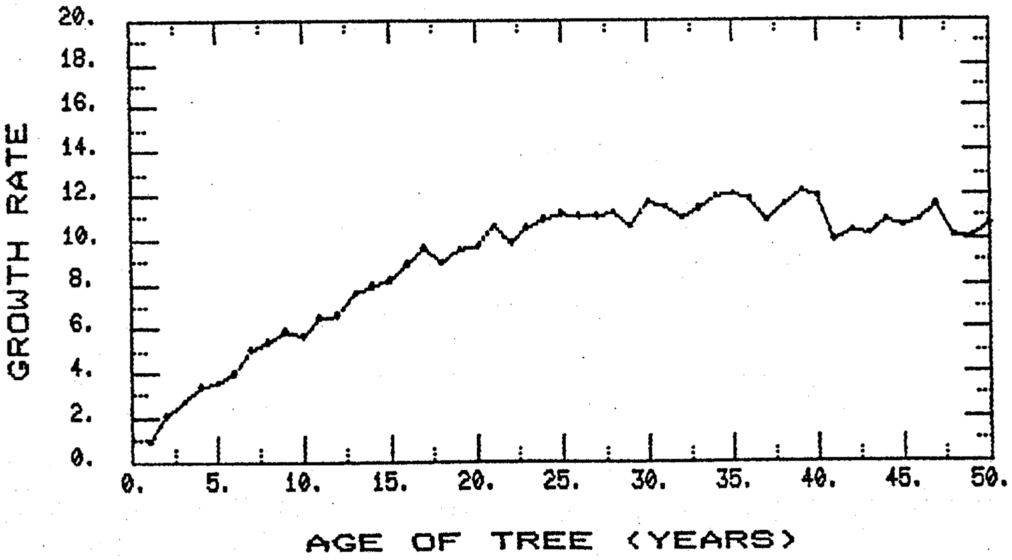
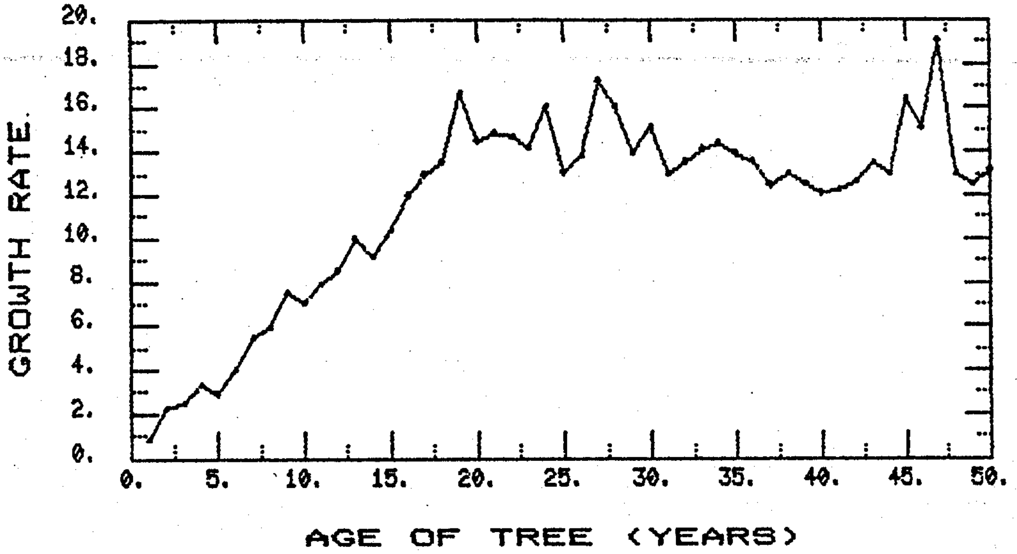


Figure 12. Mean annual basal area increments for all trees by age of tree, ages 1–50 yrs (in cm^2/yr).



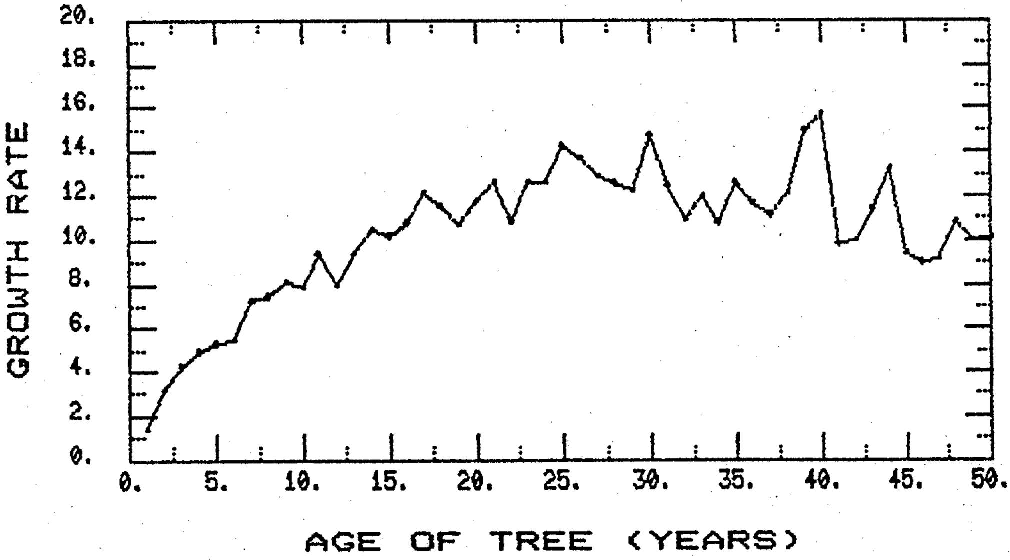
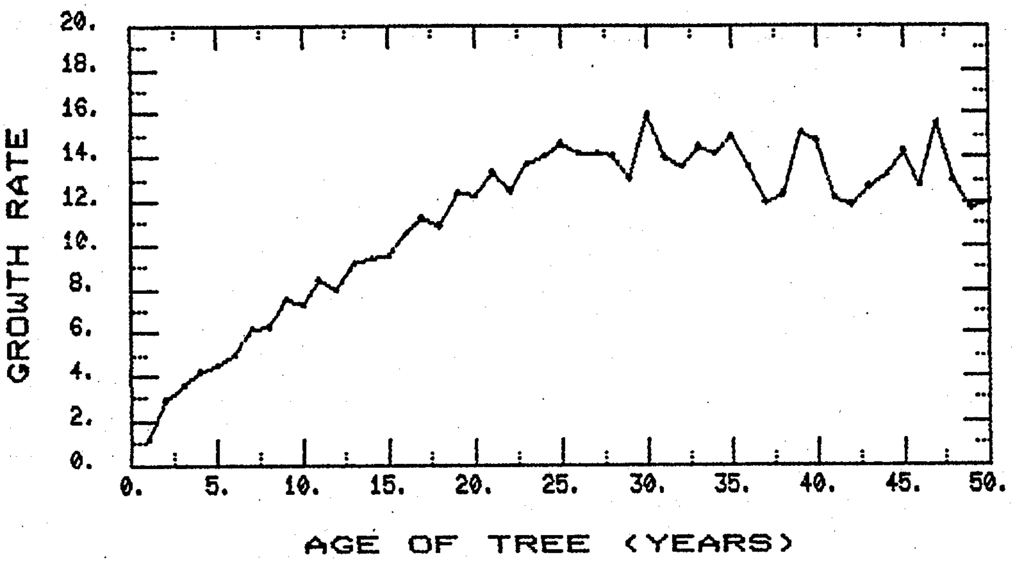


Figure 13. Mean annual basal area increments for all bank trees (top) and all floodplain trees (bottom) in floodplain forests by age of tree, ages 1–50 yrs (in cm^2/yr).

reached its maximum earlier in bank trees, at an age of 19 years compared to 25 years. This was possibly due to the greater availability of water and nutrients in the stream and sunlight (and canopy space) on the bank.

Diameter growth rates for trees in floodplain forests (top) and other ecosystems (bottom) by age of tree are given in Figure 14. Growth rates in trees in floodplain forests increased to a mean rate of 14 cm^2/yr at an age of about 23 years and then oscillated. In the mean of other ecosystem types, growth rates began to level off at approximately 15 years at about 7 cm^2/yr, and then increased slowly until an age of 35 years. The oscillations in later ages in floodplain forests may be due to the more variable conditions in these ecosystems.

Mean annual basal area increments by age of tree for bald cypress (top) and pond cypress (bottom) are plotted in Figure 15. These plots are much like those for floodplain forests vs. other ecosystems, since the division is similar. The plateau reached by the bald cypress trees is greater, approximately 13 cm^2/yr as opposed to pond's 9 cm^2/yr. As noted earlier, this difference is due more to ecosystem type than to species, as the greatest growth rates were found in Swift Creek Swamp trees, which are pond cypress.



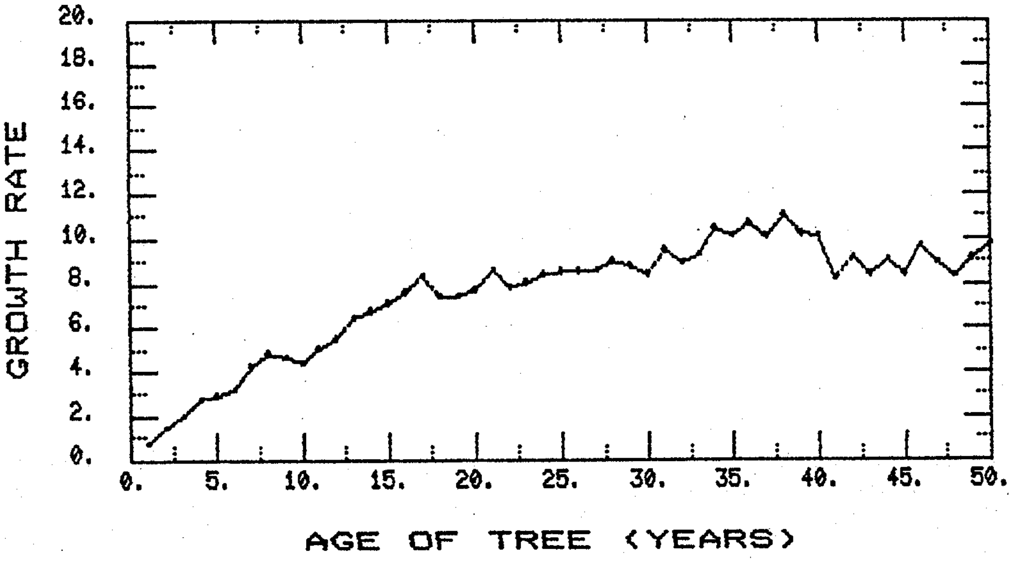
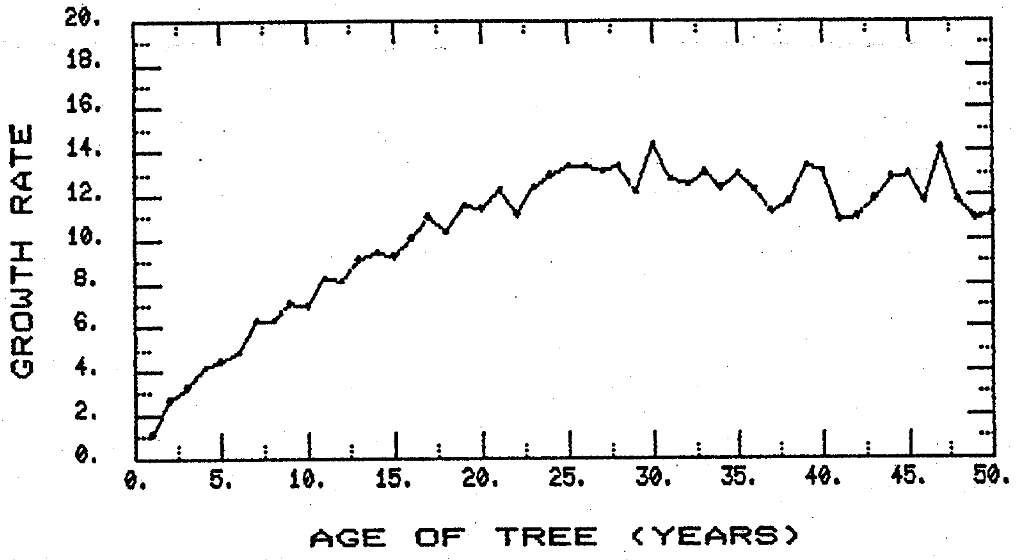


Figure 14. Mean annual basal area increments for all trees in floodplain forests (top) and all trees in other ecosystems (bottom) by age of tree, ages 1–50 yrs (in cm^2/yr).



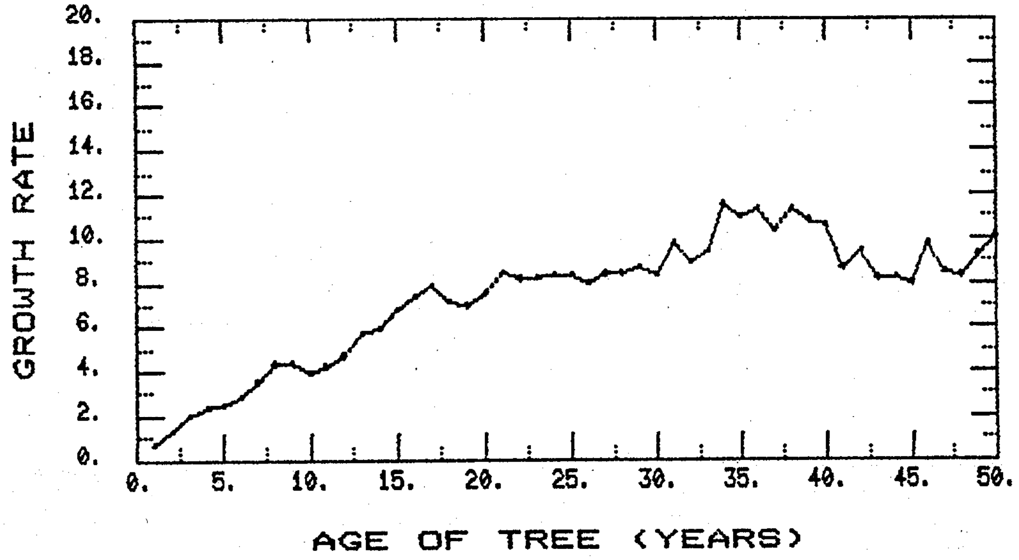


Figure 15. Mean annual basal area increments for all bald cypress trees (top) and all pond cypress trees (bottom) by age of tree, ages 1–50 yrs (in cm^2/yr).

4. SIZE DISTRIBUTION OF FLOODPLAIN VEGETATION ADJACENT TO PHOSPHATE MINING

Michael A. Miller

Introduction

Depending on regimes of hydroperiod and sediment processing, floodplain ecosystems may develop characteristic age structure, species associations, and growth rates. In this study an attempt was made to characterize forested wetland ecosystems in Florida, especially floodplain forests, including some influenced by phosphate mining. Forests that existed prior to mining and are continuing to function as natural ecosystems were examined. By examining wetlands that have had some years to adapt to changed conditions associated with mining, a scientific basis may be developed for determining safe impact limits, for predicting future wetland patterns, and for developing guidelines for wetland management.

Throughout north and central Florida ecosystems have been influenced by phosphate mining for many years. Influences include changed hydrologic characteristics of floodplains due to altered streamflow and hydroperiod, draining of perched wetlands, the deposition of phosphatic clays and silts from dredging, pipe and dam breaks and erosion, and altered stream and groundwater chemistry.

When ecosystems are exposed to influences somewhere between the extremes of devastation and negligible impact, they may change in subtle ways. Changes that are negative at first may become positive later. For example, species may make root adaptations or new species may develop that are capable of using the altered conditions. This is a study of the adaptations taking place as floodplain forests alter their structure and functions and adjust to inputs. Though one cannot generally observe forests for the years necessary to record long-term changes, the analysis of tree rings and age classes used in this study allow an examination of changes later.

Age distributions of trees indicate the nature of ecosystem growth. Some vegetation may be continually replacing itself with a stable age distribution-many small trees becoming a few large ones continuously. Floodplains, however, may have even-age distributions because of their tendency to be replaced all at once following catastrophic flooding or clear-cutting.

Since ecosystem properties are being measured as a snapshop of the large-scale driving forces of nature and industry, the methods focus on trees, which are the dominant members of the biotic community in terms of size, productivity, and longevity. The objectives are as follows:

1. Characterize vegetation of forested wetland ecosystems of central and north Florida influenced by phosphate mining.

2. Determine the responses of floodplain vegetation to influences of phosphate mining.

3. Examine age distributions of vegetation for evidence of normal and impacted patterns of replacement.

Study Sites

Vegetation was studied at seven sites. Locations and site descriptions are given in Chapter 3. All sites except Swift Creek swamp were floodplain forests. The Clear Springs and Fort Meade sites are on the Peace River. The Alafia River site is downstream of the confluence of the north and south prongs, and the other sites are on small creeks in north and central Florida.

Mizelle Creek. This is a narrow floodplain downstream of an active clay settling area in Hillsborough County. Creek banks are high, and the soil is sand with some organic matter. The site is reached via an access road that leaves Keysville Road 1 mile south of State Route 640 (one-half mile east and 2 miles south of Keysville). The road is followed east until it turns south. The study site is located approximately 200 meters north of this point in the creek floodplain.

Methods

Vegetation Transects

Basic data were collected along belt quadrats, which are 10 x 10 m quadrats laid end to end. On small creek and river floodplains these stretched from water's edge to the uplands, often a very short distance. Within these quadrats trees and shrubs were identified and counted and diameters were measured. Diameters and heights of seedlings were measured. Live herbaceous material was collected in 0.25-m^2 quadrats at 5-m intervals, oven dried, and weighed. Litter samples were collected, dried, and weighed. The density of red, green, and yellow leaves that were on the ground were counted during the growing season. In other studies recent fall of red, green, and yellow leaves was an indicator of ecosystem stress (Odum and Pigeon 1970).

Small soil pits were dug at each site, and soil samples were taken. The tree information was then used to calculate indices of diversity, dominance, and evenness, as well as information on size classes.

An index of diversity was calculated using the following expression (Shannon and Weaver 1949; Pielou 1979):

$$\bar{H} = -\sum (n_i/N)\log(n_i/N) \qquad (2)$$

where $\bar{H}$ = Shannon diversity index; n_i = number of individuals in species i; N = number of individuals in all species; and log = log to the base 10.

A dominance index was then calculated (Odum 1971; Simpson 1949):

$$c = \sum(n_i/N)2 \tag{3}$$

where c = index of dominance; n_i = number of individuals in species i; and N = number of individuals in all species.

An index of evenness was calculated as follows (Pielou 1979):

$$e = \bar{H}/\log s \tag{4}$$

where H = Shannon index (above); S = number of species; and log = log to the base 10.

Results

Basal Area in Vegetation Transects

Data on basal area of trees in transects are given in Figures 16-22. On all floodplain graphs the river edge is on left. An idea of changing dominance going away from the river can be seen in the graphs. The four most dominant species by basal area were included, and their basal area per hectare was plotted.

Figure 16 is a summary of dominance data for the Alafia River transect. Near water there was a predominance of bald cypress (*Taxodium distichum*) with some cabbage palm (*Sabal palmetto*); proceeding upland there were more live oaks (*Quercus virginiana*), cabbage palms, and dogwoods (*Cornus foemina*).

Figure 17 contains dominance data for the Mizelle Creek site. The species present are typical of the higher floodplain on this small creek and include sweetgum (*Liquidambar styraciflua*), water oak [*Quercus nigra*), laurel oak (*Quercus laurifolia*), and blue beech (*Carpinus caroliniana*), all bottomland and mesic species. No distinct, change is apparent moving away from the stream bank.

Dominance data for Sixmile Creek are given in Figure 18. This was an extensive floodplain forest though all bank vegetation was removed when the creek was channelized. Bald cypress is the dominant tree and many cabbage palms and red maples (*Acer rubrum*) are also present.

Figure 19 gives the Clear Springs data. Bald cypress and pop ash (*Fraxinus caroliniana*) were dominant. Large elms (*Ulmus americana*) occurred away from the bank. Some slough areas were treeless.

Fort Meade data are illustrated in Figure 20. The floodplain was similar to the Clear Springs site, though lower and not quite as wide. Some different tree species were present, including water hickory (*Carya aquatica*) and willow (*Salix caroliniana*).

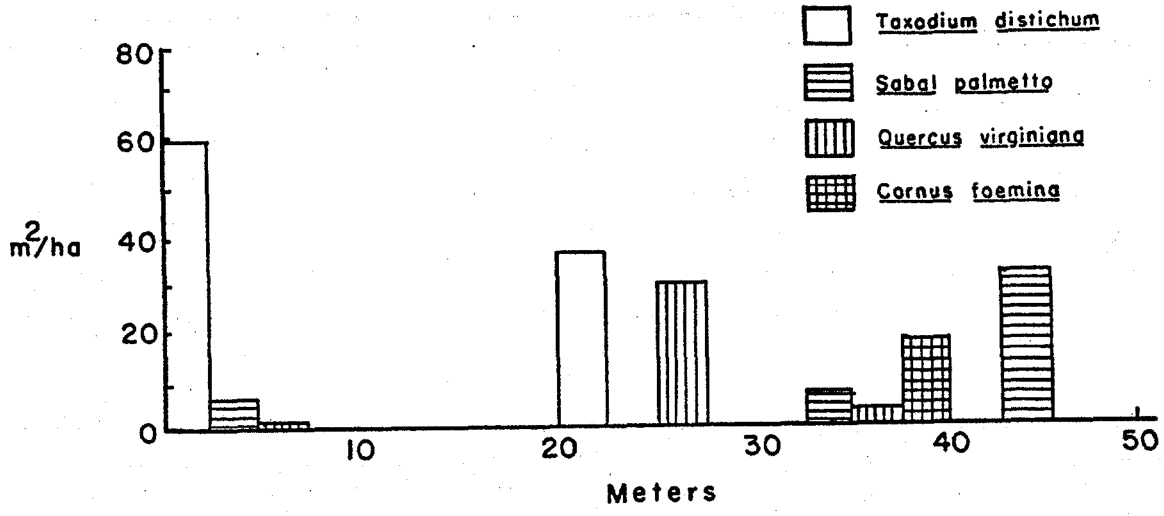


Figure 16. Dominance (basal area of trees) in a transect on the Alafia River floodplain.

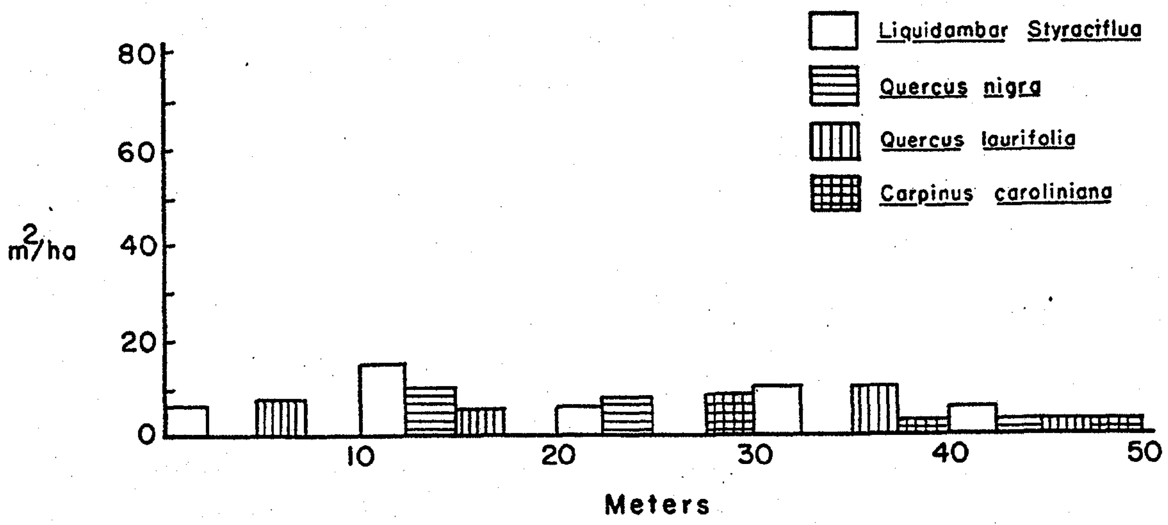


Figure 17. Dominance (basal area of trees) in a transect on the Mizelle Creek floodplain.

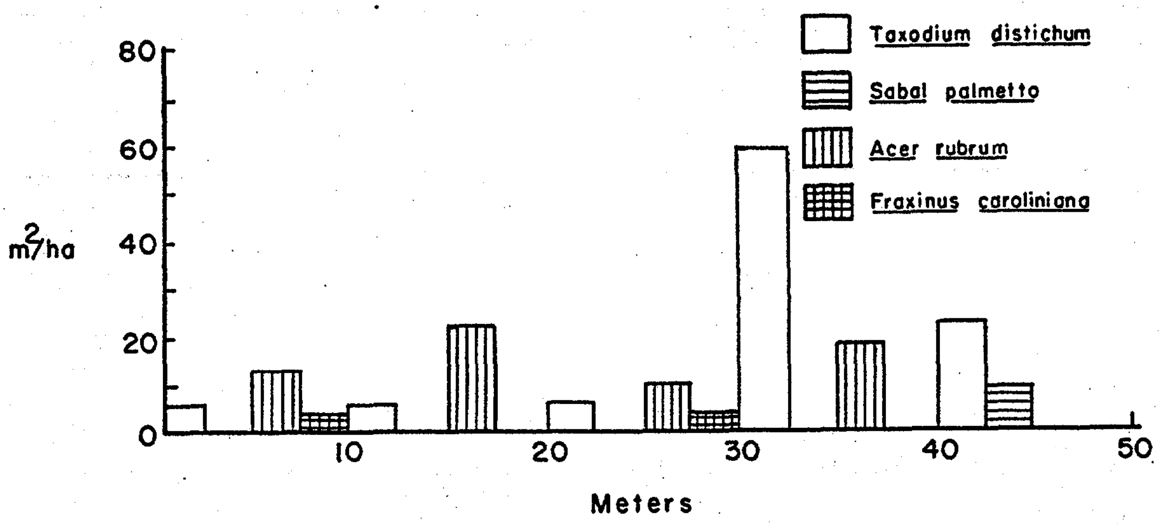


Figure 18. Dominance (basal area of trees) in a transect on the Sixmile Creek floodplain.

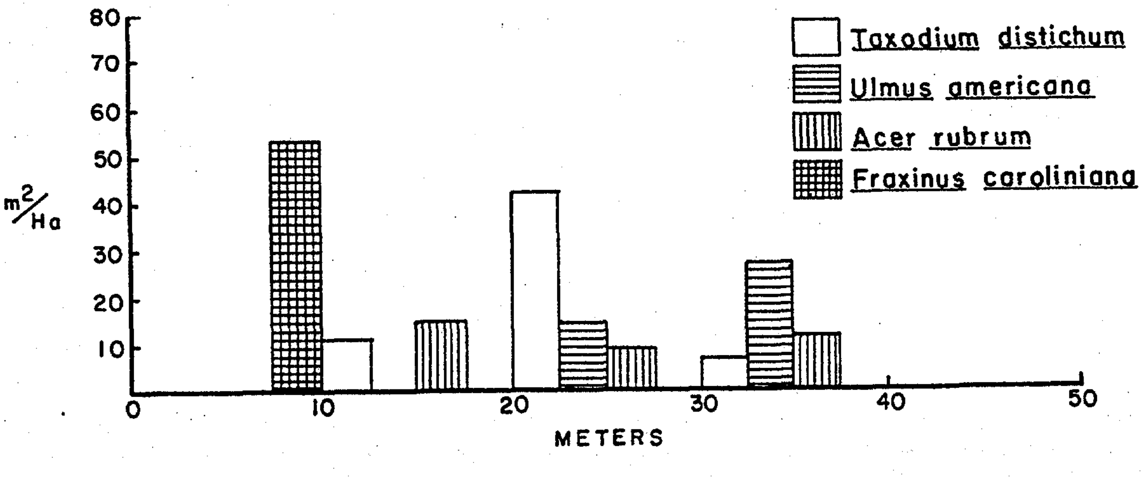


Figure 19. Dominance (basal area of trees) in a transect at Clear Springs on the Peace River floodplain.

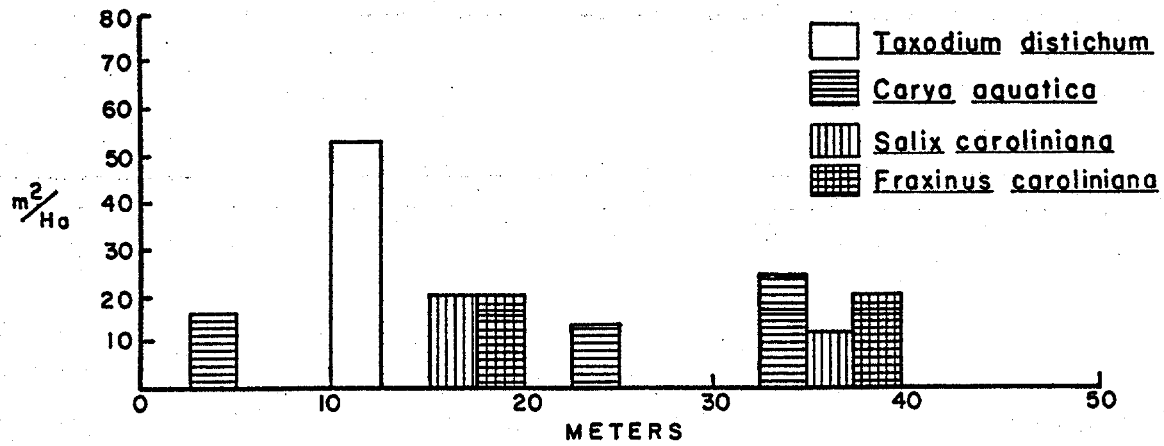


Figure 20. Dominance (basal area of trees) in a transect at Fort Meade on the Peace River floodplain.

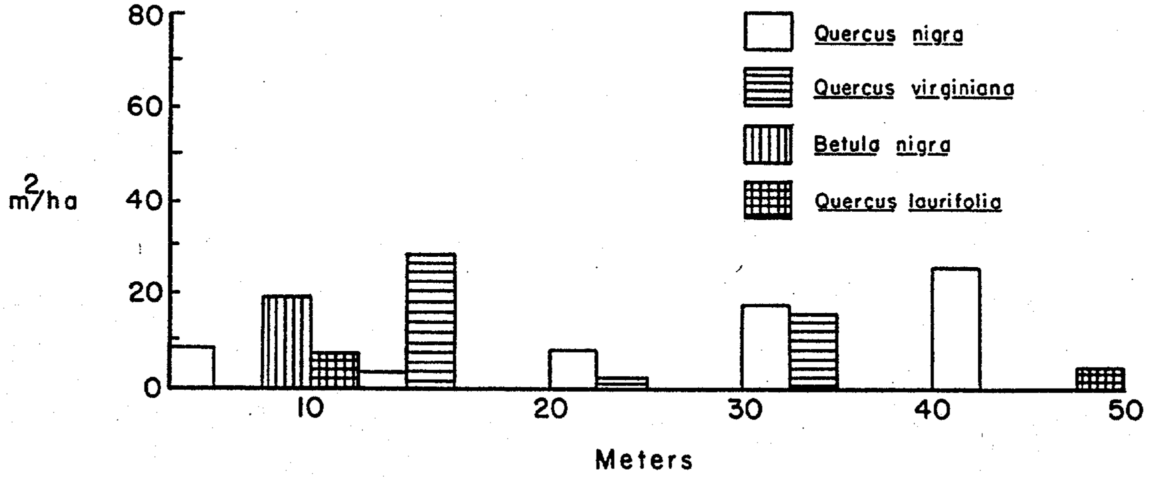


Figure 21. Dominance (basal area of trees) in a transect on Swift Creek floodplain.

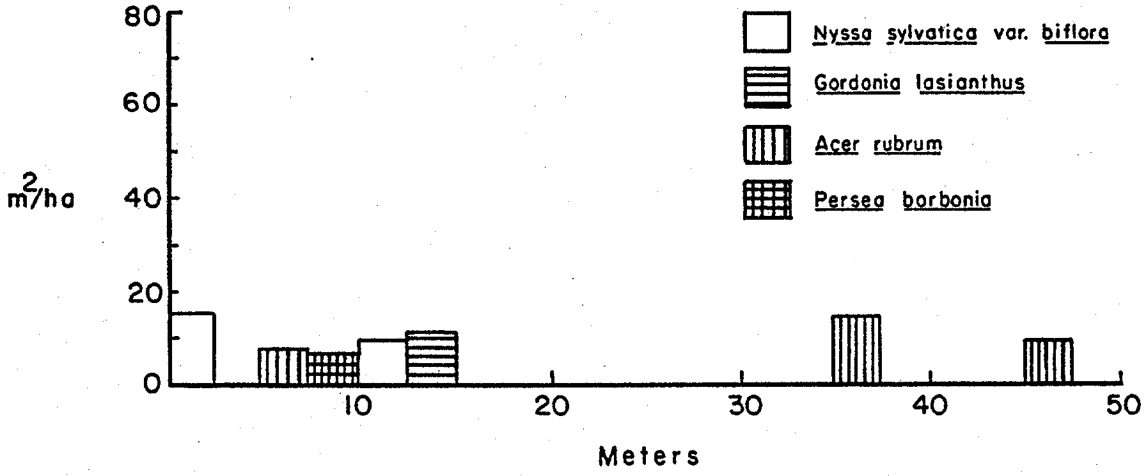


Figure 22. Dominance (basal area of trees) in a transect in Swift Creek Swamp.

Swift Creek data are shown In Figure 21. The same species were present as in some of the other small creek floodplain forests, with the addition of river birch (Betula nigra) as a dominant tree. All the bald cypress were found in the stream, on small islands, or on the bank.

Swift Creek swamp dominance data are given in Figure 22. Black gum (Nyssa sylvatica var. biflora), loblolly bay (Gordonia lasianthus), red maple, and red bay (Persea borbonia) were dominant. Pond cypress (Taxodium ascendens) and sweet bay (Magnolia virginiana) were also common. There were many open areas, often covered by vines.

Graphs of Size Classes

The information on these dominant species is displayed in a different format in Figures 23-29, where size class is on the abscissa and numbers are on the ordinate. This size class structure is indicative of the present and future makeup of the site and is being investigated as a basic ecological parameter. Uneven size (and age) distributions may be indicative of a species that only regenerates at long time intervals.

In Figure 23, for the Alafia River, cypress was only found in the largest size class, while sabal palm exhibited a possibly more common distribution. There was an even aged stand of one species and a mixed age stand of another.

At Mizelle Creek (Figure 24) the dominant trees, sweetgum, were represented by seedlings as well as the large size classes. Laurel oak and water oak were also present in three different size classes.

Sixmile Creek (Figure 25) had cypress only in the larger sizes. Cabbage palm and pop ash also gave an even aged appearance. Red maples were present in three different classes.

Bald cypress and pop ash were only present in the larger sizes at Clear Springs (Figure 26). Elm and red maple were in all but the largest class.

Figure 27 provides size class information for the Fort Meade site. Here cypress was present as seedlings and large trees, water hickory in most sizes, medium sized pop ash, and only large willows. Most dominant species were exhibiting a noncontinuous age distribution.

At Swift Creek (Figure 28) the oaks predominated and were present in large and small size classes. Only large river birches were found.

Swift Creek swamp (Figure 29) showed a much larger regeneration potential with large numbers of red maple, loblolly bay, and red bay seedlings.

Other Ecosystem Indices

In Figures 30 to 36 various ecosystem indices and other measurements are plotted for the seven study sites. These include diversity, dominance, evenness, oven dry weight of herbaceous matter, and density of seedlings. The diversity, dominance, and evenness indices vary widely along the transects,

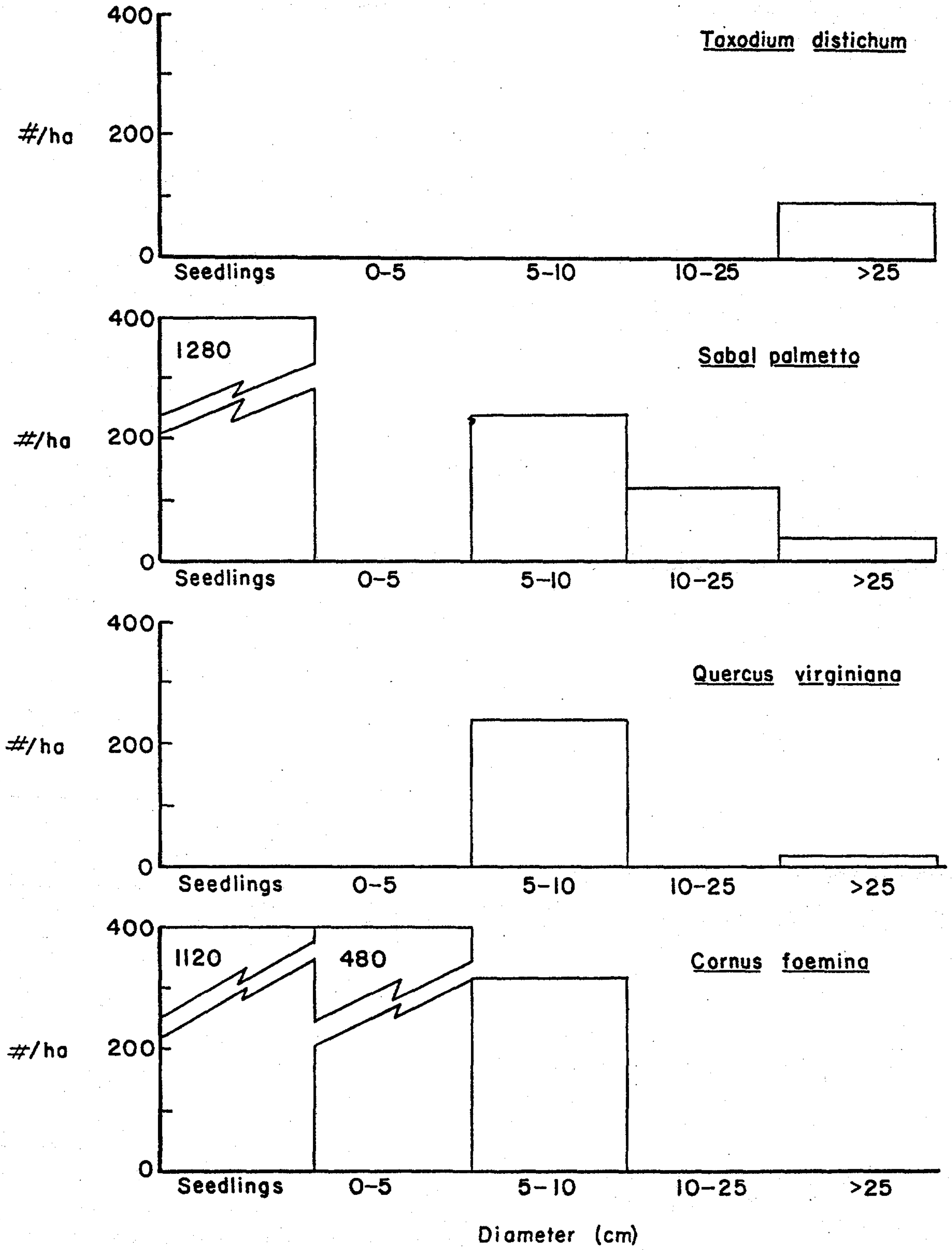


Figure 23. Size classes in a transect at the Alafia River site.

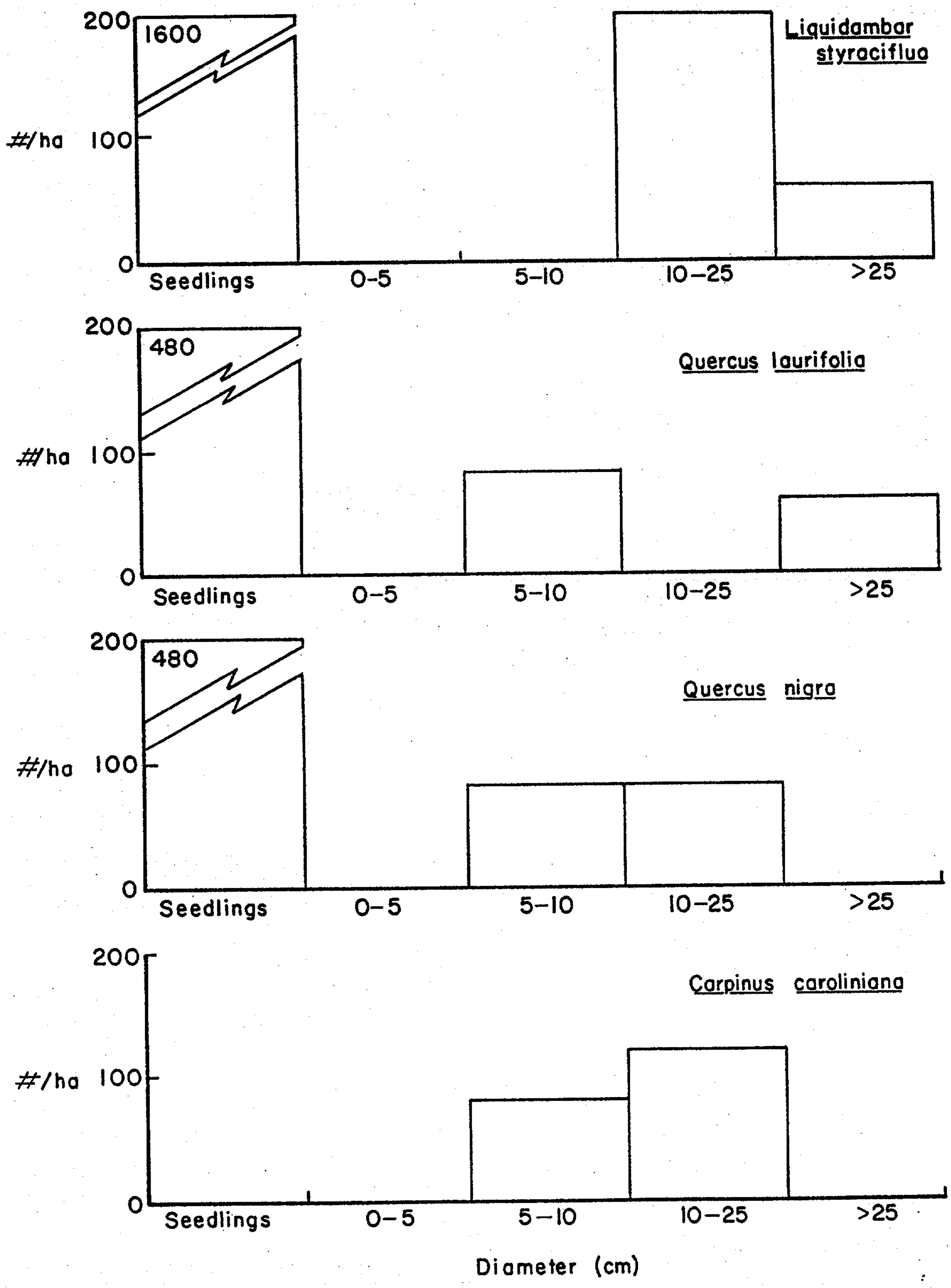


Figure 24. Size classes in a transect at the Mizelle Creek site.

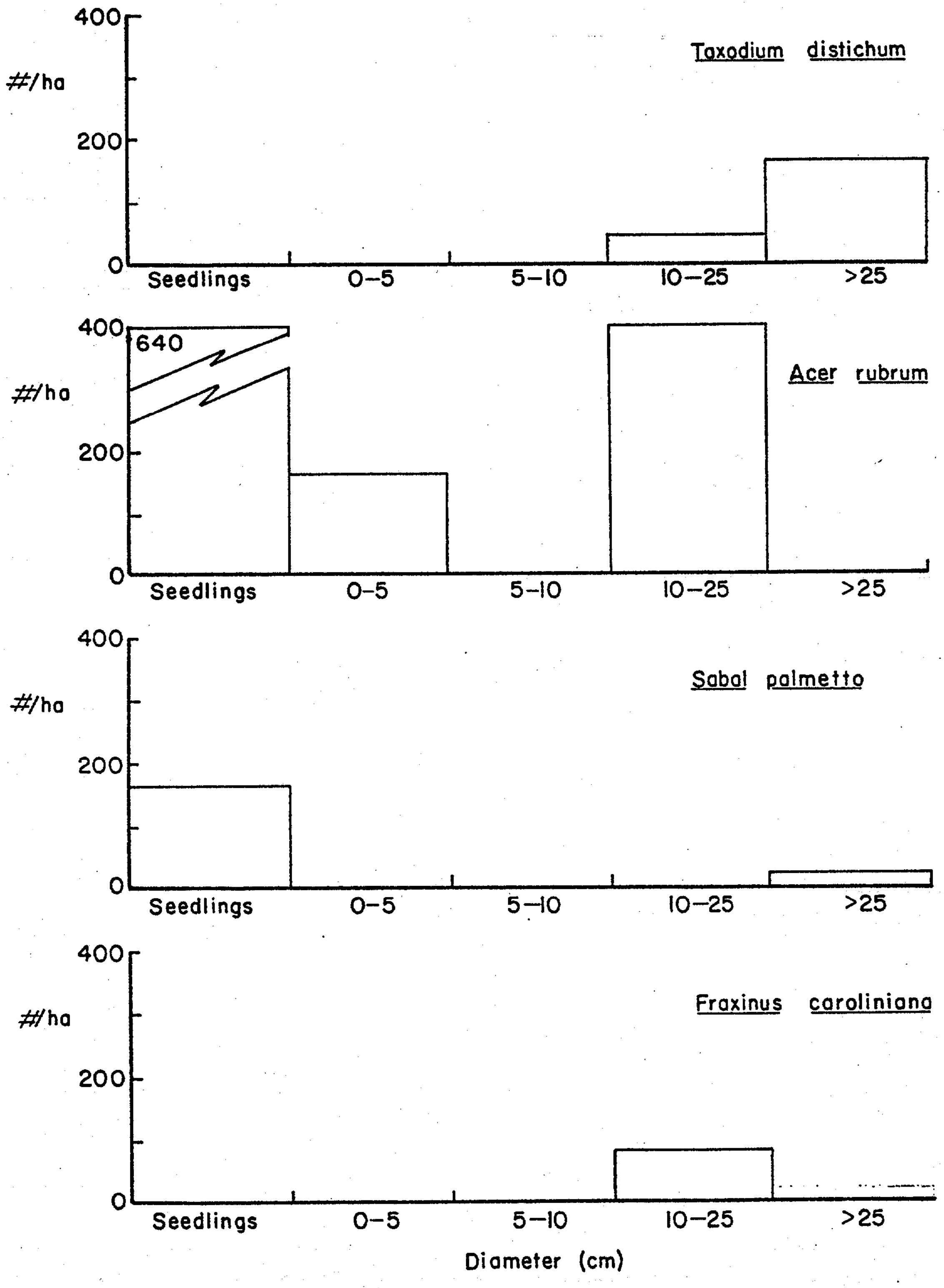


Figure 25. Size classes in a transect at the Sixmile Creek site.

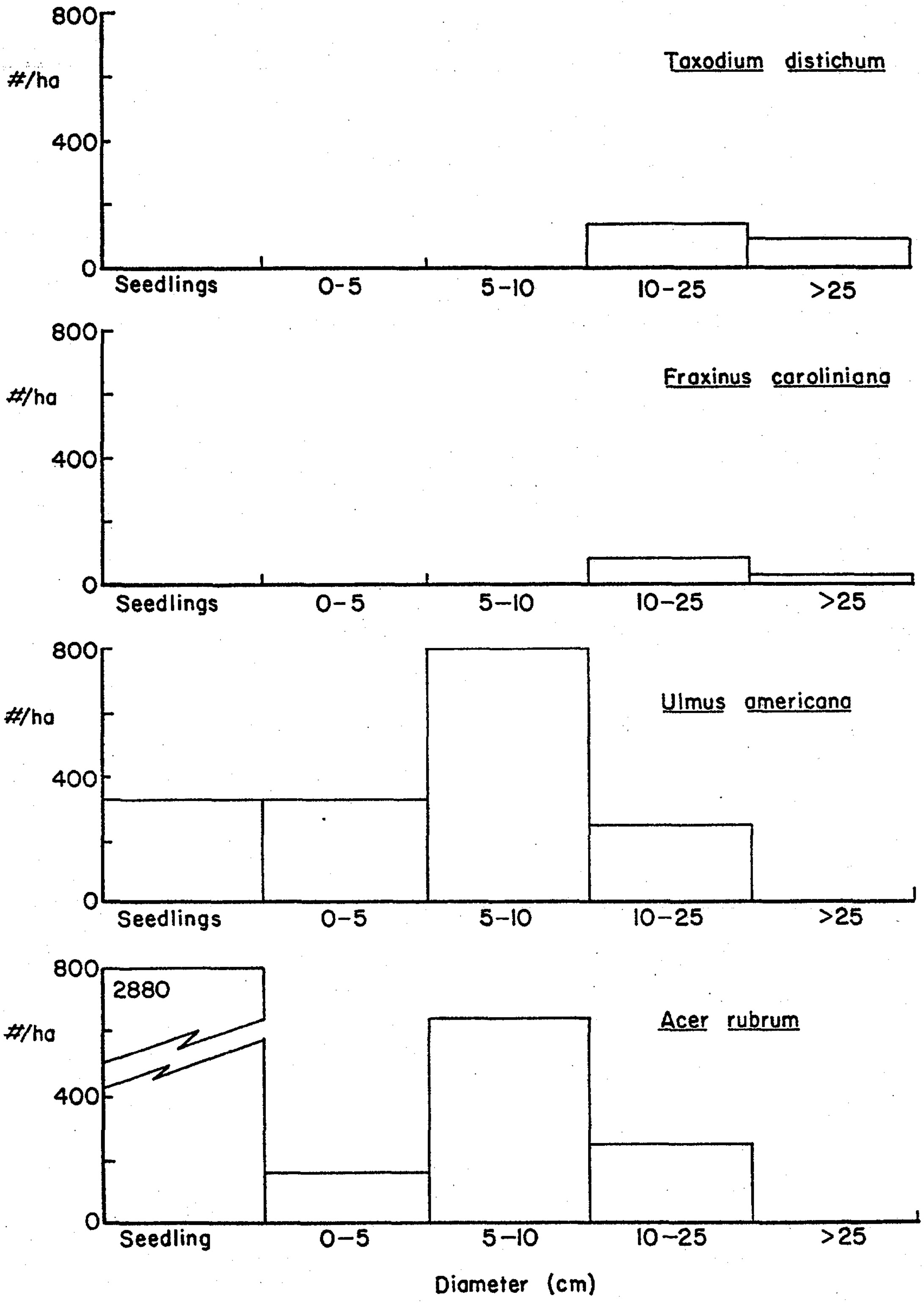


Figure 26. Size classes in a transect at the Clear Springs, Peace River, site.

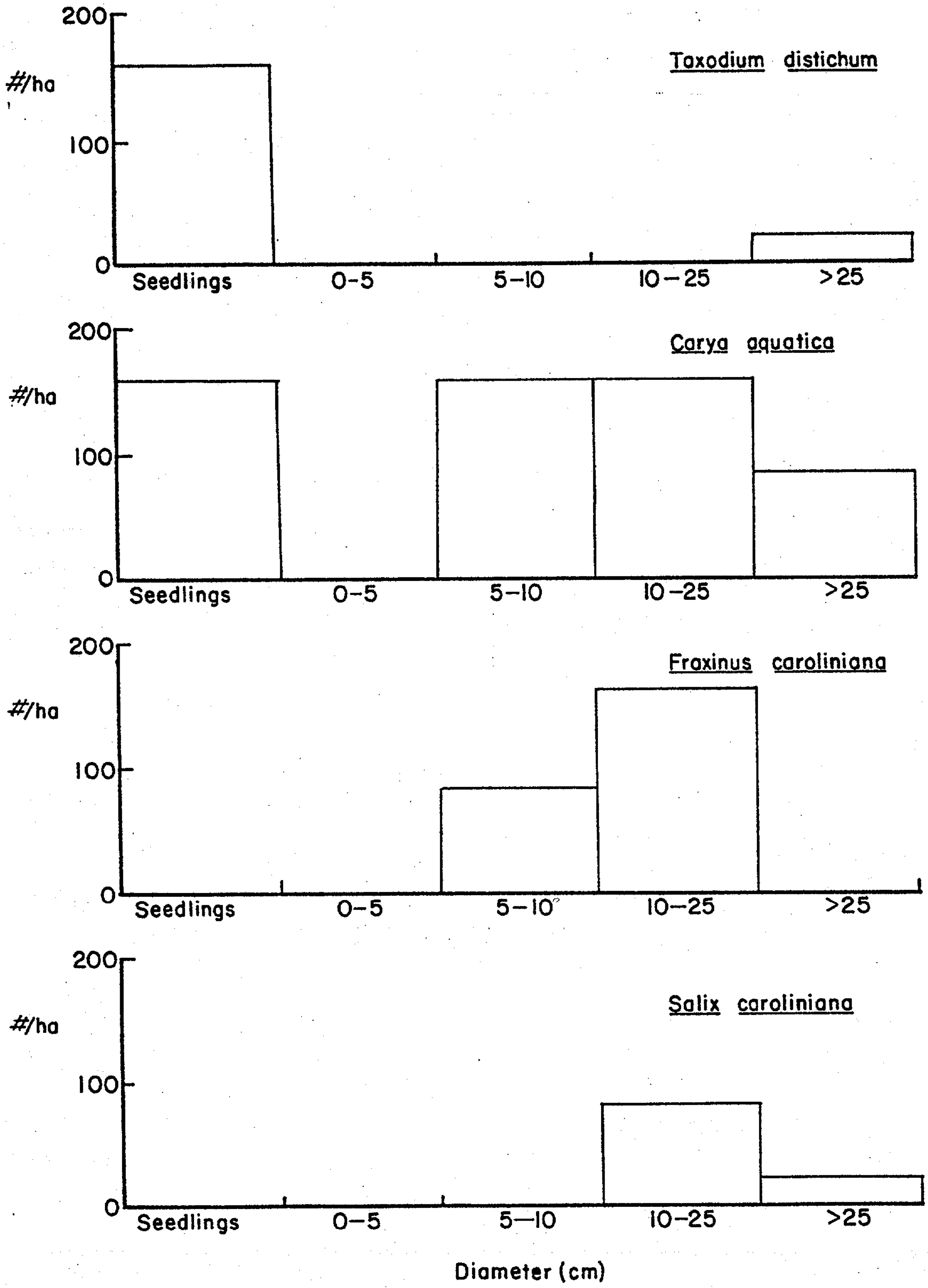


Figure 27. Size classes in a transect at the Fort Meade, Peace River, site.

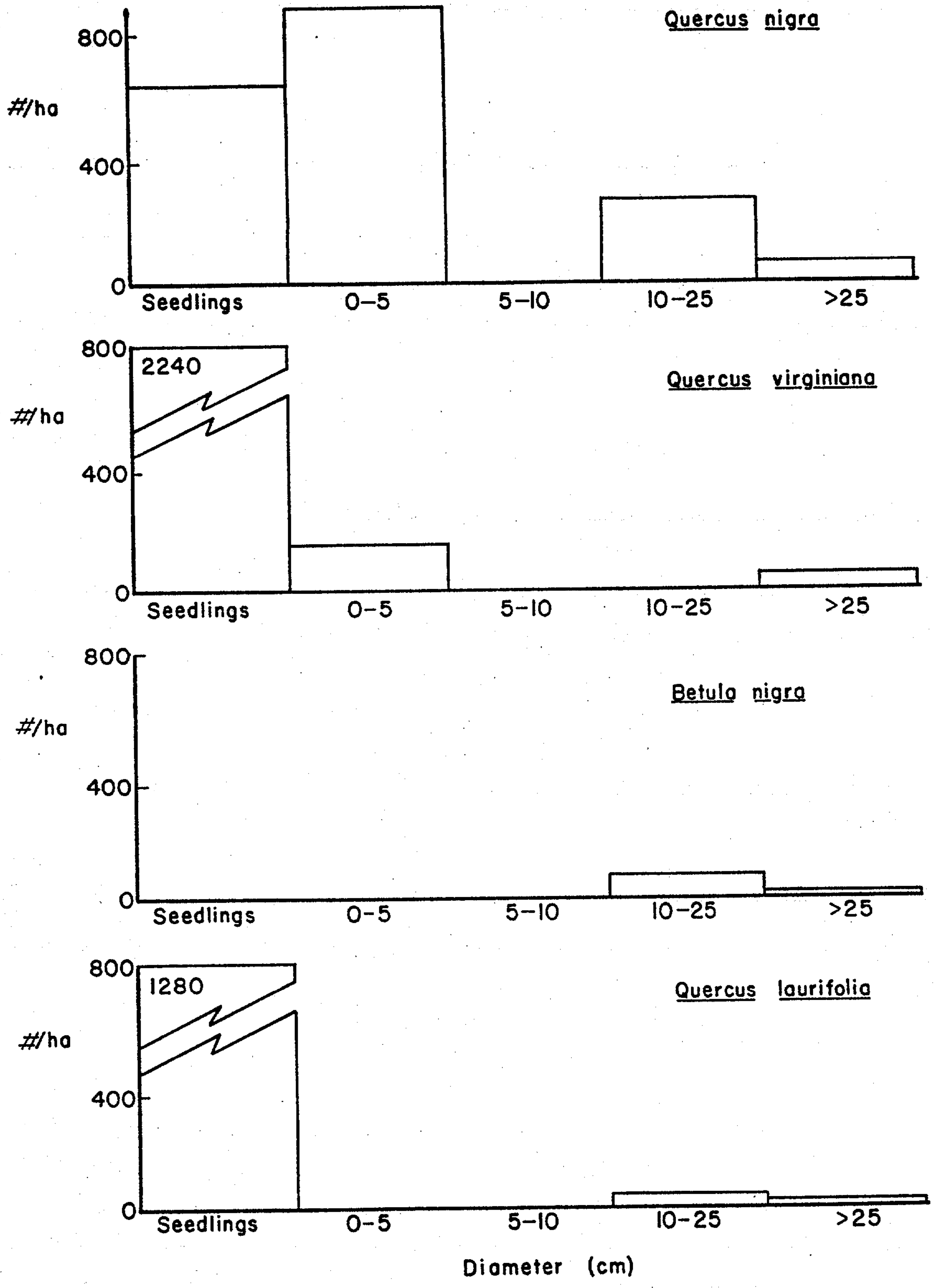


Figure 28. Size classes in a transect at the Swift Creek site.

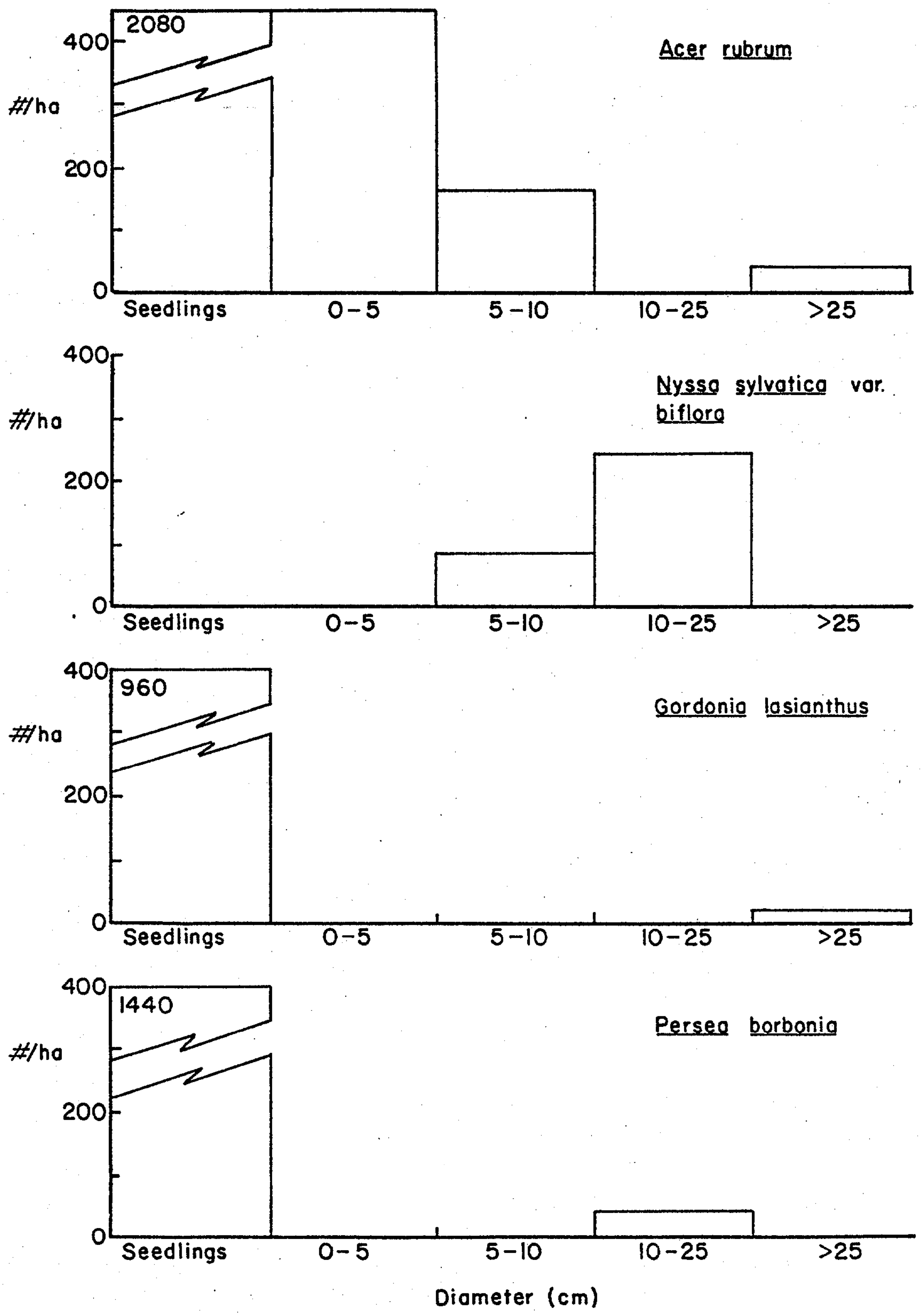


Figure 29. Size classes in a transect at the Swift Creek Swamp site.

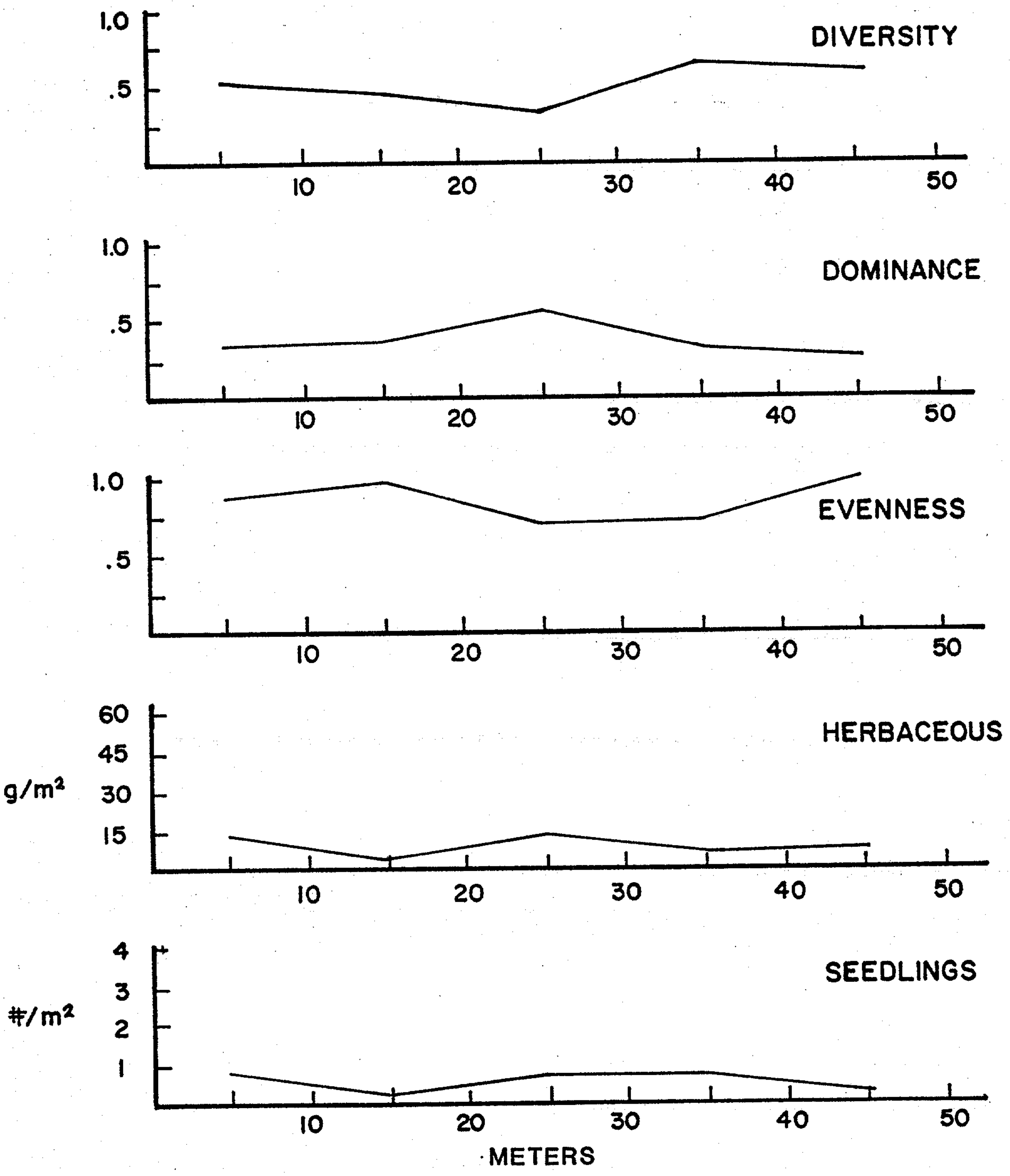


Figure 30. Ecosystem indices, herbaceous material (oven dry weight), and seedlings in a transect at the Alafia River floodplain site.

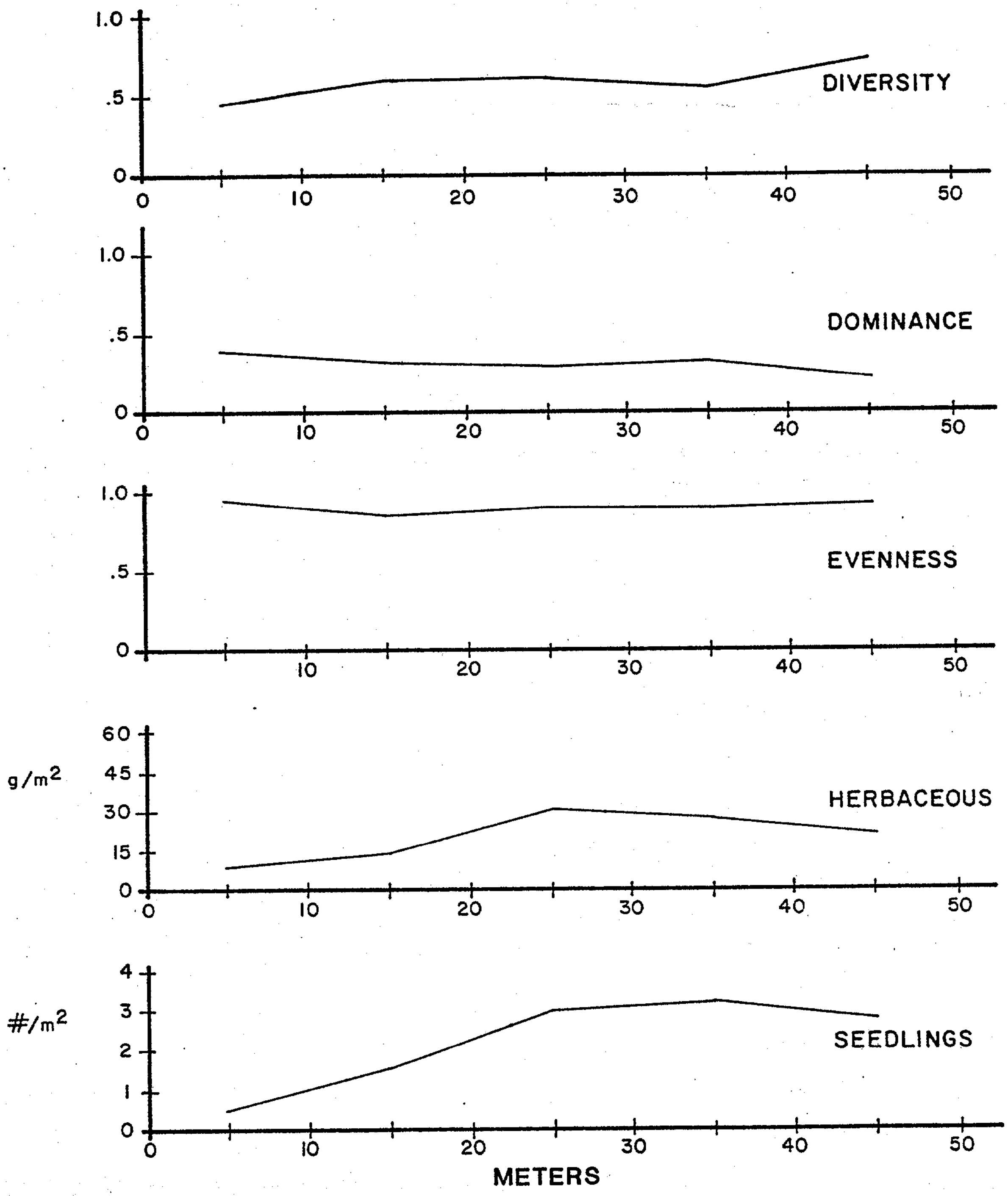


Figure 31. Ecosystem indices, herbaceous material (oven dry weight), and seedlings in a transect at the Mizelle Creek floodplain site.

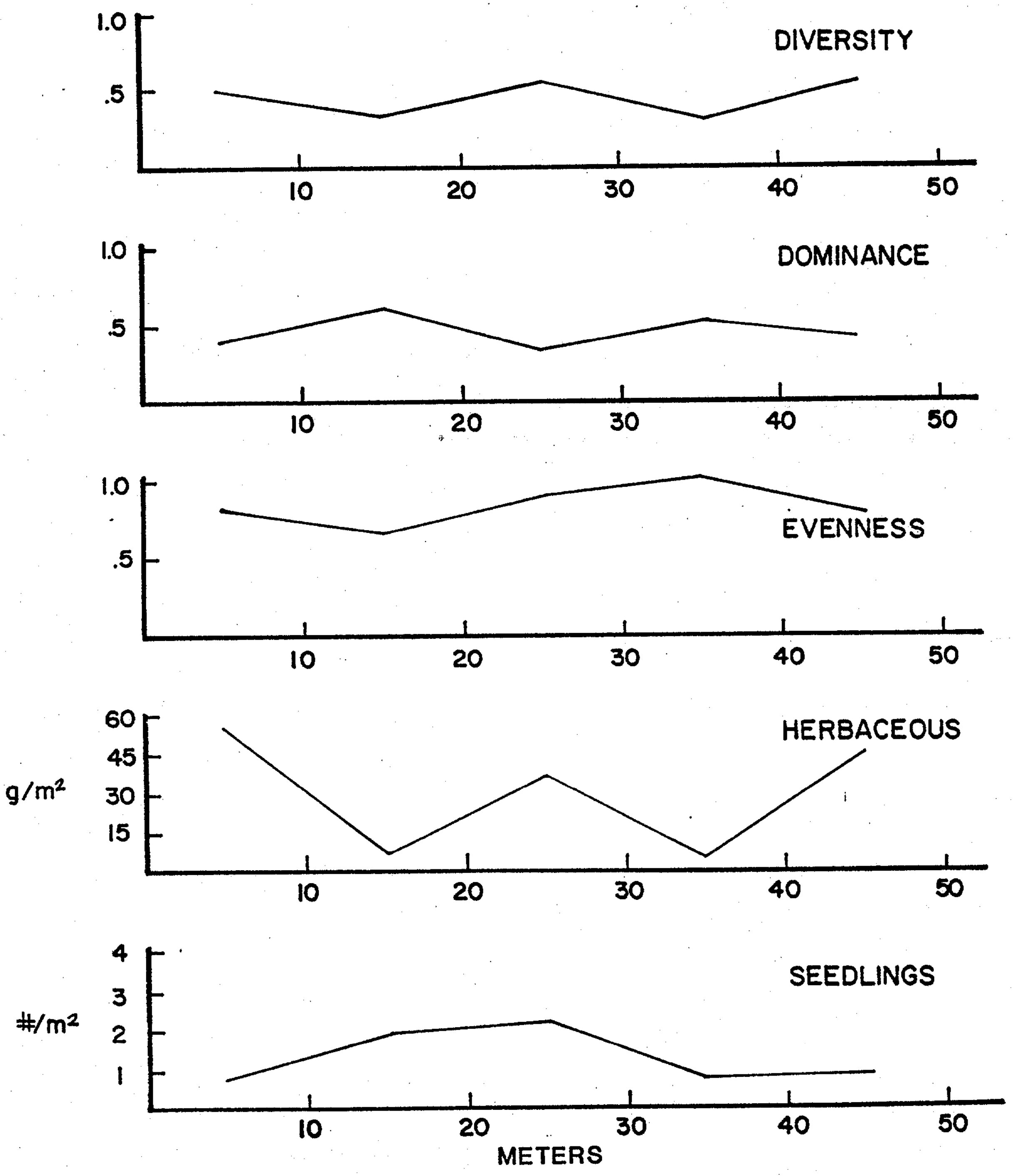


Figure 32. Ecosystem indices, herbaceous material (oven dry weight), and seedlings in a transect at the Sixmile Creek floodplain site.

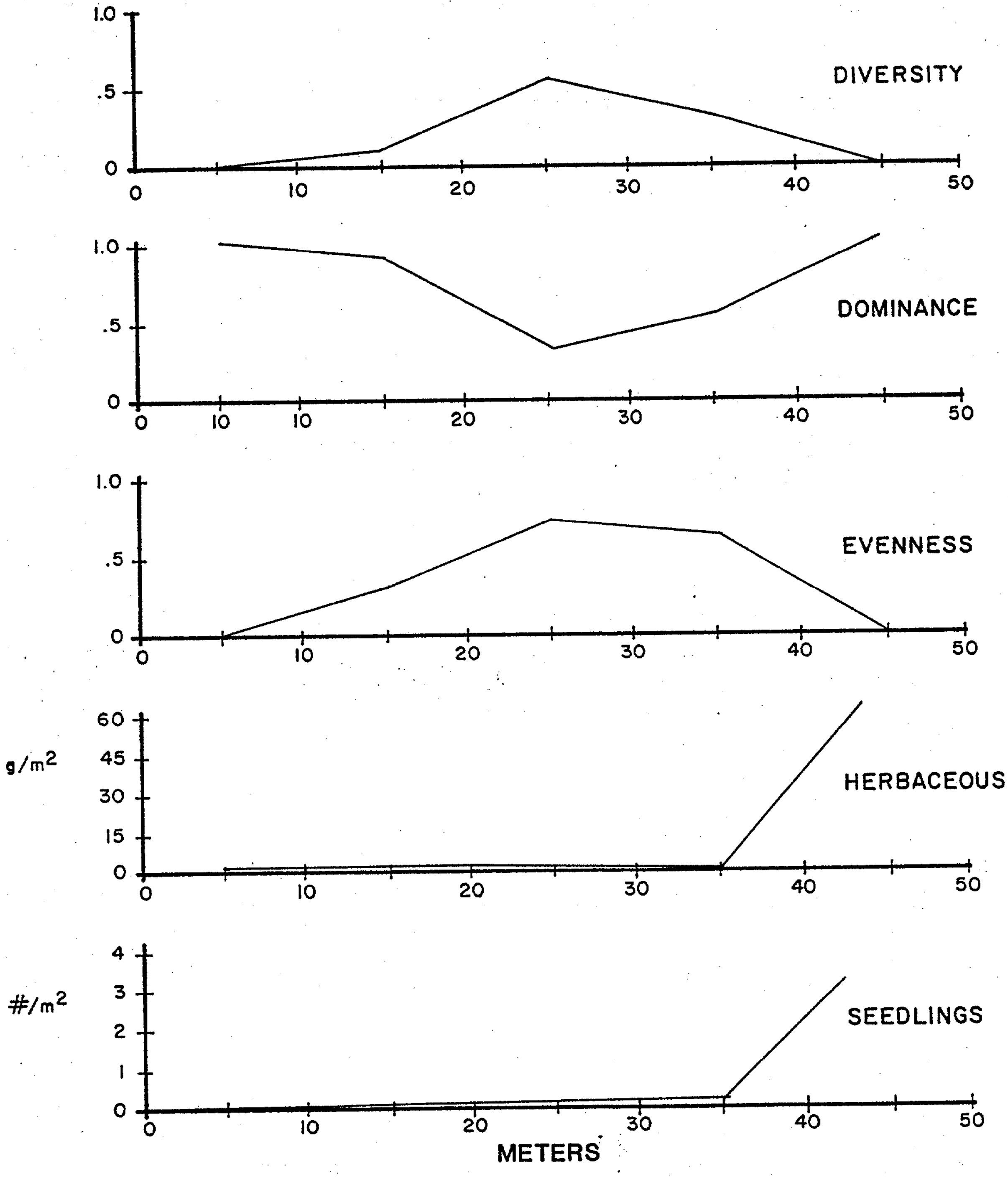


Figure 33. Ecosystem indices, herbaceous material (oven dry weight), and seedlings in a transect at the Clear Springs site, Peace River floodplain.

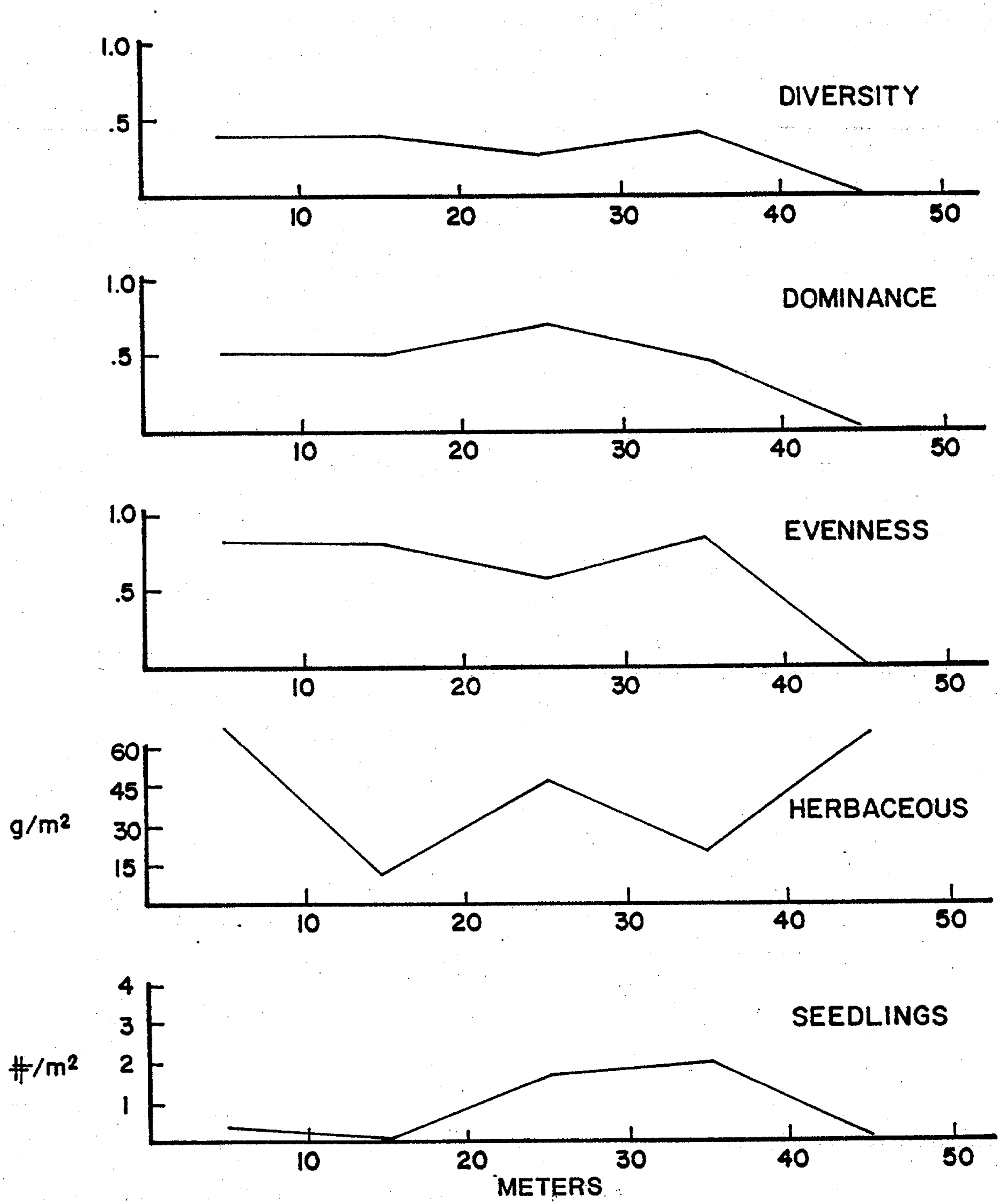


Figure 34. Ecosystem indices, herbaceous material (oven dry weight), and seedlings in a transect at the Fort Meade site, Peace River floodplain.

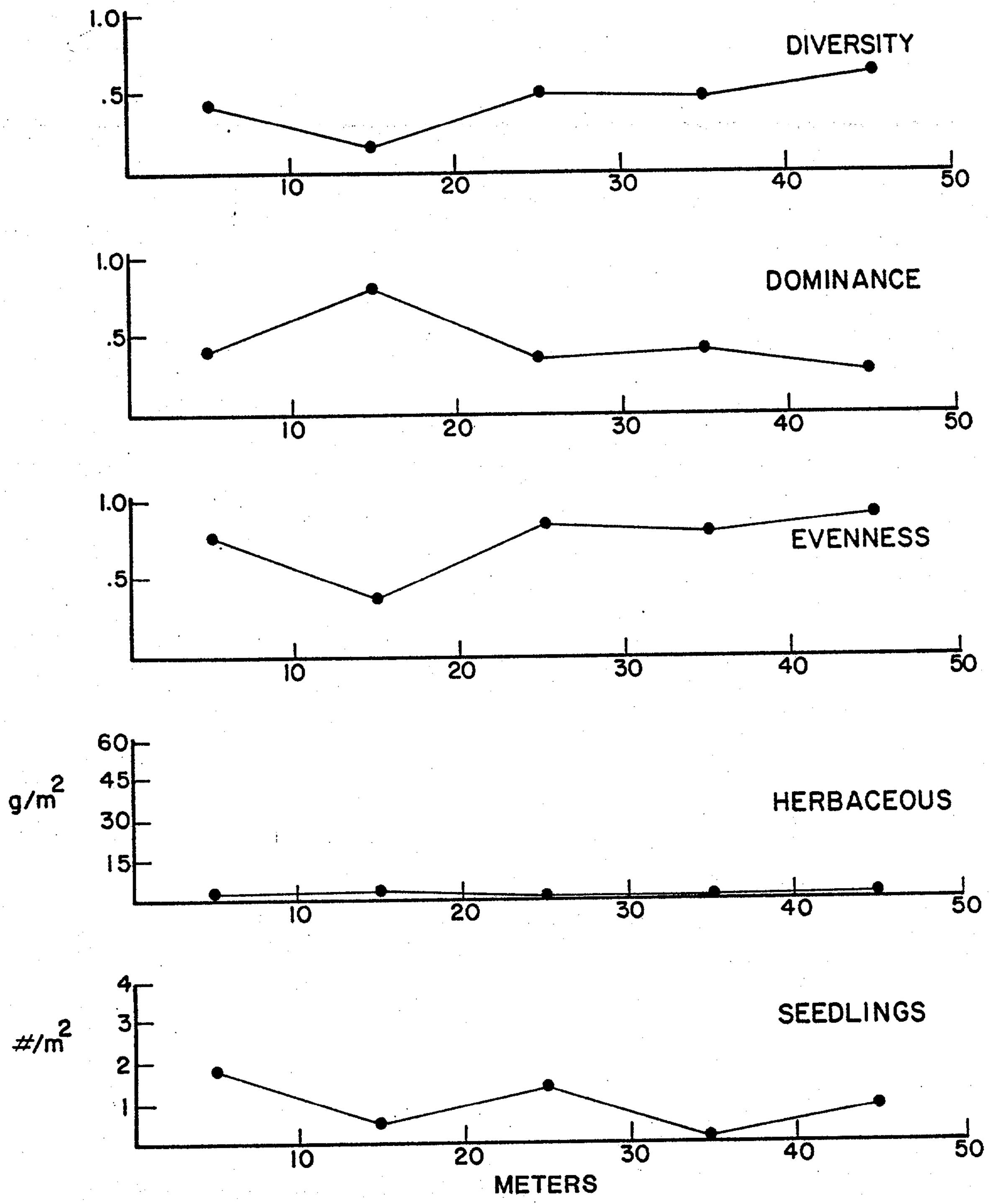


Figure 35. Ecosystem indices, herbaceous material (oven dry weight), and seedlings in a transect at the Swift Creek floodplain site.

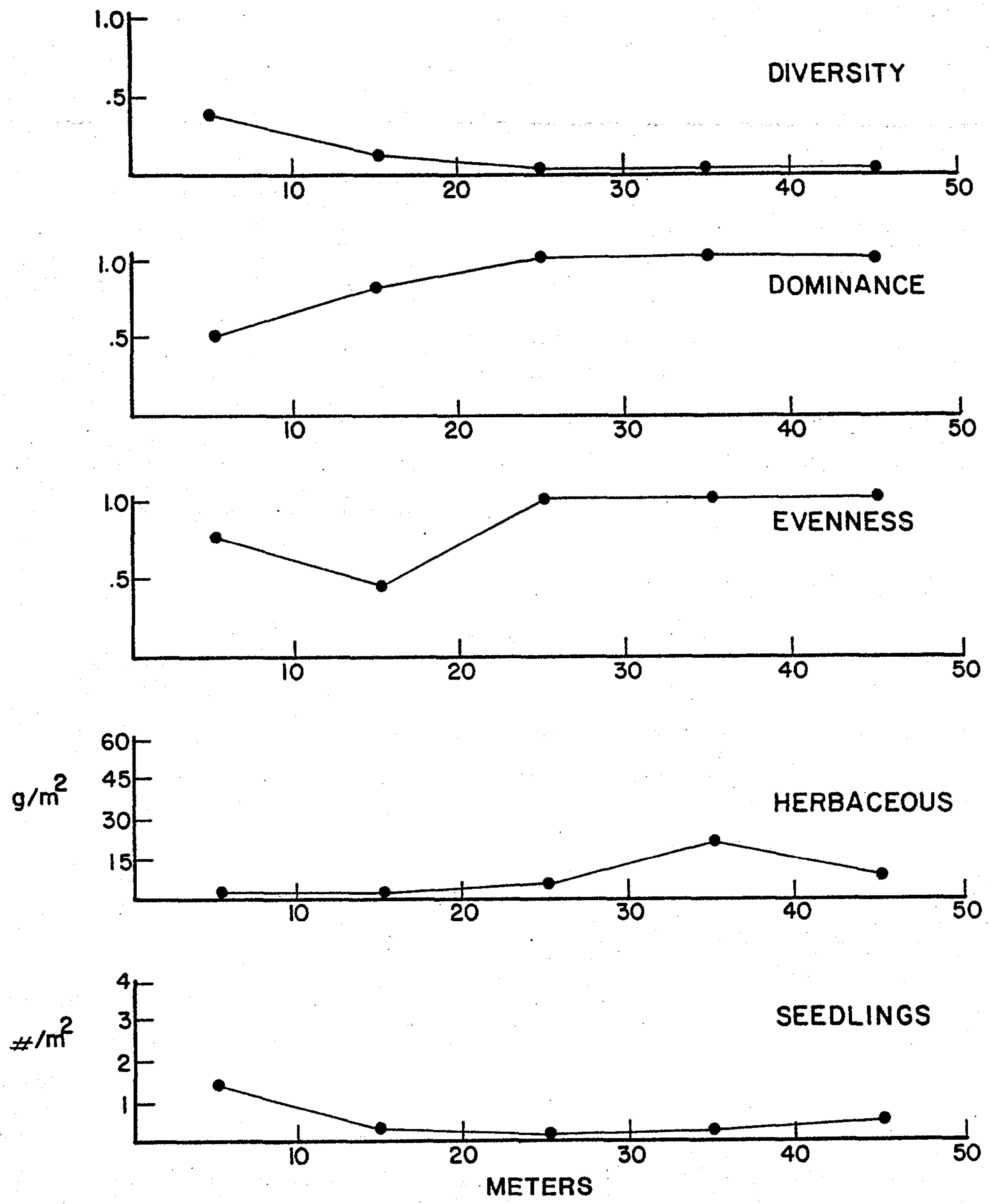


Figure 36. Ecosystem indices, herbaceous material (oven dry weight), and seedlings in a transect at the Swift Creek Swamp site.

reflecting the variable nature of these ecosystems. Weights of herbaceous materials are generally low, often below 15 g/m^2. Seedling densities vary from 0 to $3.5/m^2$.

In Table 5 are listed means of litter standing stock after autumn leaf fall for the seven study sites. Means range from 715 g/m^2 at the Sixmile Creek floodplain to 1405 g/m^2 on the Peace River floodplain at Fort Meade.

In Table 6 are numbers of red, yellow, and green leaves on the ground during the active growing season. Numbers range from $17.6/m^2$ at Mizelle Creek and Swift Creek to $39.6/m^2$ on the Peace River floodplain at Clear Springs.

In Table 7 seedling densities are listed. These vary from $0.37/m^2$ on the Peace River floodplain at Clear Springs to $2.19/m^2$ on the Mizelle Creek floodplain.

Table 8 lists aggregate indices of diversity, dominance, and evenness for trees at the seven study sites. The index of diversity was very large at the Mizelle Creek site (0.99) and the Alafia River site (0.91). Evenness was also greatest at these sites. The lowest diversity value was found at Swift Creek Swamp (0.42). Dominance was greatest at this site also.

In Table 9 are density and basal area values for trees at the study sites. The Alafia River floodplain site had the greatest basal area (48.6 m^2/ha), and the Swift Creek Swamp site had the least. The floodplain forest sites ranged from 21.7 m^2/ha to 48.6 m^2/ha. Density was least at the Swift Creek Swamp site (1100 trees/ha) and the Fort Meade site. Density was greatest at the Clear Springs site (3040 trees/ha).

Discussion

Most of the data obtained on vegetation and for floodplains previously affected by phosphate mining were similar to those in sites not related to phosphate mining. All floodplain sites had even aged populations of dominant trees rather than a stable age distribution. The combination of natural and human disturbance affecting this area in the past apparently generated pulses in the establishment and growth of principal trees. Present even aged distribution may represent general lumbering earlier in the century.

If there is a natural restart associated with old age tree falls and natural catastrophes, there is no evidence of this in the present forests, generally less than 100 years of age.

In all sites there seems to be a dominance of certain size classes of most major tree species. If this proves generally true, it follows that these species are only replacing themselves on rare occasions under a certain set of conditions. The common industry effect of an evened out pattern of river and stream flow (particularly increased low flow) may eliminate the now only rare opportunity for establishment of these dominants. Cypress, for example, may need a lengthy wet period for germination, a drier period for sprouting and

Table 5. Litter standing stock (g/m^2) after autumn leaf fall, oven dry weight.*

Site	Mean	S.E.	n
Alafia River Floodplain	1063.5	113.1	5
Mizelle Creek Floodplain	899.3	79.7	5
Sixmile Creek Floodplain	714.8	96.6	5
Clear Springs, Peace River Floodplain	1343.7	110.2	5
Fort Meade, Peace River Floodplain	1404.8	78.7	5
Swift Creek Floodplain	923.4	94.2	5
Swift Creek Swamp	773.8	40.7	5

*Mean represents mean of 5 samples, S.E. represents standard error, $S/\sqrt{n}$, where S is the standard deviation, n is number of samples.

Table 6. Red, yellow, and green leaf density (number/m^2) on ground during growing season.*

Site	Mean	S.E.	n
Alafia River Floodplain	28.0	5.2	10
Mizelle Creek Floodplain	17.6	2.5	10
Sixmile Creek Floodplain	37.2	5.3	10
Clear Springs, Peace River Floodplain	39.6	10.8	10
Fort Meade, Peace River Floodplain	18.8	2.5	10
Swift Creek Floodplain	17.6	2.7	10
Swift Creek Swamp	24.0	3.9	10

*Mean represents mean of 10 samples, S.E. represents standard error, $S/\sqrt{n}$, where S is the standard deviation, n is number of samples.

Table 7. Seedling density (number/m^2).*

Site	Mean	S.E.	n
Alafia River Floodplain	0.51	0.13	5
Mizelle Creek Floodplain	2.19	0.51	5
Sixmile Creek Floodplain	1.26	0.32	5
Clear Springs, Peace River Floodplain	0.37	0.35	5
Fort Meade, Peace River Floodplain	0.82	0.42	5
Swift Creek Floodplain	0.88	0.30	5
Swift Creek Swamp	0.48	0.25	5

*Mean represents mean of 5 plots, S.E. represents standard error, $S/\sqrt{n}$, where S is the standard deviation, n is number of samples.

Table 8. Indices of diversity, dominance, and evenness for trees at study site.*

Site	Diversity H	Dominance c	Evenness e
Alafia River Floodplain	0.91	0.15	0.85
Mizelle Creek Floodplain	0.99	0.11	0.95
Sixmile Creek Floodplain	0.77	0.22	0.80
Clear Springs, Peace River Floodplain	0.59	0.33	0.70
Fort Meade, Peace River Floodplain	0.71	0.23	0.84
Swift Creek Floodplain	0.72	0.25	0.75
Swift Creek Swamp	0.42	0.47	0.60

*Includes woody species greater than 2 m in height, excludes seedlings. H is Shannon index of diversity (Shannon and Weaver 1949); c is Simpson dominance index (Simpson 1949); e is Pielou index of evenness (Pielou 1979). Formulae are given in Methods.

Table 9. Density and basal area of trees at study site.*

Site	Basal Area m^2/ha	Density trees/ha
Alafia River Floodplain	48.6	2820
Mizelle Creek Floodplain	21.7	1560
Sixmile Creek Floodplain	35.0	1500
Clear Springs, Peace River Floodplain	38.4	3040
Fort Meade, Peace River Floodplain	40.0	1220
Swift Creek Floodplain	29.2	3160
Swift Creek Swamp	16.6	1100

*Includes woody species greater than 2 m in height, excludes seedlings.

establishment, then enough soil moisture to avoid dessication for the next year or two (Anon. 1916; Demaree 1932).

Numbers of red, yellow, and green leaves on the ground during the growing season (Table 6) were as great as or greater than those found by Richardson et al. (1983) in stressed and unstressed floodplain forest plots in north Florida. The lowest values in this study (17.6 leaves/m^2 at Swift Creek and Mizelle Creek) were identical to the highest values found in Richardson's study, possibly indicating some stress in these seven ecosystems. Total seedling density was highly variable in the quadrats sampled in this study. Some sites had high densities of seedlings and large size trees of dominant species; for example, sweet gum at Mizelle Creek (Figure 24) and bald cypress at Fort Meade (Figure 27). This is an indication of pulse regeneration in these ecosystems.

The moderately high indices of diversity found in all the floodplain forest sites are typical of other studies of similar ecosystems (Monk 1966). The lowest values found, 0.59 and 0.71, both on the Peace River floodplain, are not unusually low.

Though hydroperiod (number of days during a year when water stands on a site) was not measured, the sites were qualitatively ranked by relative wetness. The index of diversity was inversely proportional to the wetness of the site. This is in agreement with the general observation that highest species diversities are found in mesic environments, with lower diversities in both hydric and xeric environments. The drier of the sites studied in this project, though within the floodplain, were in a mesic environment most of the year.

5. ECOSYSTEM ORGANIZATION IN PHOSPHATE CLAY SETTLING PONDS

Betty Rushton

Introduction

Where patterns of bare land are formed through geologic processes or human actions, ecological systems self-organize and adapt to the new situation. Phosphate strip mining offers an opportunity to study the processes of primary succession on a variety of newly exposed land surfaces. If the major factors controlling and limiting desirable vegetation can be understood, guidelines may be developed for more rapid reclamation.

This project considers the course of succession taking place on phosphate clay settling ponds in central Florida. These sites are rapidly colonized by a willow shrub community; however, uncertainty exists as to whether succession to more mature types of wetlands will occur.

Maximum Power as a Self-Design Principle

Maximum power as a self-design principle (Odum 1967, 1971, 1983; Odum and Odum 1981) is useful for analyzing the processes and reactions taking place in the new situation of clay settling ponds. The maximum-power principle Is defined as "Survival and competitive selection of systems which transform the most energy into useful work for themselves and their surrounding systems" (Odum and Odum 1981:291). It suggests survival of those combinations of components that contribute most to the system, thus making their habitat more favorable for the well being of each. In forest succession small initial storages increase as energy flows through the system, thus pioneer species prepare the way for more complex structures. System development may be prevented or retarded where ecosystem choices are limited, where stress requires the slow evolution of new components, or where inflowing energy sources are inadequate.

The theory of maximum power suggests several principles that may improve our understanding of reclamation alternatives. Landscape designs develop to match the available energy input. Rainfall, drainage, erosion, and differential settling feed back useful work to land structure creating a more diverse landscape mosaic. A variety of plants and animals adapt to partition and utilize the resources of the new landform. The self-organizational process is accelerated when there are ample choices for selection. As systems become more diverse, longer, more complex food webs and mineral cycles provide reward loops for plants. Those systems prevail that have a positive feedback loop from the next larger system. Understanding these principles and assisting nature may enhance self-design and manage succession.

When the principles of maximum power are applied to clay settling ponds, many barriers to succession are observed while other conditions may provide an energy subsidy. The various factors involved are summarized in the energy diagram presented in Figure 37. Clay ponds are elevated and isolated from the surrounding landscape by an Impoundment dike. The outside energy sources available are the sun, wind, and rain falling directly within their boundaries; however, the rain continues to be drained away to dry the clays. Large seeds characteristic of more mature species, microbes necessary for nutrient recycling, and other inputs normally available to disturbed grounds from the next larger system are separated by the impoundment dike. In fact, sites may be far removed from any undisturbed vegetation. Clays are phosphorus rich, have good water holding capacities, slow infiltration rates, and may provide a suitable substrate for forest wetland succession.

During the filling stage, when the ponds receive the subsidy of water and clay slurry from the industry, they are productive wildlife habitats (Zellar-Williams and Conservation Consultants 1980; King et al. 1980). Once the water is drained, they go through a depauperate plant and animal stage (Schnoes and Humphrey 1980; Maehr 1980). Beyond 25-30 years, they have often been covered with sand tailings and reclaimed for pastures. What they might become if productive feedback of seeds, soil structure, shade, etc. were established sooner is only speculation. This study was made to gain insight about the future course of succession in slime pond sites as follows:

1. Understanding the principles involved in adaptation, succession, and self-organization to the new situation imposed by clay settling ponds;
2. Analyzing the patterns adopted by nature to see if these same processes can be employed or enhanced for land reclamation alternatives;
3. Determining the possibility for clay settling ponds to be managed so as to constitute a new permanent wetland, one that meets the need for replacing wetlands with wetlands after mining; and
4. Comparing the willow system on clay settling ponds during the 30-40-year period of its dominance with other willow systems to see their similarities and differences.

Clay Settling Ponds

Phosphorus, one of three, primary plant nutrients contained in chemical fertilizers, is believed essential to modern agriculture. In response to this demand, United States phosphate production has risen dramatically in the last few decades. Of all the phosphate mined in this country since 1870, about 51% has occurred in the last 12 years (U.S. General Accounting Office 1979). The 11 phosphate mining companies now operating 16 plants in Florida produce over 75% of the domestic and over 25% of the world's supply (U.S. Bureau of Mines 1975).

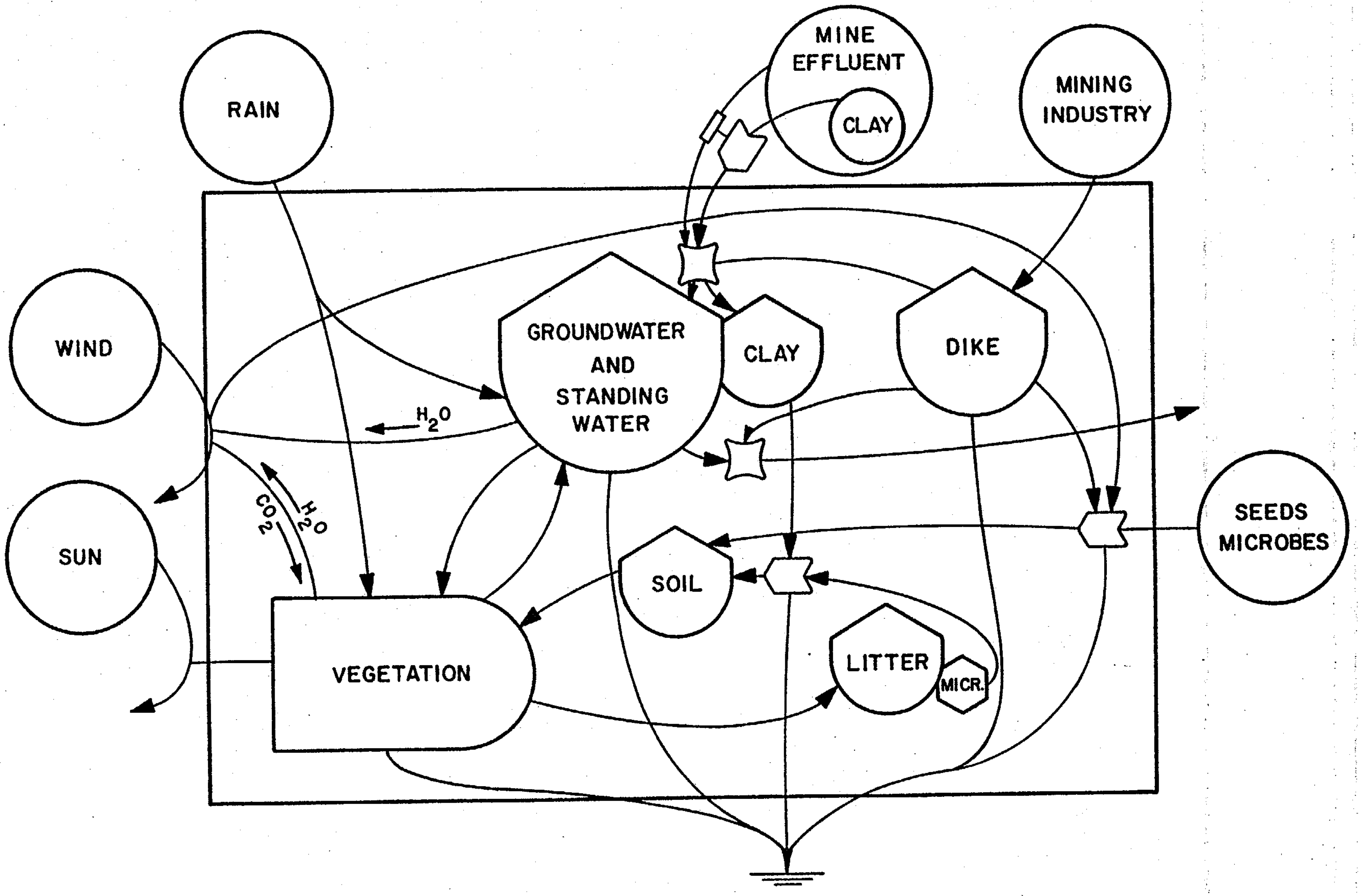


Figure 37. Energy diagram of a clay settling pond.

The Florida deposits are mined by the open pit method. where the overburden is moved to one side by dragline before the matrix is removed and sent by slurry to the beneficiation plant. There it is separated into the phosphate product, sand tailings, and phosphatic clay slimes. Although the clays represent only one-third of the matrix by weight, they expand to many times their original volume because they retain a high percentage of water. A typical settling pond is about 12 meters below ground and 10 meters above ground, but may reach heights or depths as great as 18 meters (Lawver 1981).

Clays are transported from the beneficiation plant to the clay settling pond in a slurry at 2-5% solids where they are allowed to settle and the water is decanted for reuse. After several months of consolidation under their own weight they reach approximately 15% solids and after several years about 25% (Miller 1980). Once they reach 30% solids the settling ponds are usually back to original ground elevation. The clay mineral attapulgite is responsible for the poor settling characteristics of clay slimes (Lamont et al. 1975). Since attapulgite occurs in variable quantities at different locations, clay dewatering is also highly variable. The colloidal nature of the slimes results in low weight bearing strength; which precludes the future use of clay ponds for industrial and residential development. Although there has been considerable research on methods to accelerate dewatering (Bromwell et al. 1978; Boody and Barwood 1982) none appear to be feasible at this time.

Clay settling ponds will occupy 60-70% of the mined land in the central Florida phosphate district (Wang et al. 1974). They require a period of 10-20 years for a crust to form before reclamation attempts are made. Today common practice caps them with sand tailings or overburden and converts them to pastureland. Acceleration of the rate of mining, increased public awareness of the intrinsic value of productive land, and new state and local laws have focused attention on reclamation alternatives.

Previous Studies on Succession in Slime Ponds

A few studies have evaluated ecological succession in clay settling ponds. Some of their conclusions are summarized here. Reclamation on slime ponds presents a difficult problem (Farmer and Blue 1968) and a major deterrent to effective land recovery in the phosphate mining district (Lamont et al. 1975). Present regulation requires the draining of these areas with the consequent establishment of a terrestrial community (Breedlove and Adams 1977). Reestablishment of natural communities may be more logical than the present agronomic and replanting approach (Schnoes and Humphrey 1980). Natural succession may be a viable revegetation and reclamation alternative and perhaps can be accelerated (Kangas 1981; Butner and Best 1981). Water management practices might provide valuable wildlife habitats or recreational area on unreclaimed clay settling ponds (King et al. 1980).

Succession on clay waste areas was described as slow, resulting in senescent forests and a depauperate animal community (Schnoes and Humphrey 1980). Bird species diversity, species number, and density show a downward trend from unmined pine flatwoods through early and late successional settling ponds to reclaimed habitats (Maehr 1980). The investigators agreed on the early course of succession. Vegetation developed rapidly with islands of cattail (Typha latifolia) established in ponds still in the filling stage. Once the surface begins to dry, there was an invasion of woody species dominated by willow (Salix caroliniana) usually in association with groundsel-tree (Baccharis halimifolia) and wax myrtle (Myrica cerifera). The only site studied greater than 20 years old recorded a few hardwood species occurring along with vines and senescent willows (Zellar-Williams and Conservation Consultants 1980). No attempts have been made to reclaim these sites to forested wetlands until the last year or two when some mining companies have planted cypress and hardwoods on the exposed clay as part of the overall reclamation of clay settling ponds.

Successional Concepts

Although considerable debate surrounds current succession theory, an analysis of some of the concepts provides insight into possible patterns and processes of primary succession taking place on clay settling ponds. Classical succession theory was recently restated by E. P. Odum (1969, 1971) as an orderly, reasonably directional, predictable process that results in modification of the physical environment by the community and culminates in a stabilized ecosystem. This pattern produces an accumulation of organic matter, a decrease in herbaceous vegetation, an increase in taller woody species, reduced light penetration, and possibly an increase in species diversity.

One of the first to formalize succession theory was Clement (1936). He proposed all communities in a region converged to the same climax community; which was determined solely by the prevailing climate. Communities other than climatic climax were considered temporary. He emphasized communities as closely associated discrete units with sharp boundaries. For Florida the climatic climax is the southern hardwood forest with bottomland hardwood swamp the climax, vegetation for hydrarch succession (Laessle 1942). Mixed swamps and bayheads are climax on areas that are seasonally flooded while cypress-gum ponds are considered subclimax communities (Monk 1966) on more frequently flooded sites.

Gleason (1962) emphasized succession as determined by individuals who were found together because their seeds arrived and survived the prevailing environmental conditions. They were not necessarily directed toward the same monoclimax, and climatically identical sites may be occupied by entirely different associations. Species were organized along an environmental gradient.

Tansley (1935) introduced the concept of ecosystem and vegetation in the landscape as a mosaic controlled by environmental factors of moisture, nutrients, topography, perturbations, and animal activity.

Egler (1954) proposed two models for succession. “Relay floristics” restates the view that vegetation follows a replacement process, but he further observed that established vegetation resists invasion from the outside. His concept of “initial floristics” emphasized, at least in secondary succession, the presence of seeds and seedlings of later successional species from the start. Cooper (1923) demonstrated climax species were present in the first years even in primary succession on glacial till. Niering and Goodwin (1974) found a closed canopy of shrubs has prevented the invasion of nearby tree species for at least 45 years.

Horn (1971, 1974) proposed competition as the major force controlling succession, the early species producing an environment in which later species are competitively superior. Drury and Nesbit (1973) suggested the establishment of more mature ecosystems may be delayed by a delay in immigration and by physical stress. Whittaker and Woodwell (1967) found species occupied unique ranges with peaks of abundance associated with environmental conditions.

Connell and Slatyer (1977) presented three alternative models for succession. Model 1 assumes that only certain, "early successional" species are able to colonize the site in the conditions that occur immediately following the perturbation. Models 2 and 3 assume that any arriving species, including those that usually appear later, may be able to colonize.

Margalef (1963) proposed the idea that mature ecosystems with complex structure, rich in information, need a lower amount of energy for maintaining such structure and that in adjacent systems there will be a flow of energy toward the more mature system and a boundary shift from the more mature system into the less mature system.

H.T. Odum (1983) accentuates the total system in succession including cleared ground, light, water, nutrients, Immigration of seeds, living animals, and existing storages. The process of organizing new programs of succession involves offering choices, followed by selection by the next larger system for those patterns that feed back work toward maximizing power input and useful transformation.

Willows as a Pioneer Stage

Worldwide studies of succession describe willows as the first vegetation to cover and protect wet ground laid bare by receding glaciers, by burned over forests, and by earthquakes, floods, war devastation, gravel pits, and mine wastes (Smith et al. 1978). Willows are dispersed by small windblown seeds or by suckers, sprouts, and root shoots (Rawson 1974). In most species the flowers are insect pollinated and have small seeds with short viability (3-4 days), nearly no food reserves, and bear long hairs for aid in wind dispersal (Dorn 1976).

Willows are among the first pioneer species; seedlings occur only in open areas directly exposed to the sun (Hefley 1937). Willows do not compete well with other tree species and are intolerant of shade. Therefore mature stands are usually very open (Lamb 1915).

Willows grow best in deep, rich, moist alluvial bottomlands, but survive moderately well on heavy clay soils if there is sufficient moisture. Otherwise they survive but grow slowly, become stag-headed, and seldom attain tree stature (Lamb 1915). They are generally highly tolerant of flooding and are able to carry on root functions where free oxygen is very limited or absent (McLeod and McPherson 1973). in a study that compared 17 bottomland species with their tolerance to saturated soil conditions along the Mississippi River, Hosner and Boyce (1962) found willow seedlings along with green ash, pumpkin ash, and water tupelo to be the most tolerant species; in fact, they grew better under saturated conditions. Willows are reported to be very susceptible to drought (Albertson and Weaver 1945; Putnam et al. 1951) and their extensive shallow root system needs an abundant and continuous supply of moisture during the growing season (Fowells 1965).

In central and southern Florida, the native species of willow (*Salix, caroliniana)* is considered a successional or pioneer species. Laessle (1942) indicated it was scattered about in a *Spartina* marsh occupying the higher portions with groundsel-tree and wax myrtle. He further observed that some of the larger of these shrubby areas contained swamp ash and red maple and were well on their way toward the next stage of succession, the swamp. When fire is absent, willow was described as occupying an estimated time scale from 12 to 25 years in the succession of a deep water marsh to a cypress strand forest, while wax myrtle dominated the shrub stage from 5 to 15 years in the succession of a shallow water marsh to hammock (Wharton et al. 1977).

Most descriptions of *S. caroliniana* were made from vegetation studies done in the Everglades. Tomlinson (1980) described it as a small tree often much branched at the base. He noted it is deciduous, the leaves fall mainly in September, and remain leafless for about 2 months with regrowth and flowering resuming in December. Craighead (1971) described willow heads as forming around large solution holes, basins,. or sloughs that hold water much of the year. They were usually deep, 1 to 3 meters, where roots can reach water during the driest periods. They were found in association with pond apple, red bay, sweet bay, wax myrtle, red maple, cypress, buttonbush, coco plum, holly, buttonwood, and poisonwood. Alexander and Crook (1974) concluded that where willows did not produce a closed canopy, maples, water oaks, and cabbage palms together with young cypress form the secondary forest. Gunderson (1977) stated willow forests were maintained by frequent fires, but changed into a cypress-mixed hardwood forest if fire was excluded. In *S. nigra,* a closely related species, it was noted hot fires kill entire stands while slow, light fires can seriously wound willows, allowing wood rotting fungi to enter (Fowells 1965).

Wetland Communities that follow Willows

The communities that would be expected to follow willows on disturbed soils depend on hydroperiod. Cypress and/or gums grow in the lowest and wettest sites. They have been described by Wharton et al. (1977) as occupying depressions underlain by clays as thick as 30 meters. The clay slows infiltration rates keeping water levels above land surface. The pH is low (4 to 5) and since water comes entirely from rainfall in the watershed, nutrients are limited but losses are few. The rate of litter buildup is usually not very rapid. Fires and natural decomposition prevent the domes from filling up with organic matter. if detritus is accumulated, succession may move toward bayheads or mixed hardwood swamps (Monk 1966). The dominant tree species are *Taxodium distichum* var. *nutans* and *Nyssa sylvatica* var. *biflora*.

Bayheads occur on upland situations with little inward drainage, developing soils high in organic matter. They are peat forming, the acidity is high (pH 3.6 to 4.3), and most of the nutrients are retained in the peat (Monk 1966). Dominant tree species include the evergreen bays *Magnolia virginiana, Persea palustris*, and *Gordonia lasianthus*. Bay swamps occur as perched basins in sandy terrain where there is a clay layer to keep them constantly wet by seepage and where the water table does not fluctuate widely. They may be intermediate in fertility between low nutrient cypress ponds and the richer bottomland forests (Wharton et al. 1977).

Where hydroperiod of flooding is short, bottomland hardwood forests develop with a wide range of tree species adapted to a variety of environmental conditions. They would be expected to colonize better drained sites with moist soils and brief occasional flooding. Common species include red maple (*Acer rubrum*) water oak (*Quercus nigra*), ash (*Fraxinus caroliniana*), Dahoon holly (Ilex cassine), sweetgum (*Liquidambar styraciflua*), cabbage palm (*Sabal palmetto*), elm (*Ulmus americana*), laurel oak (*Quercus laurifolia*), and hackberry (Celtis *laevigata*) . Hydric hammocks grow best on moist soil maintained by rainfall above an Impermeable clay layer (Wharton et al. 1977).

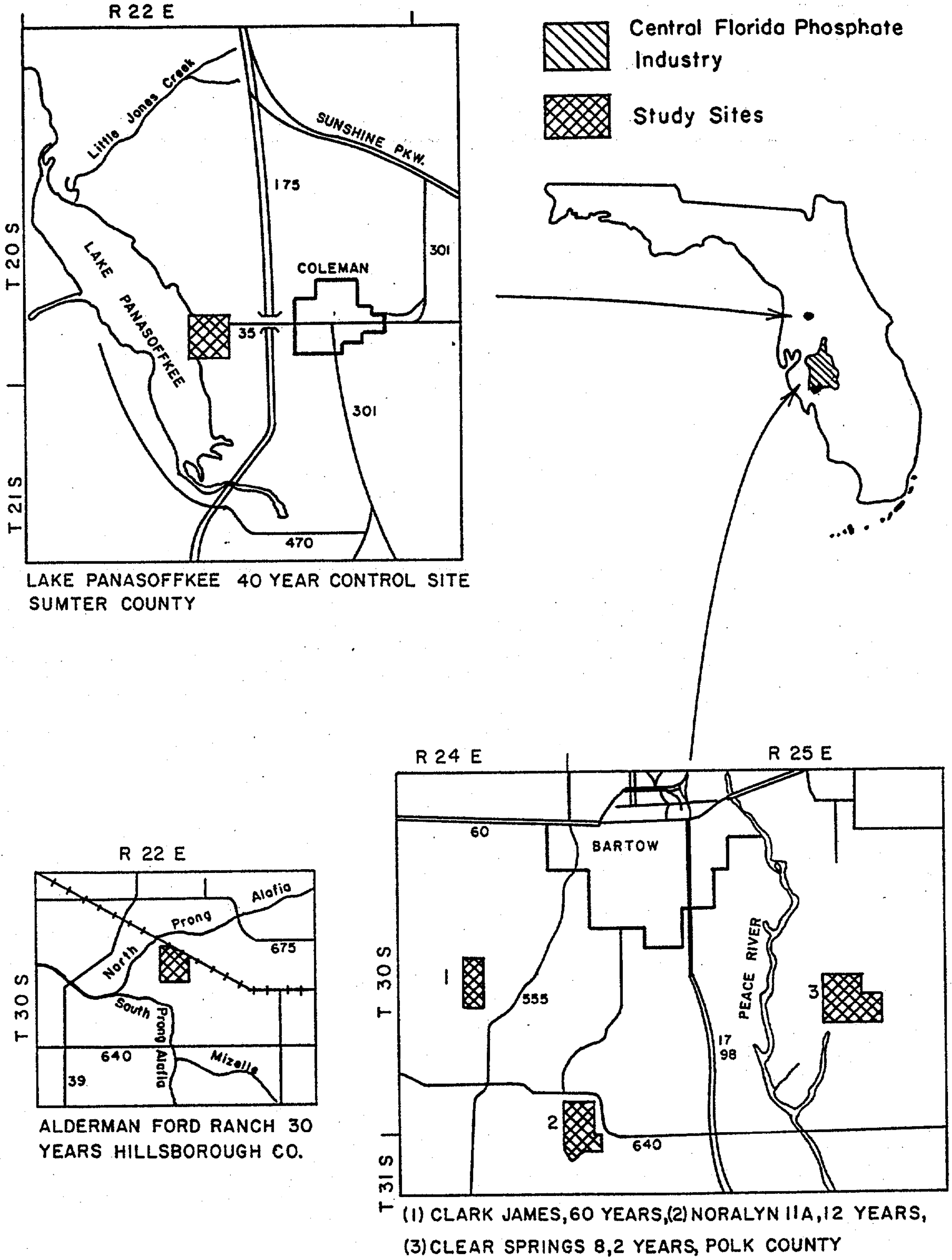
Description of Study Sites

Study site locations are shown in Figure 38. Summary information is found in Table 10. In order to evaluate natural succession, a time series of clay settling ponds was selected where no alteration or reclamation had been done. Sites were chosen to represent clay settling ponds that have received little additional use for 2 years, 12 years, 30 years, and 60 years. In addition, a 40-year-old control site was studied. The age of the sites represents the time since they were decommissioned from active use to December 1982, when sampling of the vegetation was completed. The ages were estimated from mining records and aerial photographs.

Clay settling ponds create a drainage system similar to a small watershed with shallow relief. Clays are transported by pipe in a slurry from 2% to 5% solids. The larger particles drop out near the inflow pipe. A delta is often formed, which supports vegetation. even while the pond is in active use. Definite dendritic channels are cut as water flows from higher to lower elevations. Low pockets are scattered throughout. On the downslope side a lake with islands persists for many years after deactivation, which is extremely attractive to waterfowl. Water continues to be decanted and reused from these ponds until they dry up.

in order to compare sites it was decided to select transects near the upslope inflow side and to follow the contours downgrade. Transects were begun when the dominant upslope, typical willow community was recognized and, where possible, included a gradient between two vegetation types.

Figures 39 through 43 are sketches of the vegetation and the location of the transects at the sites. The four mined sites are arranged from youngest to oldest with the control site last. Locations were designated using the Township, Range, Section grid system found on the United States Geological Survey (USGS) map and the Florida Department of Transportation (FDOT) maps.



LAKE PANASOFFKEE 40 YEAR CONTROL SITE
SUMTER COUNTY

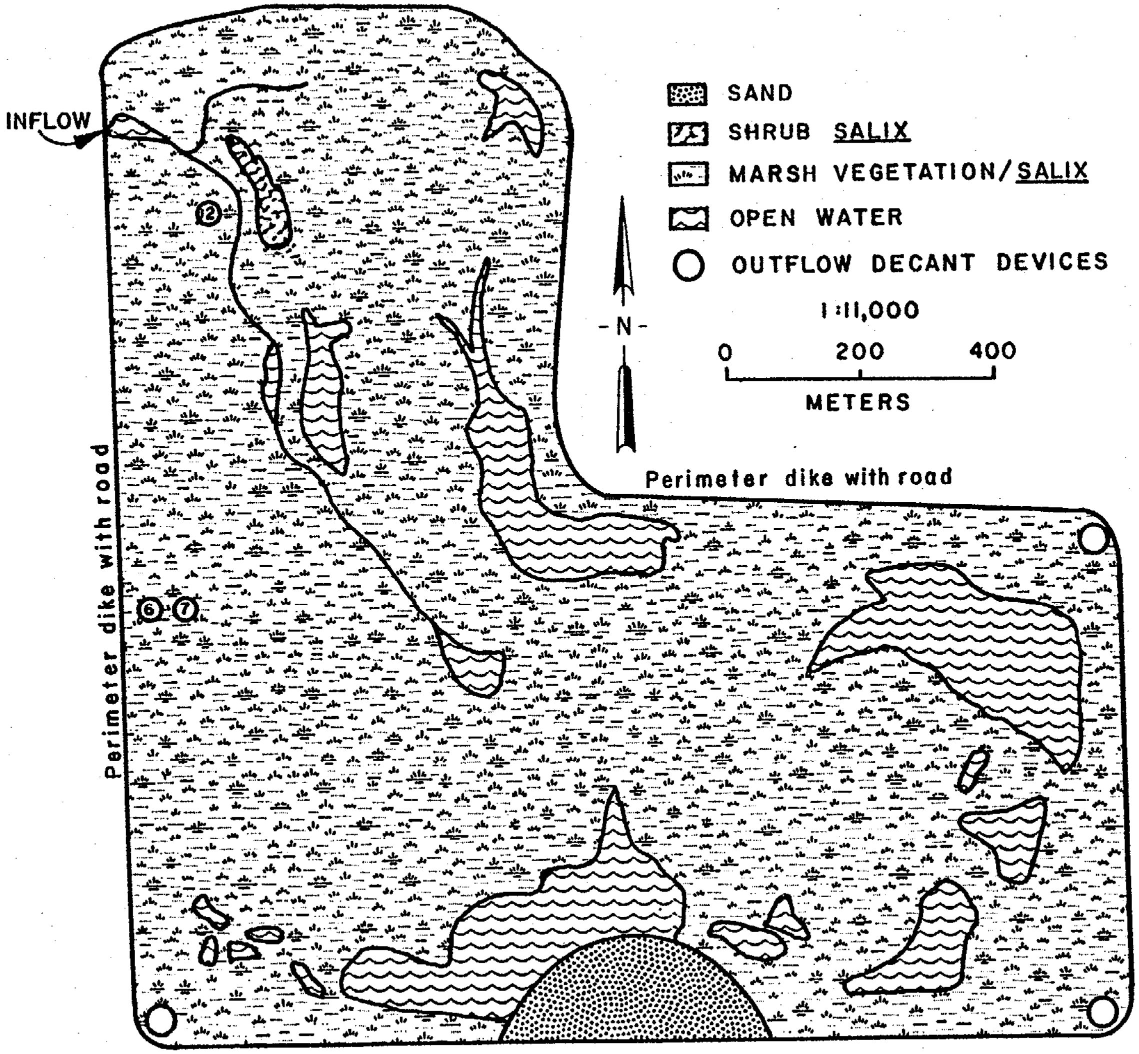
ALDERMAN FORD RANCH 30 YEARS HILLSBOROUGH CO.

(1) CLARK JAMES, 60 YEARS, (2) NORALYN IIA, 12 YEARS, (3) CLEAR SPRINGS 8, 2 YEARS, POLK COUNTY

Figure 38. Location of the study sites. The control site represents the time since it was a marsh. The four clay settling ponds are dated from the time they were decommissioned from active use until December 1982 when vegetation sampling was completed.

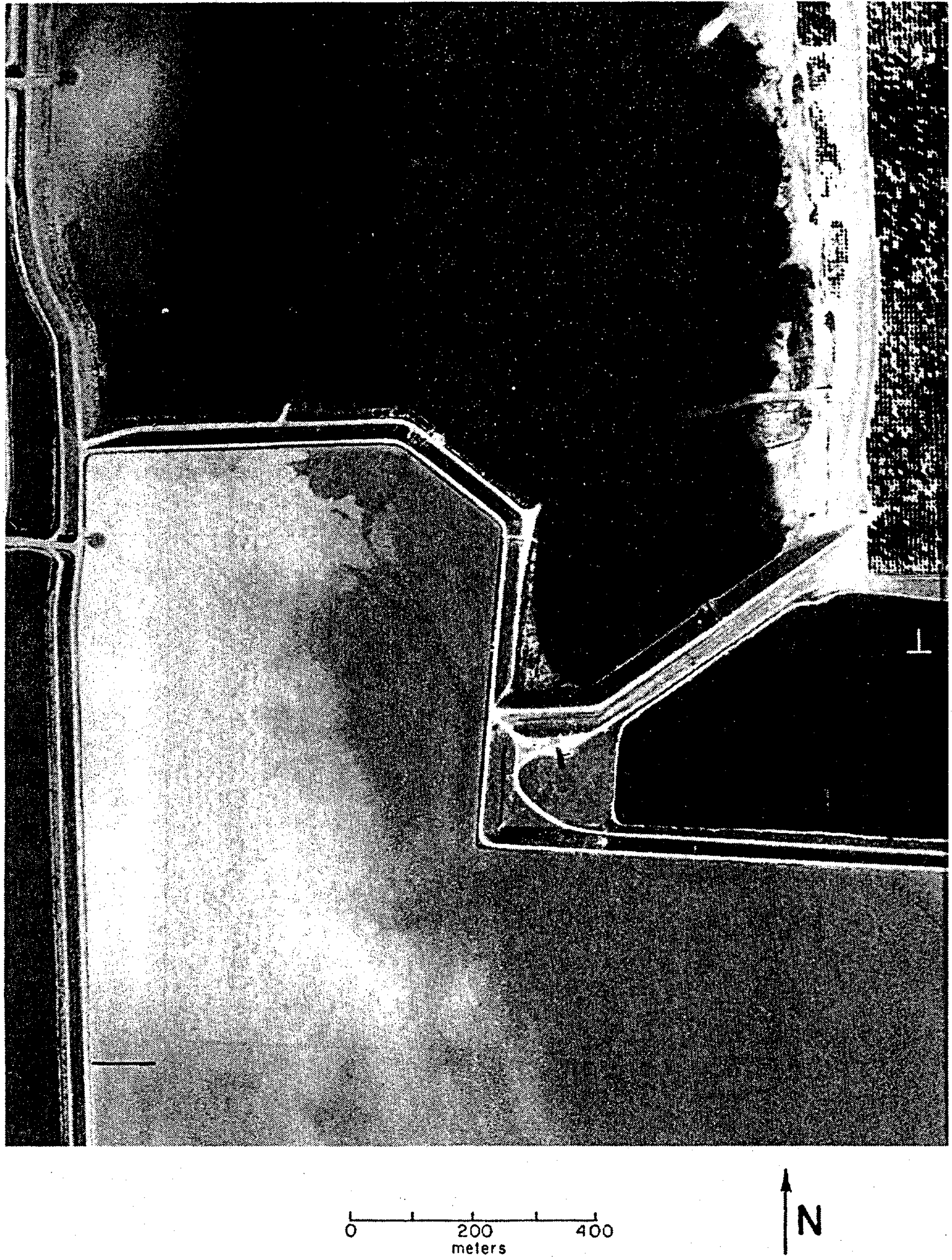
Table 10. Summary information of study sites (see Figure 38).

Name	Years Since Decommissioned	Size, ha	Transect Numbers	Dominant Vegetation	Soil
Clear Springs-8	2	133	6,7	Marsh	clay
Noralyn-11A	12	110	14,15	Willow shrub	clay
Alderman Ford Ranch	30	70	16,17,18	Emerging hardwoods	clay
Clark James	60	21	1,2,3,4,5	Willow shrub	clay
Control site Lake Panasoffkee	40	*	8,9	Willow trees	muck



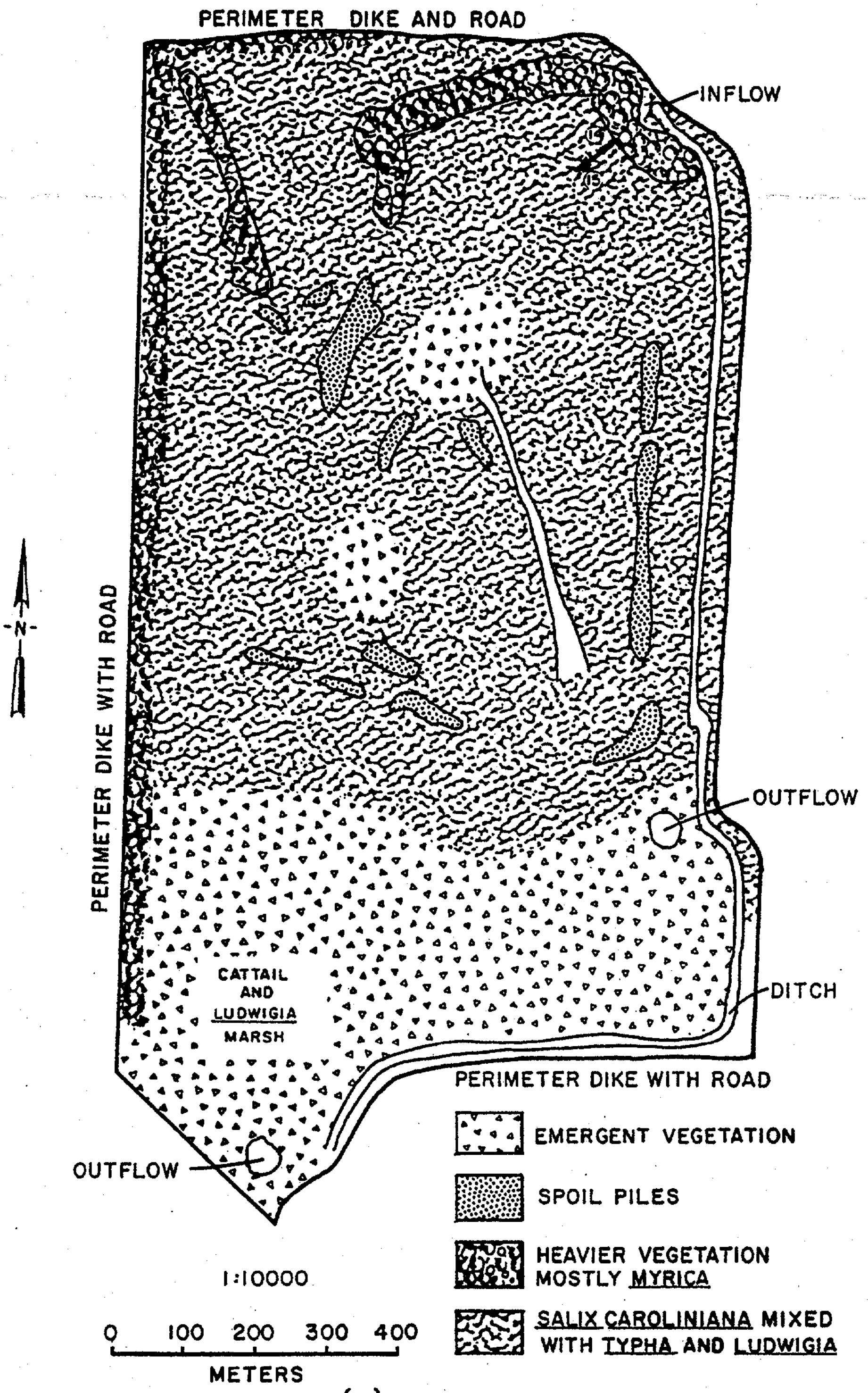
(a)

Figure 39. Clear Springs-8, 2-year-old clay settling pond. a) vegetation map, b) aerial photograph (1979), courtesy of Agricultural Stabilization and Conservation Service, lower pond shown during the filling stage; upper pond in an earlier stage of use.



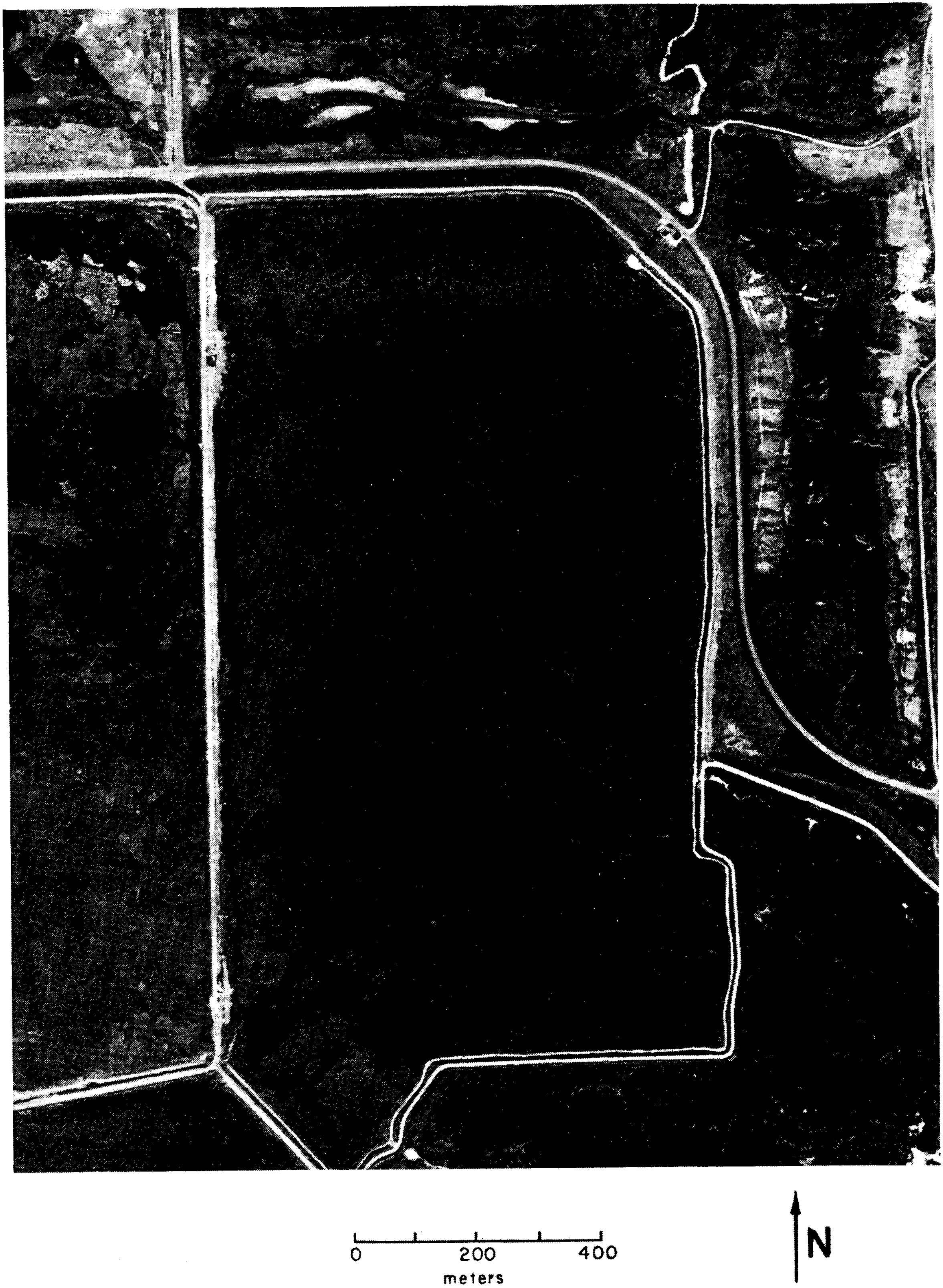
(b)

Figure 39. (continued)



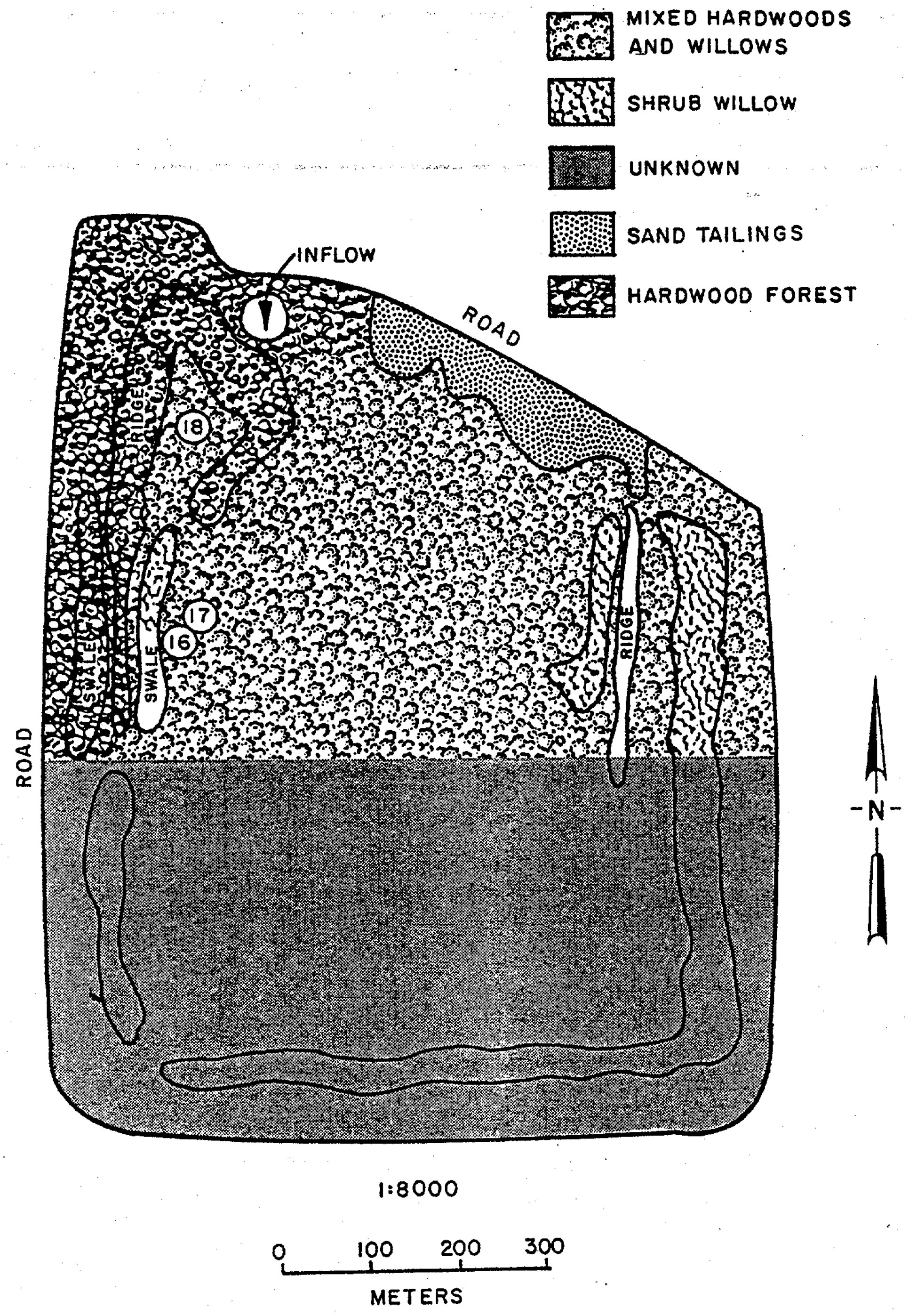
(a)

Figure 40. Noralyn-11A, 12-year-old clay settling pond. a) vegetation map, b) aerial photograph (1979), courtesy of Agricultural Stabilization and Conservation Service.



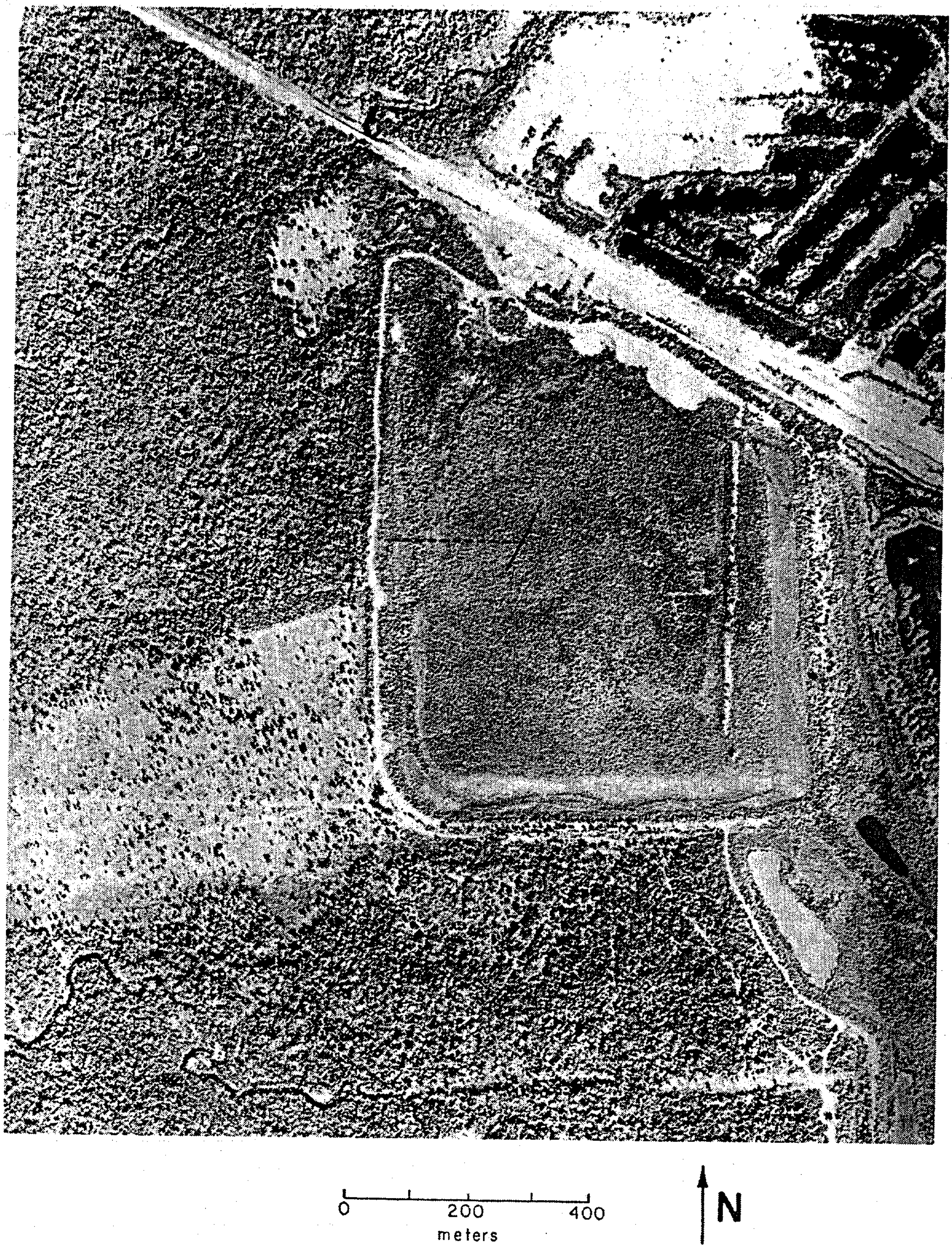
(b)

Figure 40. (continued)



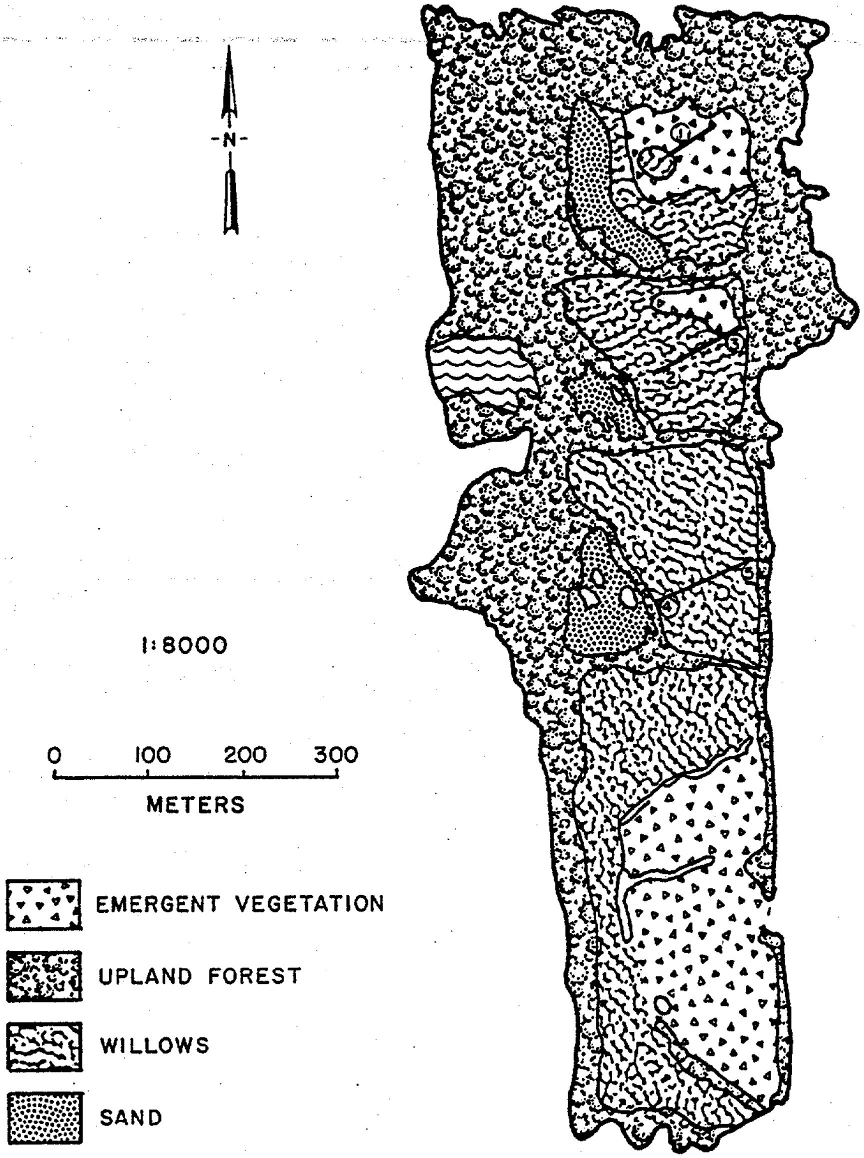
(a)

Figure 41. Alderman Ford Ranch, 30-year-old clay settling pond. a) vegetation map, b) aerial photograph (1968), courtesy of Agricultural Stabilization and Conservation Service, scale 1:10,000, north at top.



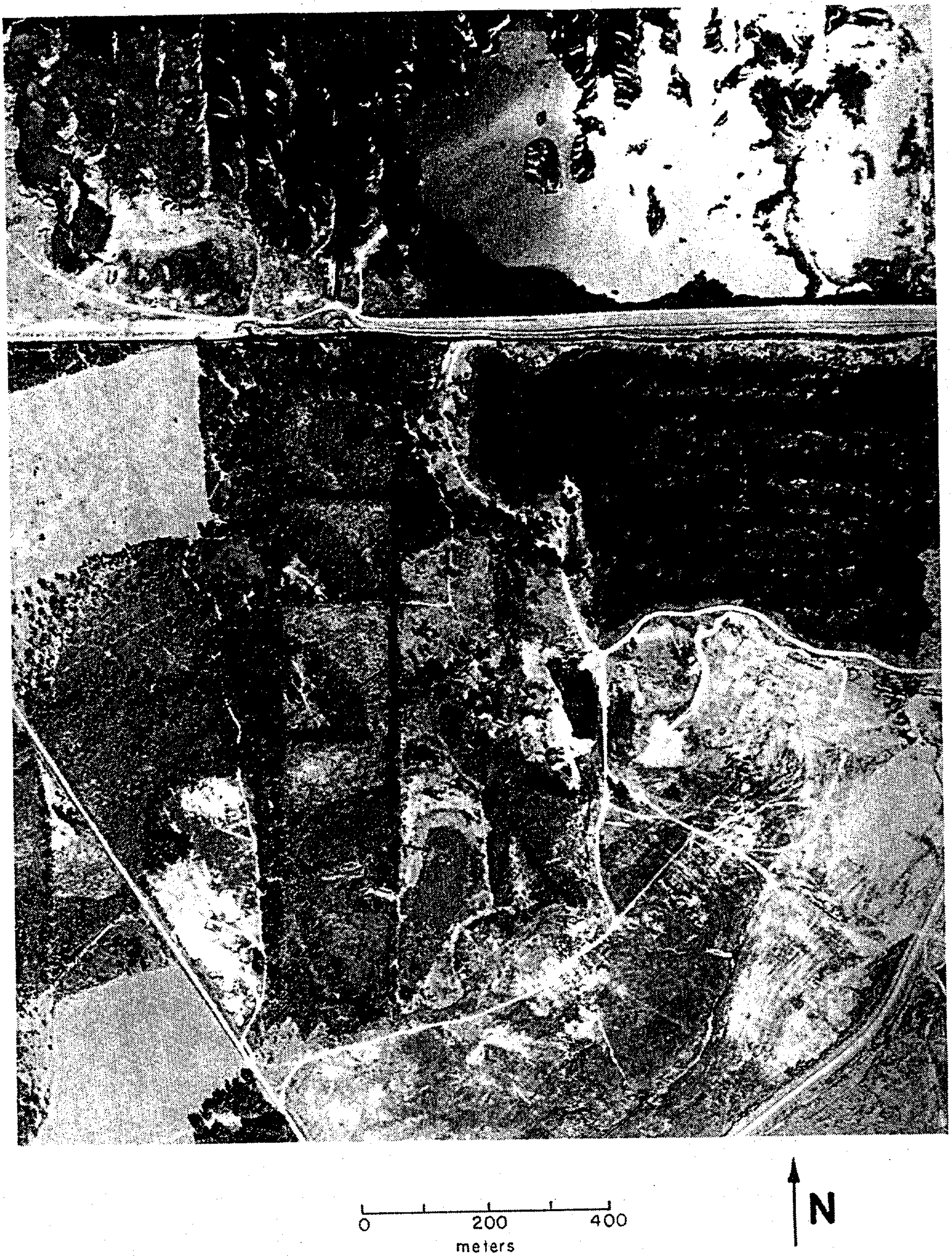
(b)

Figure 41. (continued)



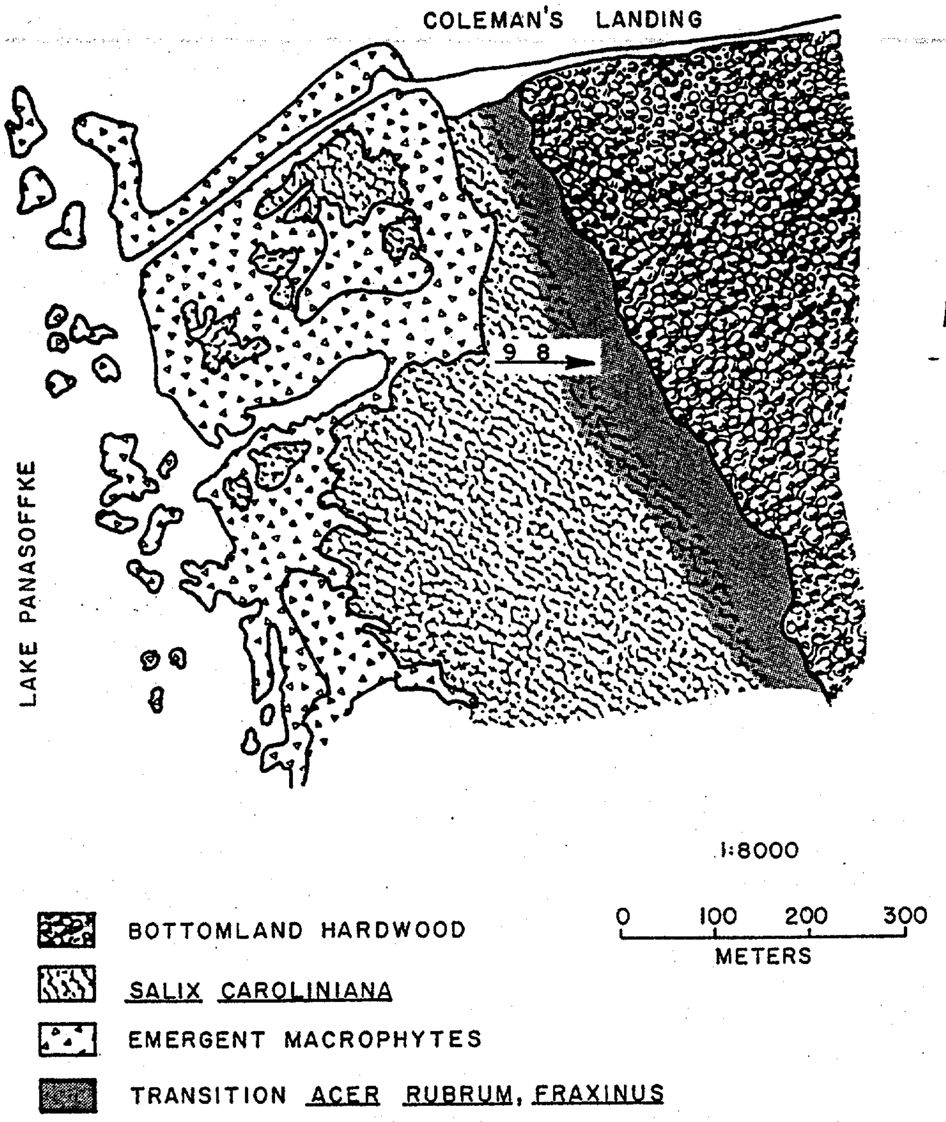
(a)

Figure 42. Clark James site, more than 40 years old. a) vegetation map, b) aerial photograph (1979) courtesy of Agricultural Stabilization and Conservation Service, scale 1:10,000, north at top.



(b)

Figure 42. (continued)



(a)

Figure 43. Lake Panasoffkee, 40-year-old control site, has changed from a marsh to a willow community over the past 40 years. a) vegetation map, b) aerial photograph (1974) courtesy of Agricultural Stabilization and Conservation Service, scale 1:10,000, north at top.

(b)

Figure 43. (continued)

Clear Springs-8, 2 years old (Figure 39 [location: T30S, R25E, south 1/2 Section 23]).

This 133-hectare clay settling pond is owned by IMC. It is part of their Clear Springs mining operation, designated CS-8, and was originally built on an abandoned mined out area. It was deactivated in December 1980 and in just 1 year supported a dense cover of herbaceous vegetation. Several well-defined channels drained water to the decant devices at each corner. The major open water on the east was interspersed with islands. The area sampled was located on the upper (west) side, which was drying out first. It consisted of anaerobic clays at water level and pockets of slightly deeper water. The CS-8 site was put back into active service after the sampling for this project was completed.

The volume of clay wastes is greater today than in the past. For this reason dikes were higher at CS-8 than at the older sites studied, and spoil piles from the mining activity had been removed to give greater storage capacity and to provide dike material. The dikes were 14 meters high and, in compliance with state regulations, they were mowed. Most of the surrounding land was disturbed. A sizeable orange grove was on the east. The nearby Peace River located 0.8 kilometers to the west was the closest seed source.

Noralyn-11A, 12 years since decommissioned (Figure 40 [location: T30S, R24E, lower 1/4 Section 36]).

Noralyn 11A comprises about 110 hectares. It is the oldest of five clay settling ponds located to the south and is part of IMC's Noralyn mining complex. It is still used as a flow-through system, which transports clay slurry in well-defined channels to other slime ponds.

It was built in an old mined out area and has emergent mining spoil piles with a different type vegetation. The clay settling area had a narrow band of myrtles near the inflow pipe. Shrub willows, cattails, and primrose willows were the dominant vegetation on the rest of the site. The transect followed the slope downgrade from the myrtles through the willows. It was surrounded by miles of disturbed land, the dikes are 8 meters high and were kept mowed. The closest seed source was 5 kilometers away.

Alderman Ford Ranch, 30 years since decommissioned (Figure 41 [location: T30S, R22E, SW 1/4 Section 16]).

This site was strip mined by the American Agriculture and Chemical Co. and was known as their Elanore Mine. It is owned by Mr. C. L. Knight and is used as a ranch. Aerial photographs show the clay settling area being filled in 1948. This unreclaimed clay settling pond is approximately 70 hectares and is located immediately above the confluence of the north and south prong of the Alafia River. A considerable undisturbed floodplain has been left at this point providing an abundant seed source for revegetation located immediately across the dike. Sand tailings have been added to the north side.

The clay settling pond itself has much greater topographic relief than most. The ridges, solid clay for at least a meter, supported a variety of hardwoods and a closed canopy, but no willows. The lowest swales fill with water during wet weather and are revegetated with a shrub willow community. The remainder of the site is characterized by dying willows and myrtles with some hardwood trees. There were a considerable number of gaps in the canopy where vines and blackberries were dominant. There were also grassy areas and a maze of cow paths reflecting its use as an unimproved pasture.

It was diverse, and not all community types were sampled. Since willow succession was one of the topics of this study, two sites were selected where willows were present. One represented a wet depression, the other a drier location. The site does demonstrate that many of the species of the southern hardwood climax forest are able to survive on clay settling ponds.

Clark James, 60-year-old dredge pits (Figure 42 [location: T30S, R24E, West 1/2 Section 23]).

The Clark James site is comprised of a series of five old dredge pits, 21 hectares in size, owned by IMC. It was high graded in the 1920's---a process that removes only the largest phosphate particles of the highest grade ores (Schnoes and Humphrey 1980). It is scheduled to be remined. It appears to represent the wastes from the mining process used by the industry between 1908 and 1920. Ownership was shown as the Florida Mining Corporation on a 1914 map. During that time period the overburden was removed by steam shovel and loaded into cars that were then drawn to the overburden dump; or the overburden was removed by the hydraulic method, the material being pumped through pipe lines to the overburden dump (Sellards 1914). At the washer plant, usually central to a 200-acre tract, the pebble was screened out as the phosphate rock product and the “debris” consisting of phosphatic sand and clay was discarded as waste (Zellar-Williams 1978).

Many of these old dredge pits are lakes in the contemporary landscape. Of the five pits at Clark James, the one to the north was a lake as recently as 1968 and the middle pit appeared to be partially covered by open water in 1941. Otherwise, the dredge pits showed considerable vegetation cover resembling the pattern observed today when the first aerials of Polk County were taken by the Agricultural Soil and Stabilization Sat-vice in 1941. They also show that there was new mining activity adjacent to the site at that time. The spoil banks and pit rims are heavily vegetated, dominated by *Quercus virginiana* and *Q. nigra* and some pines. At each southwest corner of the three northern pits there was a sandy area covered with grass where the sand and clay waste was dumped together. When sand and clay are pumped together the sand settles rapidly whereas the clay settles very slowly and tends to migrate to the lower elevations (Hawkins 1973).

Lake Panasoffkee, control site, 40 years old (Figure 43 [location: T20S, R22E, NW 1/4 Section 34]).

Lake Panasoffkee is located in midwest Sumter County. It was chosen as a control. site to study willow succession because the eastern shore has undergone a gradual change from open lake surface to shallow swamp over the past 35 years (Greiner Engineering Sciences 1978). Most of the woody shrubs responsible for this invasion were the same species found on phosphate slime ponds. Willow (*Salix carolinana*) was a dominant.

Lake Panasoffkee and the swamp on the eastern shore receive a significant portion of their water budget directly from the Floridan Aquifer. The position of the aquifer at or near the surface along with several fault fractures act as a direct connection to the water bearing strata (Taylor 1977). in this respect It differs from many other Florida lakes. Since the construction of the Wysong Dam in 1965, variation in stage has been much less than before (Taylor 1977). Stabilized water levels have encouraged the growth of shrubby species and it was expected that if lake levels were not allowed to fluctuate, the willow community would become a swamp forest similar to the one found on the adjacent uplands (Greiner Engineering Sciences 1978). The Southwest Florida Water Management District (SWFWMD) has begun to operate the dam to vary water levels in much the same manner nature would if there were no structure (Hydroscope 1982).

Methods

To sample the four phosphate clay settling ponds and the control site at Lake Panasoffkee, belted transects (10 meters x 50 meters) were laid out in a stratified systematic design (Oosting 1948; Smith 1980). Belted transects are also referred to as elongated quadrats and should not be confused with line transects. To determine exact locations of plots, a 50-meter tape was extended down the midpoint of the length of the transect at the beginning of each sampling period. Appropriate quadrat frames were used to determine exact boundaries of plots (see Figure 44 for an example of the sampling design). An effort was made to follow the land contours downgrade. At most sites it was determined that l00-meter transects would give more information. In these cases two transects were placed end to end to make a continuous l00-meter transect. A total of 14 50-meter transects were evaluated (see site description in Table 10).

Community Structure

Plant Biomass

Trees and shrubs. The tree size class included those individuals with diameter at breast height (dbh) greater than 10 centimeters. Species name and dbh were recorded in 2 meter x 10-meter increments along the length of the transects. The shrub size class was defined as those individuals with dbh greater than 1 centimeter and less than 10 centimeters. Species name and dbh were recorded for 25 2-meter x 2-meter quadrats along the length of the transect. Average height of the canopy for both trees and shrubs was also measured.

Willow (Salix carolinana), the dominant shrub species, characteristically has many trunks originating from the same root system. it also has the habit of falling over with the branches forming new trees. This growth pattern complicated measurements. It was decided that each stem that contained roots would be measured separately. When trees leaned over to a considerable degree or when lying on the ground, dbh was taken 130 centimeters from the base of the tree. Red maple (Acer rubrum) often has two almost identical vertical trunks at breast height. It was reasoned these have the same effect on the forest as two trees of this size; therefore, each stem was measured and recorded.

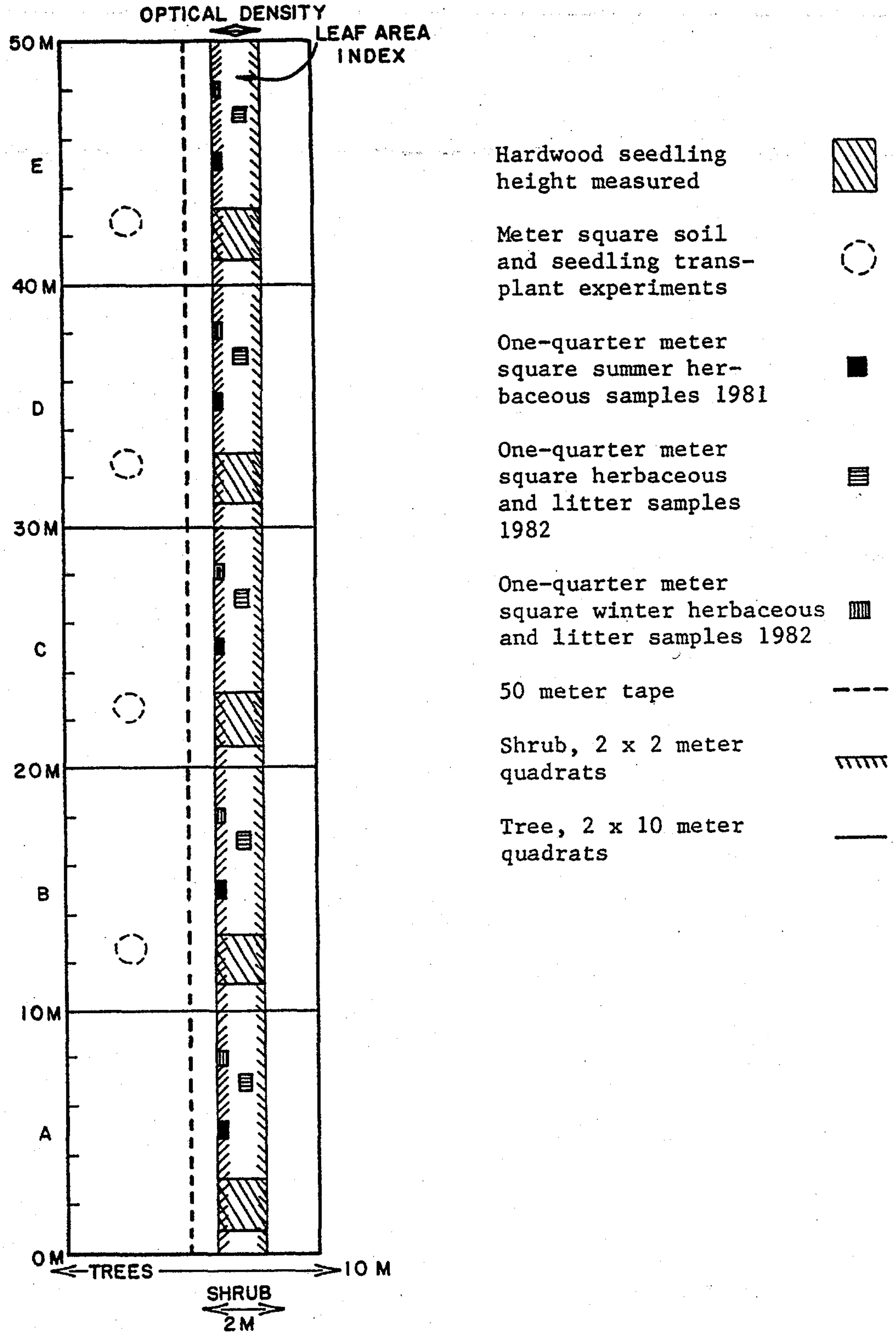


Figure 44. Sampling design. Belted transects, 10 x 50-m elongated quadrats, were used to sample each study area.

Herbaceous vegetation. Harvest sampling of the aboveground biomass of the herb layer (less than 1 centimeter dbh) was made in 0.25-meter^2 quadrats at equal lo-meter intervals along the transect. Some sites were measured for the summer of 1981. These locations were at 5, 15, 25, 35, and 45 meters and located 1 meter from the tape marking the midpoint of the transect. All sites were sampled in winter 1982. The locations were 8, 18, 28, 38, and 48 meters and 1 meter from the center of the transect. The summer 1982 samples for all sites were located 7, 17, 27, 37, and 47 meters and 2 meters from the tape marking the midpoint of the transect. Each plot was clipped to ground level, the species separated and recorded, and the material dried at 80°C in a forced draft drying oven before weighing. A sample was weighed at intervals to determine length of drying time. Plots were frequently a tangled mass of vines or spreading vegetation. If a plant originated or had a considerable number of roots in the plot it was counted. If its biomass occupied only air space above the plot it was not counted.

importance values were calculated from plant data using the following formulas:

Relative dominance (trees and shrubs): $\frac{\text{(dbh of species) (100)}}{\text{(Total dbh all species)}}$

Relative dominance (herbaceous): $\frac{\text{(Dry wt. of species) (100)}}{\text{(Total dry wt. all species)}}$

Relative density: $\frac{\text{(Number of stems/species) (100)}}{\text{(Total number stems all species)}}$

Relative frequency : $\frac{\text{(Number of points of occurrence of species) (100)}}{\text{(Total number of points all species)}}$

The Relative Importance Value Index (RIVI) Is the sum of the three relative values divided by 3 to put on a 100% basis.

Accumulated Litter Biomass

The total litter accumulation was collected at the same time and in the same 0.25-meter^2 quadrats as the herbaceous samples in 1982. The winter accumulation represents the litter after several freezes. The summer samples were taken during the active growing season. Litter included all standing dead, leaves, seeds, branches, and logs that occurred within the boundaries of the plots. The material was dried at 80°C in a forced air drying oven before weighing.

Leaf Area index (LAI)

Leaf area index is defined as the ratio of total leaf area, counting one side only, to ground area (Etherington 1975). For example, a value of 2 for LAI indicates there were, on an average, 2 meters^2 of upper leaf surface for 1 meter^2 of ground. In this study, the LAI was measured using a weighted fishing line technique similar to the one described by Benedict (1976). An extendable pole made from sections of PVC pipe raised a short, fairly rigid fishing rod above the canopy from which a line and small weight were dropped. Leaves touched by the hanging line were counted and the species recorded. The line was marked at 2-meter intervals to roughly divide the vegetation into herbaceous (0-2 meters), shrub (2-4) meters), understory trees (4-6 meters), and canopy trees greater than 6 meters. To be accurate, it is important to use the smallest size line possible to reduce overestimation of leaf area (Wilson 1963). For this study a 50-pound test monofilament fishing line of 1.0-millimeter diameter was used. it should also be noted that since leaves on trees rarely lie in a horizontal plane, the method overestimates the contribution of species whose leaves are more nearly parallel to the ground (Wilson 1960; MacArthur and MacArthur 1961).

Twenty-five determinations of LAI were recorded in each 50-meter belted transect during the middle of summer when vegetation should be near maximum for the year. Measurements were taken every 2 meters along the transect and as close to 2 meters from the center’ line as possible. The method was accurate to a height of about 7 meters, above that, leaf interception was estimated.

Optical Density

Vegetation mass was measured optically using Beer’s Law and the relationship between light intensity and the electrical output of photometers (Odum et al. 1970). in this study a portable solar radiometer with a silicon cell (Matrix inc., Mark IV Sol-a-meter) was used. it generates electrical output in proportion to photons absorbed in the range of light intensity of wavelengths of 360-1140 nm (Brown 1978). It responds in the visible spectrum and part of the infrared. Since vegetation absorbs these wavelengths, especially the blue, red, and infrared up to 1500 nm (Gates et al. 1965), the method seems suitable for the estimation of forest biomass and the penetration of solar energy into the forest. Although the response is different for different wavelengths, the instrument may be used to estimate light intensity where spectral distribution of input energies being compared are the same. In this case since daylight is used, spectra are similar, and the instrument can be used.

The instrument is equipped with a percent transmission scale which was adjusted to 100% by pointing the sensing cell perpendicular to the sun in an open field at the beginning of each sampling period. Readings were made with the meter held level and as close to the ground as possible. Measurements were taken in a regular pattern, three readings, 0.5 meters apart, made in a straight line perpendicular to the midline of the transect. These were repeated at 2-meter intervals for a total of 75 points along the length of each 50-meter transect. Direct light from sunflects and gaps were recorded as well as diffuse light through the vegetation. The percent transmission was rechecked in the open field at the end of the sampling period, usually within 2 hours.

Since readings were taken as the sun changed position overhead, it was necessary to correct for sun angle. A clinometer was used (board and hanging pointer) to read the sun angle from the vertical.

The following formulas were used to calculate optical density:

$$T = \frac{I_m}{I_o \cos \theta} = \frac{\text{incident light}}{\text{Transmitted light}}$$

where T is the fraction transmitted, I_m is the light intensity read by the meter in the horizontal position, I_o is the full light intensity (100%) pointed directly at the sun, and θ is the sun angle read from the vertical plane. The negative logarithm of transmittance is defined as optical density or the absorbancy of forest structure.

$$D_o = - \log T$$

where D_o is the optical density of the slanting path of light and T is transmittance.

$$D = D_o \cos \theta$$

where D is the estimated optical density had the light path been in the vertical position at the zenith.

With the exception of one site, measurements were made between 10 AM and 3:30 PM (daylight savings time) during a 3-day period from May 11 to May 13, 1982. On several occasions there were scattered cumulus clouds, which interrupted the measurement while we waited for the shadows to pass.

Species Diversity Measurements

Species diversity was measured by counting about 1000 individuals in each 50-meter, transect. A leaf or some other identifying object was collected from two or more line transects running parallel to, but offset one or more meters from, the center line of the elongated quadrats. A cumulative count to 100 individuals (50 individuals per side) was made for each 5-meter segment. Additional parallel line transects were established if the cumulative counts for each 5-meter segment were less than 100. The identifying objects were placed in plastic bags. The process was repeated until the entire 50-meter transect had been surveyed. The individuals were sorted into species and counted back in the lab.

A species richness index (number of species/1000 individuals) was calculated. in cases where fewer than 1000 individuals were counted the species were plotted on a linear scale and the number of individuals counted were plotted on a logarithmic scale to estimate the number of species. This technique takes advantage of the observed fit between the usual hump-shaped curves resulting from species-individual data with theoretical log-normal curves of the same graph (H. T. Odum et al. 1960).

There are several indices that include relative abundance as well as the number of species. The Shannon-Weiner index developed from Information theory is one of these. The units in which diversity are measured depend on the base of the logs-log to the base 2 is a bit, to the base 10 is a decit, and natural logs a nat (Pielou 1975). Species diversity calculations for this study were made using natural logs and logs to the base 2.

The Shannon index of General Diversity:

$$H = \sum\left(\frac{n_i}{N}\right)\log\left(\frac{n_i}{N}\right) \qquad (5)$$

where n_i = number of individuals of each species; N = total number of individuals; and H = bits per individual.

With the Shannon-Wiener index rare species count relatively less than common ones. it is possible to rescale the diversity index so it is proportional to the number of species by expressing the Shannon-Wiener index as an exponential function.

Soil Texture Analysis

Soil cores were taken by digging holes in the substrate to a depth greater than 40 centimeters with a shovel. A clean sample was taken from the 0-20-centimeter level and another at the 20-40-centimeter level to be analyzed separately. These were stored in plastic bags and refrigerated.

The soil was prepared for analysis by roiling it fiat and letting it air dry for several days. The samples were then broken into chunks and mixed before subsamples were removed for testing.

Soils are made up of a mixture of particles of different sizes and shapes. Particle size distribution is measured by mechanical analysis based on the principle that particles settle out of a soil water suspension in order of decreasing size. For this study the hydrometer method (Day 1965) was used to determine particle size distribution. Summation curves were plotted from the data showing the percent particles smaller than the diameter shown on the x-axis. The results were divided into percent sand, silt, and clay from these curves using the U.S. Department of Agriculture scheme (<0.002 millimeters clay, 0.002-0.05 millimeters silt, and >0.005 millimeters sand).

Hardwood Seedling Survival

Hardwood Seedlings Plots

Establishment and survival of hardwood seedlings were measured in the older sites (greater than 25 years). There were five 2-meter x 2-meter subplots in each 50-meter belted transect, as shown in the sampling scheme in Figure 44. In April 1982, seedling number, height, and species’ were recorded for each plot.

The process was repeated in January 1983 to establish growth and survival rates. The data from the subplots were calculated to represent the number of individuals expected in the total 0.1-hectare transect. In the 60-year-old site, there were too few seedlings to designate subplots. Instead ail the seedlings in the entire 0.1-hectare belted transect were counted and measured.

Soil Plot Transplant Experiments

To determine if the introduction of microbes and seeds might accelerate succession, dirt and roots from 13 1-meter x 1-meter x 5-centimeter plots were dug from several ecosystem and promptly transplanted to two of the study sites (60-year-old Clark James and two locations in It-year-old Noralyn-11A). The donor sites represented the following plant communities and locations (Township and Range using the USGS grid system).

1. Bottomland hardwood, Lake Panasoffkee, Sumter Co. (R22E, T20S, NW 1/4 Section 34)
2. Bottomland hardwood, HWY 62 near Duette School, Manatee Co. (R22E, T33S, S 1/8 Section 20)
3. Cypress dome, HWY 37 near Four Corners Mine, Manatee Co. (R22E, T33S, NE 1/4 Section 1)
4. Oak hammock, HWY 17 south of Bartow, Polk Co. (R25E, T30S, 1/8 Section 20)

A sample from the above areas was dumped on the 12-year-old and 60-year-old sites in the most convenient manner, and no effort was made to reconstitute the natural organization in an effort to simulate conditions that might occur if this technique were used on a large scale. identical meter square plots were also dug and dumped back into the donor sites and marked as controls.

Measurement of Depth to Water Table

Water table measurements were made along each transect in January 1983. In cases of standing water the depth to ground surface was measured using a meter stick. When the water table was below ground level, a hole was dug using a shovel or post hole digger and the depth to water was recorded after allowing a few minutes for water level stabilization.

Results

Measurements of community structure for each individual transect are given. Then comparisons are made by age to observe successional trends.

Transects and Community Structure

The quantitative measurements for each of the belted transects are depicted graphically in Figures 45-52. They are arranged from youngest to oldest clay settling pond with the 40-year-old control site last. The youngest site, Figure 45, demonstrates the rapid growth of herbaceous vegetation since it was decommissioned the previous year. Dense willow seedlings (*Salix caroliniana*) have colonized the slightly higher elevations. The 12-year-old site, Figure 46, shows a willow shrub community with the water table near or below the surface during the year of measurements. The transect began at the outer edge of a myrtle (*Myrica cerifera*) thicket, which increased LAI at the upper, drier end. The 30-year-old site, Figure 47, indicated willows and myrtles declining in importance, and hardwoods, especially red maples (*Acer rubrum*), colonizing the site. Other hardwood trees and shrubs within the transects include oaks (*Quercus nigra*, *Q. laurifolia*, *Q. virginiana*), elm (*Ulmus americana*), and sweetgum (*Liquidambar styraciflua*). The 30-year-old wet site, Figure 48, had willows codominant with red maples. Both sites had increased accumulated litter where large hardwood trees had died. The 60-year-old dredge pits, Figures 49-51, were characterized by a shrub willow community with minor associations of elder (*Sambucus simpsonii*) and buttonbush (*Cephalanthus occidentalis*). The drier end of transect 4, Figure 50, also had some myrtles, oaks, and red maples. The northern transect, Figure 51, was a lake until 10 years before measurements were taken. Figure 52 shows a control site on the edge of a lake that has shifted from a marsh to a willow shrub community with scattered hardwoods over the past 40 years.

All the graphs show herbaceous biomass under gaps in tree and shrub canopy. Knotweed (*Polygonum* sp.) and primrose willow (*Ludwigia peruviana*) dominated the gaps in the wet sites while blackberry (*Rubus* sp.) or groundset (*Baccharis* sp.) associated with several vine species were in the drier locations.

Red maple trees increased leaf area index (LAI) but had little affect on optical density, probably because they create an opening in the herbaceous vegetation for side light to reach the forest floor. Litter biomass in winter was increased by the herbaceous vegetation killed by the freezes of 1982. There was little regrowth of the plants eliminated by the freeze when summer herbaceous samples were collected. Large trees accounted for large increases in litter biomass by dropping dead branches and limbs. Willow, the most common species, is deciduous, putting out several flushes of vegetation during the summer, which, even though the leaves were of different ages, fell together in September (Tomlinson 1980).

Summarized Comparison Data for All Sites

Succession may be measured by growth curves of ecosystem parameters. The clay settling ponds were compared to each other and to the control site to observe patterns of organization as the systems matured. Averaged values for tree, shrub, and herbaceous biomass, hardwood seedlings, accumulated litter, LAI, and optical density are compared in Table 11 and Figure 53. The curves represent the overall average for the 50-meter belted transects at each site during 1982. Two transects were evaluated at the 2- and 12-year-old sites and the 40-year-old control site, three at the 30-year-old site, four at the 60-

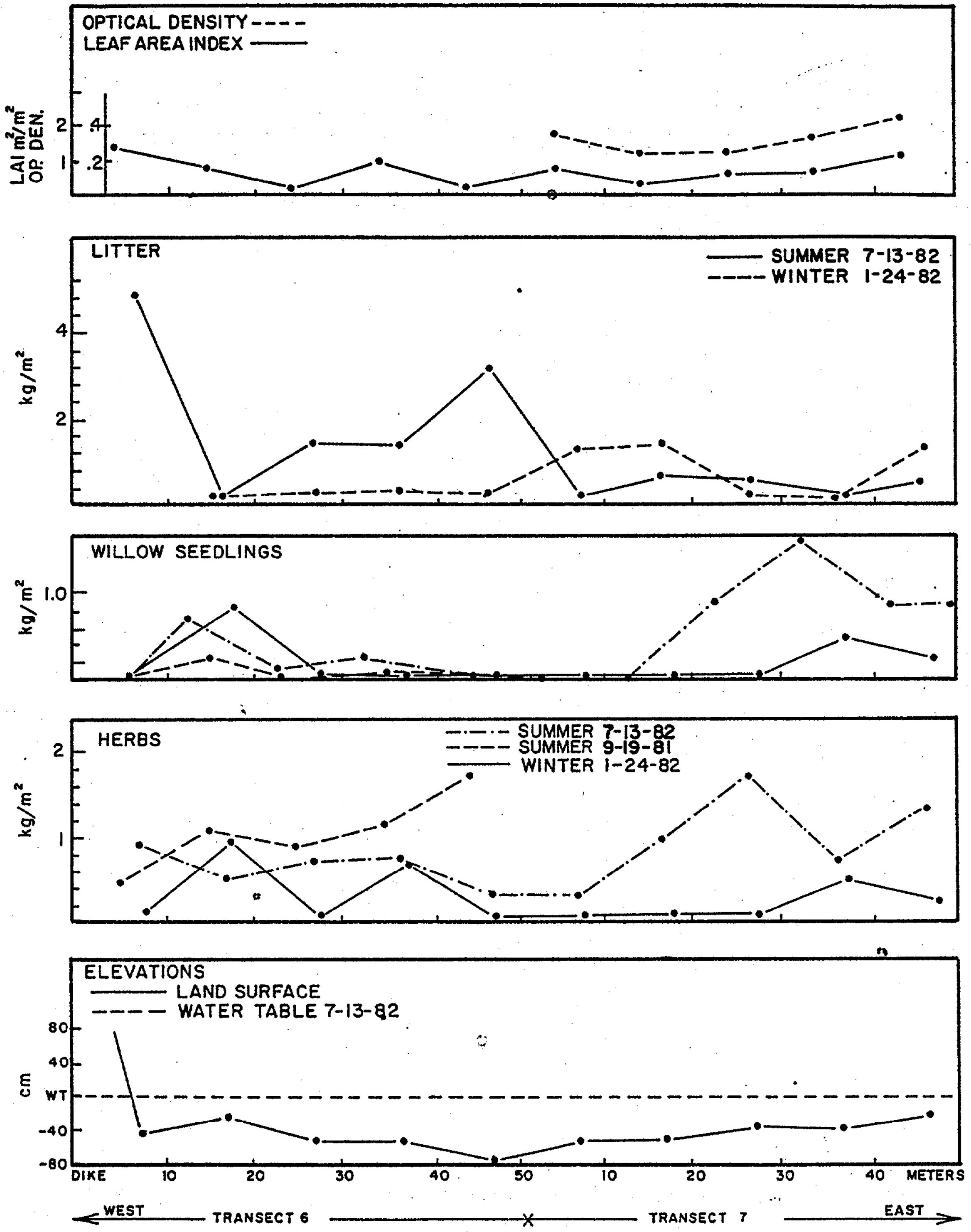


Figure 45. Community structure measurements presented along the long axis of the quadrat for a 2-year-old clay settling pond (Clear Springs-8).

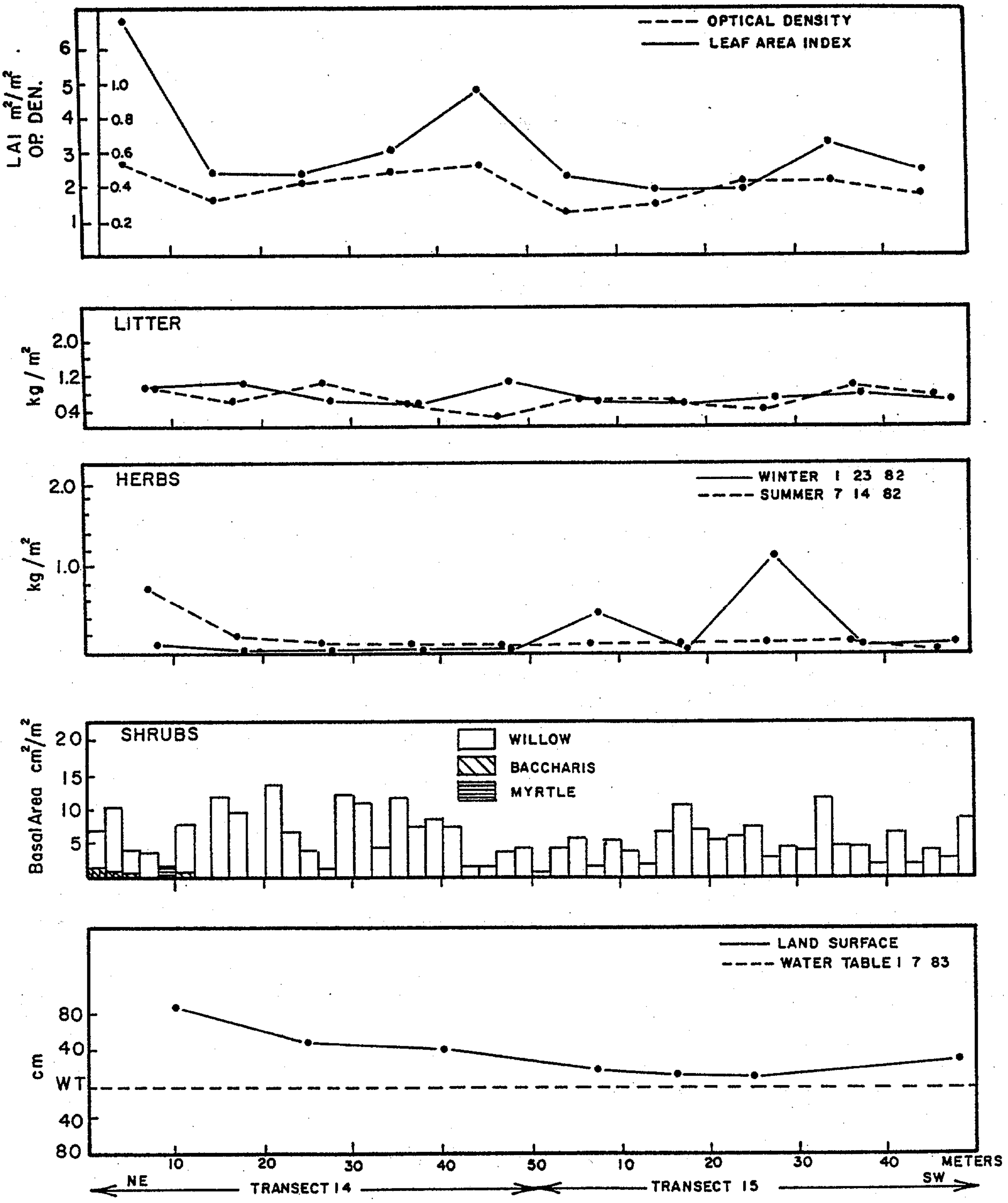


Figure 46. Community structure measurements presented along the long axis of the quadrat for a 12-year-old clay settling pond (Noralyn 11A).

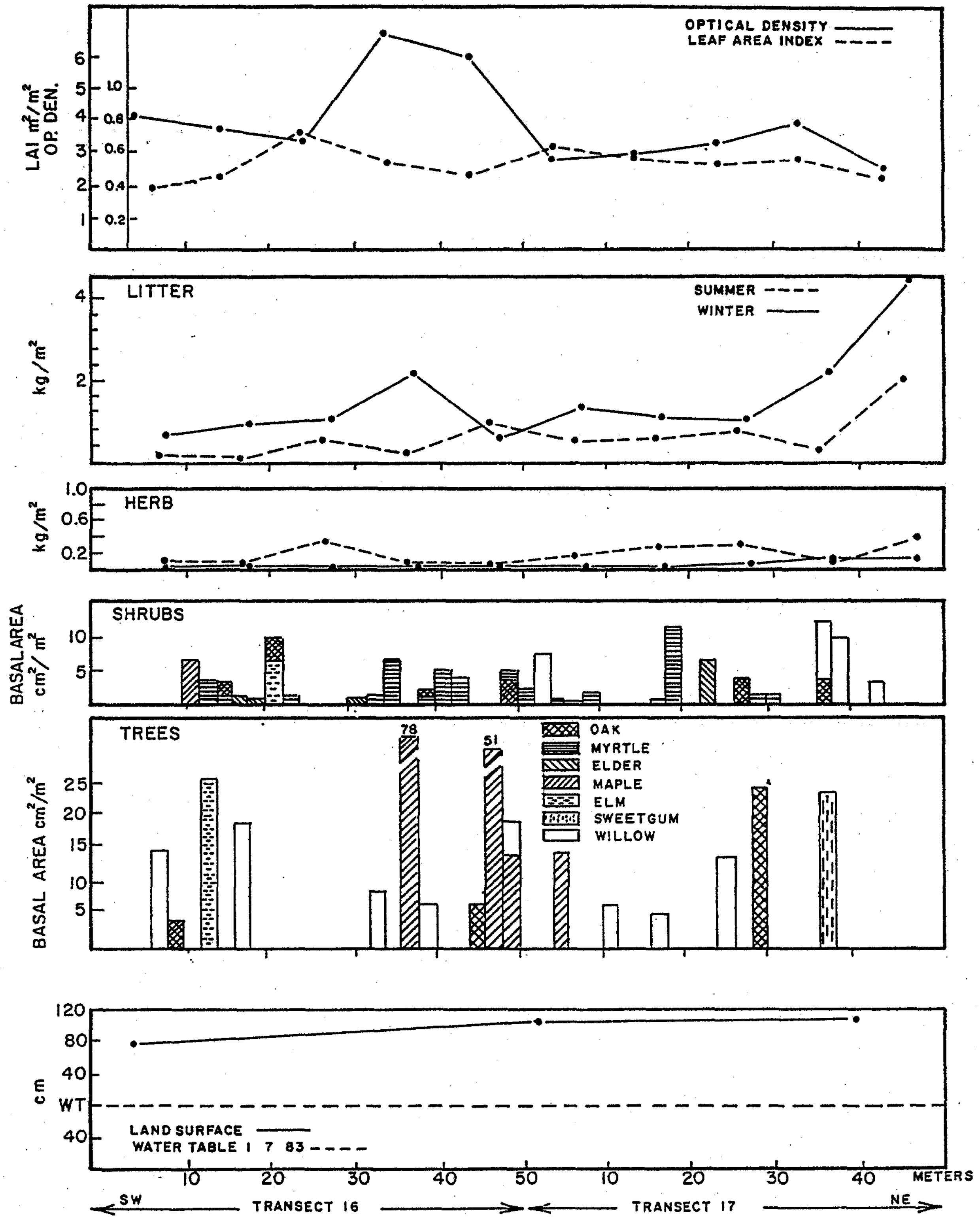


Figure 47. Community structure measurements presented along the long axis of the quadrat for a 30-year-old clay settling pond (Alderman Ford Ranch, drier site).

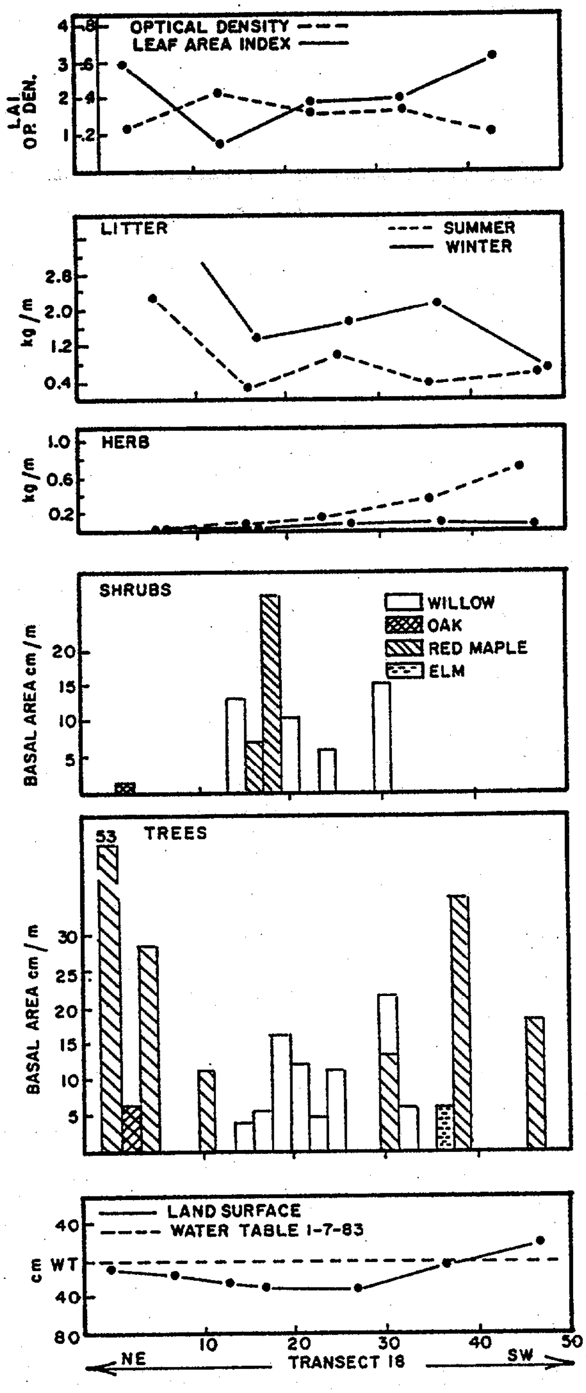


Figure 48. Community structure measurements presented along the long axis of the quadrat for a 30-year-old clay settling pond (Alderman Ford Ranch, wetter site).

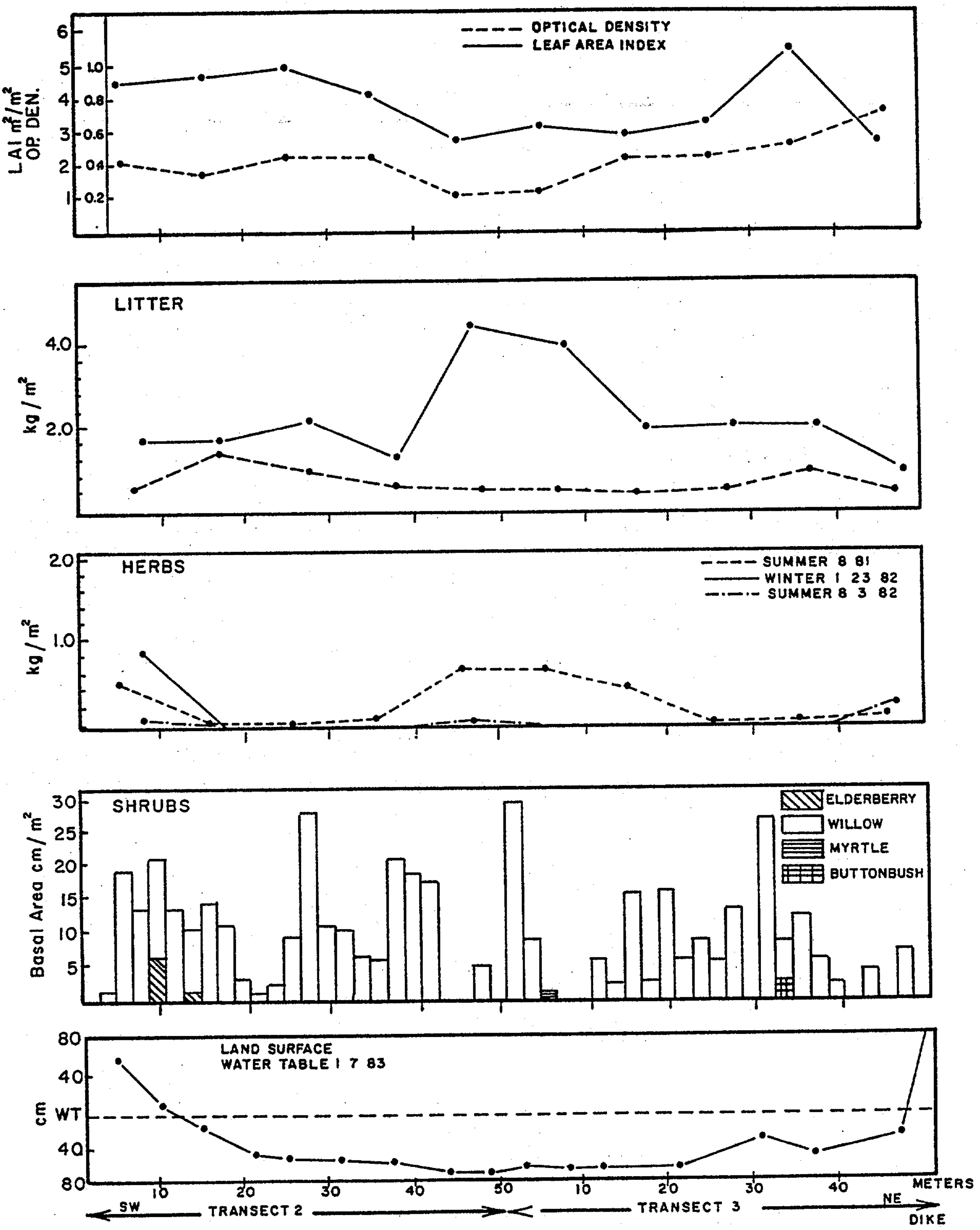


Figure 49. Community structure measurements presented along the long axis of the quadrat for a 60-year-old clay settling pond (Clark James dredge pit, middle transect).

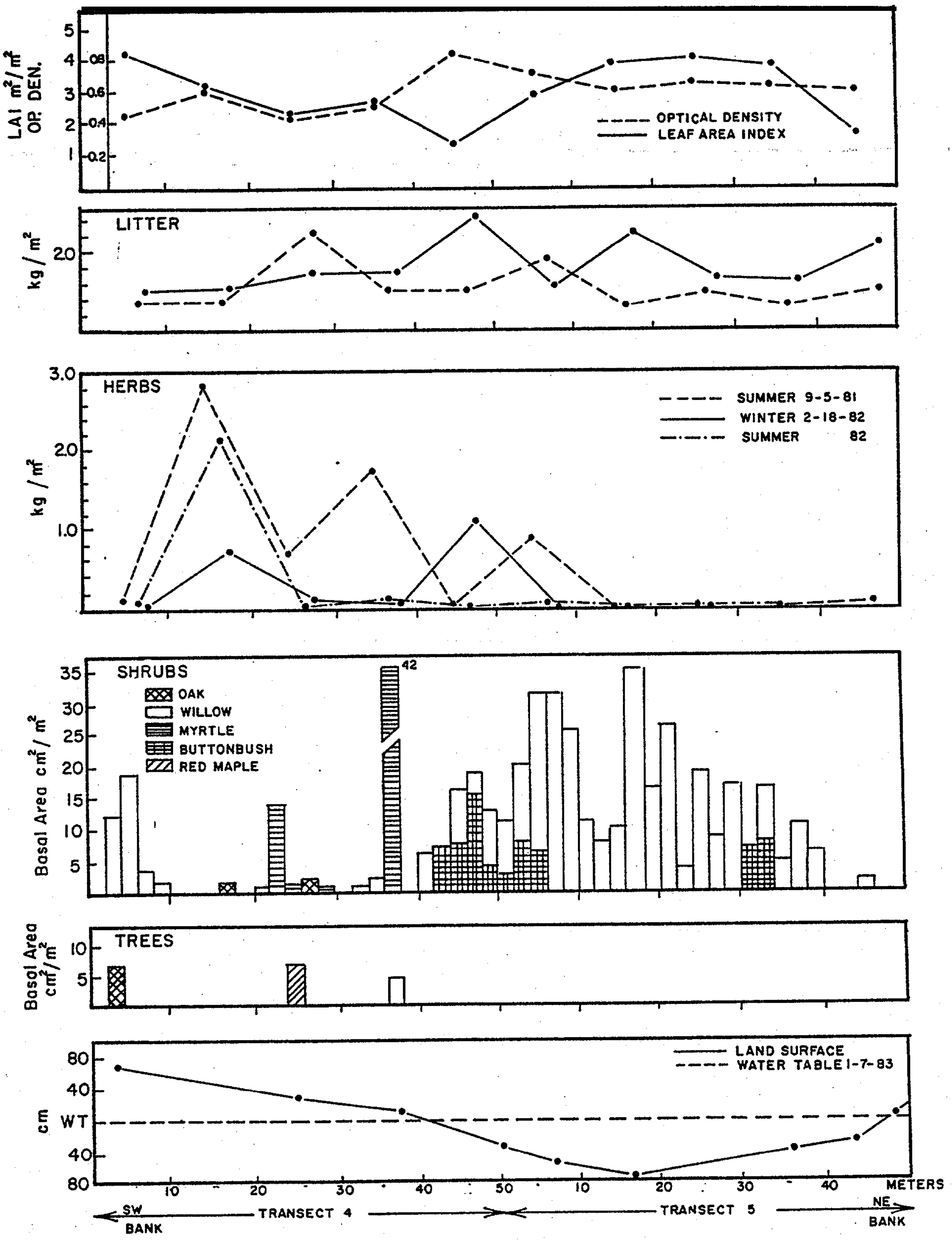


Figure 50. Community structure measurements presented along the long axis of the quadrat for a 60-year-old clay settling pond (Clark James dredge pit, southern transect).

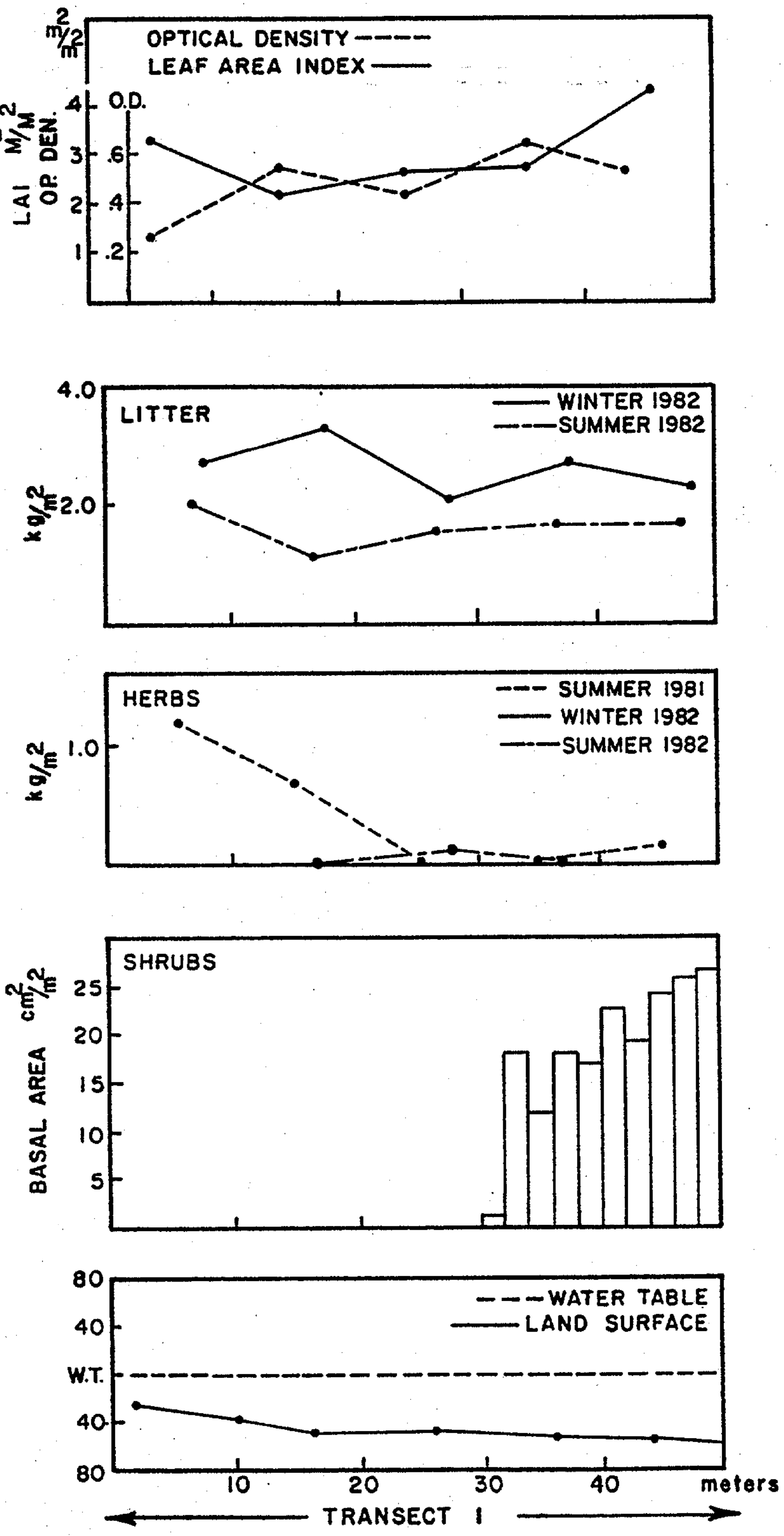


Figure 51. Community structure measurements presented along the long axis of the quadrat for a 60-year-old clay settling pond (Clark James dredge pit, northern transect, was a lake until 10 years ago).

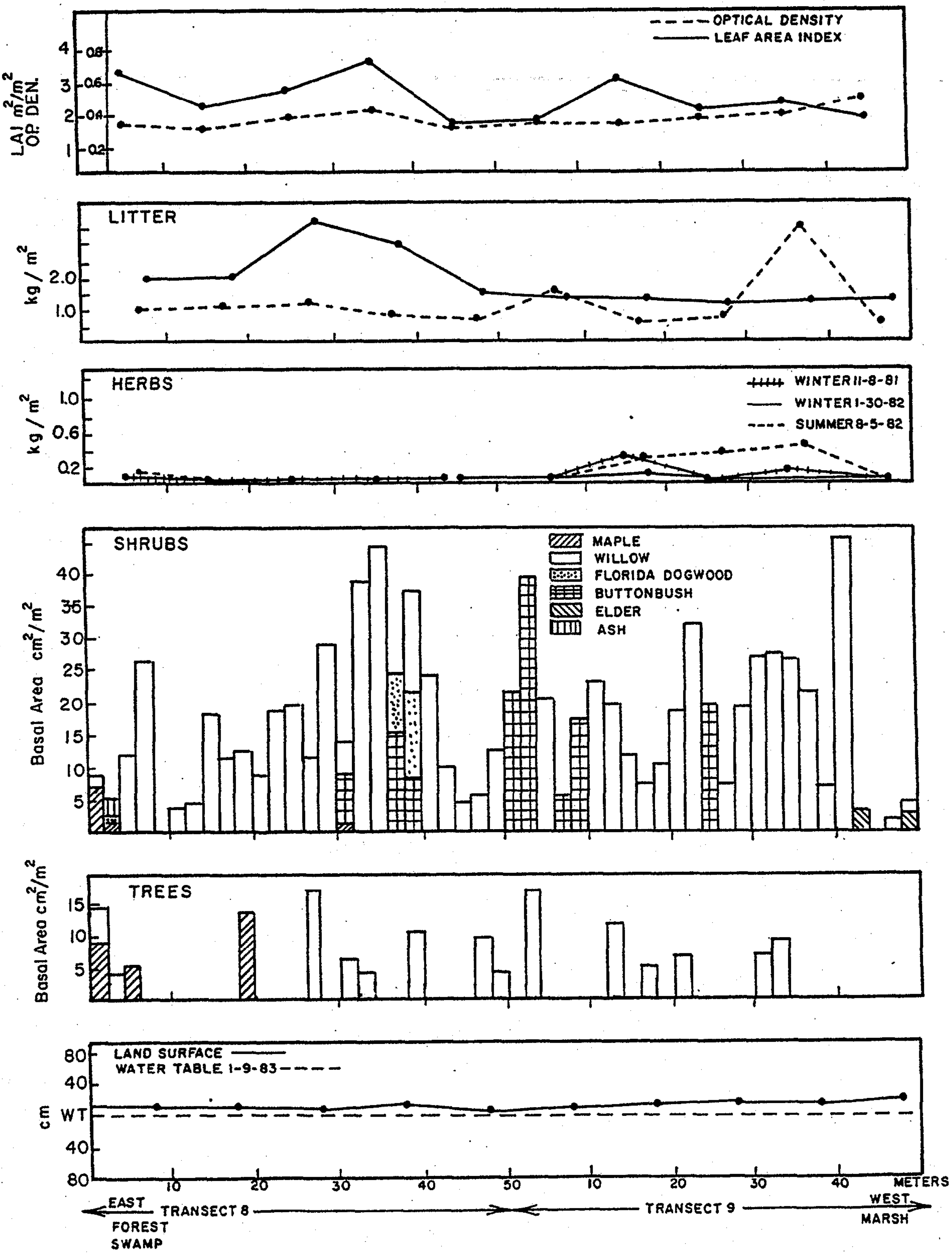


Figure 52. Community structure measurements presented along the long axis of the quadrat for a 40-year-old clay settling pond (Lake Panasoffkee, control site).

Table 11a. Community structure. Values are expressed as the mean of n measurements ± one standard error.

	Trees						Shrubs			
Site	n	Canopy Height, m	n	Stems per ha	Basal Area, m^2/ha	Mean dbh cm	n	Stems per ha	Basal Area, m^2/ha	Mean dbh cm
Noralyn-11A (12 yrs)										
Transect 14	27	4.14±0.11	0	0	0.0	0.0	87	8700	5.77	2.05±0.31
Transect 15	25	2.94±0.10	0	0	0.0	0.0	183	18300	4.18	1.61±0.43
Average	52	3.55±0.11	0	0	0.0	0.0	270	13500	4.97	1.83±0.37
Alderman Ranch (30 yrs)										
Transect 16	24	6.52±0.61	16	320	9.32	17.67±1.98	28	2800	1.95	2.62±0.27
Transect 17	25	3.25±0.55	7	140	3.46	16.85±2.28	27	2700	2.37	2.66±0.39
Transect 18	25	5.84±1.15	25	500	10.23	15.36±1.01	9	900	4.42	7.38±1.00
Average	76	5.20±1.47	48	320	7.67	16.51±0.93	64	2133	2.91	4.22±0.90
Clark James (60 yrs)										
Transect 2	27	4.87±0.40	0	0	0.0	0.0	70	7000	10.18	3.91±0.22
Transect 3	24	3.62±0.30	0	0	0.0	0.0	46	4600	7.81	4.08±0.33
Transect 4	25	2.45±0.34	5	100	0.69	10.80±0.1	61	6100	6.79	3.49±0.18
Transect 5	25	4.15±0.24	0	0	0.0	0.0	97	9700	12.55	3.77±0.15
Average	101	3.77±0.19	5	25	0.17	2.7±0.03	274	6850	9.33	3.81±0.23
Control Site										
Lake Panasoffkee (40 yrs)										
Transect 8	25	4.60±0.29	23	340	3.53	11.27±0.29	101	10100	17.00	4.29±0.17
Transect 9	24	5.26±0.36	8	160	2.22	13.23±0.50	79	7900	17.93	5.02±0.21
Average	49	4.93±0.24	31	250	2.37	12.25±0.42	180	9000	17.47	4.65±0.19

*Trees (individuals >10 cm dbh) and shrubs (individuals >1 cm and <10 cm dbh). Measured for willow communities in phosphate clay settling ponds and in a control site.

Table 11b. Community structure. Values are expressed as the mean of n measurements ± one standard error.*

Site	n	Herbs (g/m²)		Litter (g/m²)	
		Winter	Summer	Winter	Summer
Clear Springs-8 (2 years old)					
Transect 6	5	355±171	684±122	2259±798	208± 37
Transect 7	5	184± 64	1002±235	477± 97	858±242
Average	10	269± 91	843±136	1368±482	569±172
Noralyn-11A (12 yrs old)					
Transect 14	5	28± 26	278±126	799±108	650±133
Transect 15	5	346±177	156± 10	606± 45	587± 81
Average	10	187±100	217± 63	702± 63	619± 74
Alderman Ford Ranch (30 yrs old)					
Transect 16	5	17± 7	110± 57	1077±273	393±148
Transect 17	5	42± 19	226± 50	2025±673	678±202
Transect 18	5	34± 16	243±133	1843±458	886±350
Average	15	31± 8	224± 53	1648±287	652±143
Clark James (60 yrs old)					
Transect 2	5	221±190	24± 15	2272±533	923±179
Transect 3	5	46± 46	41± 41	2236±470	626±106
Transect 4	5	425±236	483±425	1614±327	1196±320
Transect 5	5	3± 1	26± 17	1641±253	1013±208
Average	20	173± 80	144±108	1940±202	940±110
Control Site					
Lake Panasoffkee (40 yrs old)					
Transect 8	5	5± 4	41± 23	1039± 62	775± 56
Transect 9	5	7± 4	334± 86	1979±319	1127±466
Average	10	6± 2	187± 64	1509±219	951±229

*Vines and shrubs (<1 cm dbh) were harvested and accumulated litter collected in 0.25-m^2 quadrats.

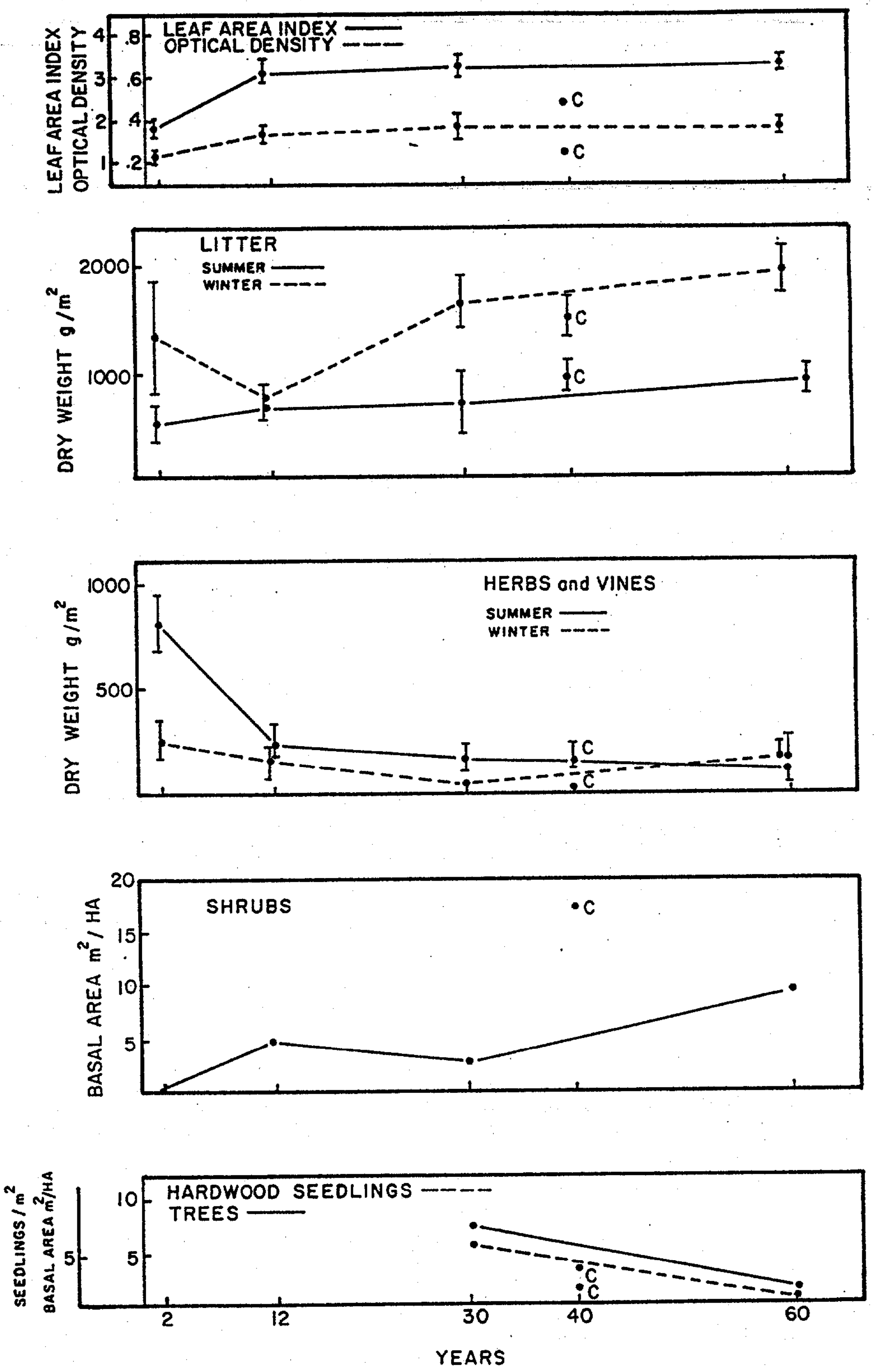


Figure 53. Summarized community structure measurements averaged for the clay settling ponds and the control site. Vertical bars are ± 1 standard error of the mean. The 40-year-old control site is designated with a C. For the first 30 years there is an increase in biomass; however, the 40-year-old control site and the 60-year-old dredge pits appear to be cases of retarded succession.

year-old site, one site was not included because it was a lake until 10 years ago. More detailed data can be found in Appendices D, E, F, and G.

For the first 30 years, community structure and biomass increased over time as herbaceous vegetation was replaced by shrubs, which were replaced by trees. This follows the trend expected for classical succession theory where biomass of the community increases with time as short-lived weedy species are replaced by longer lived mature species of better structure. However, the graphs for trees, seedlings, and species diversity show a decline after 30 years, indicating some factors may be retarding succession at the 40-year-old control site and the 60-year-old dredge pits. Moisture regimes might explain different rates of succession since a mesic habitat will produce a forest more quickly than a wet one. This appears to be the logical explanation for the control site. The willow communities in the 60-year-old dredge pits appear to be a case of arrested succession. This might be caused by widely fluctuating (1-2 meters) water levels and the absence of a seed source.

Data for individual Parameters

Trees and shrubs. Size frequency histograms of the trees and shrubs have been graphed in Figure 54. The raw data are in Appendix D. The graph shows many small diameter willows (2-6 centimeters) are replaced by hardwoods from 12 to 30 years old. The 60-year-old site and 40-year-old control site were still dominated by the shrub willow community. The 60-year-old site had a few hardwoods in transect 4 near the waste deposition site; the 30-year-old control site had numerous hardwoods clustered near the adjacent swamp forest, which was not sampled, and a few scattered hardwoods throughout the willow community shown on the diagram.

Litter accumulation. Litter is compared between four vegetation types in the different aged clay settling ponds and the control site in Figure 55. The 2-year-old site-is dominated by marsh herbaceous vegetation. Cattails (Typha sp.) produced more litter than the water hyacinth (Eichhornia crassipes) dominated communities. The clumps of willow seedlings produced some litter from leaf fall. By 12 years, small willow trees with an understory of herbaceous species produced the litter. For 30 years and beyond in clay settling ponds, litter biomass accumulation is increased by woody perennials and hardwood trees as well as the willows. in the 40-year-old control site, litter biomass came primarily from the well-developed willow shrub. community.

Relative Importance Value index (RIVI). Relative importance values were calculated for each of the sites that had two contiguous 50-meter belted transects. The results for each site are in Appendix, E. A summary of all species with a RIVI of over 10% is in Table 12. The RIVI for trees in one of the 60-year-old sites is based on three individuals. Salix caroliniana continues to dominate the tree and shrub strata at ail except the 30-year-old site. With the exception of Ludwigia peruviana there was no specific herbaceous vegetation associated with the Salix communities in the clay settling ponds.

Leaf Area Index (LAI). Photosynthetic primary production converts sunlight to biomass. The LAI is an attempt to measure this contribution to the system. In Figure 56, the LAI of four clay settling areas of different successional ages and the control site were compared. There is a considerable increase from 1 to

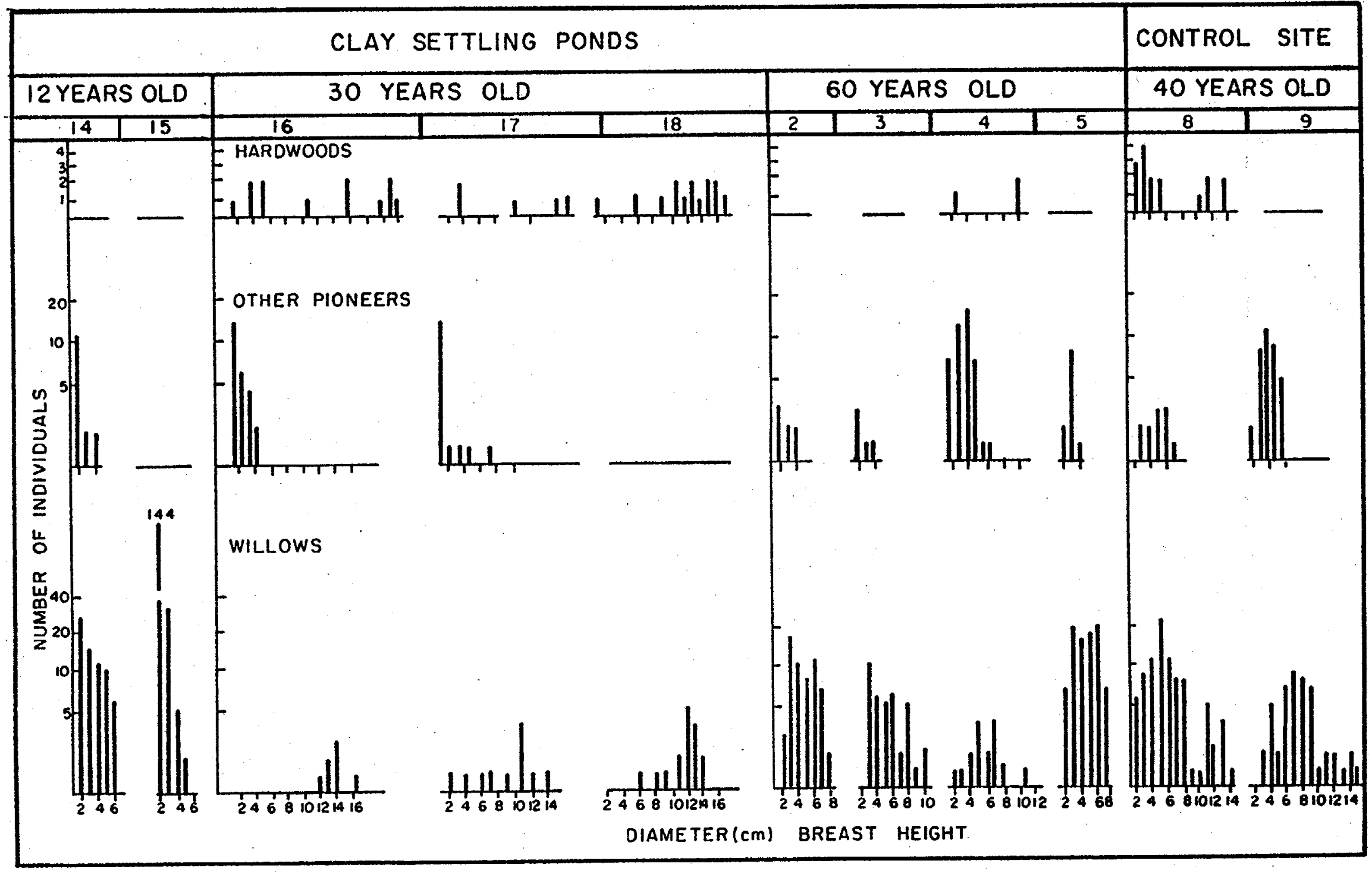


Figure 54. Size frequency histograms of the trees and shrubs in clay settling ponds and the control site. The bottom row is willows (Salix caroliniana), the middle row is other pioneer species (Cephalanthus occidentalis, Myrica cerifera, Sambucus simpsonii, Baccharis sp.) and the top row is hardwoods (Acer rubrum, Fraxinus sp., Cornus foemina, Ulmus americana, Celtis laevigata, and Quercus sp.).

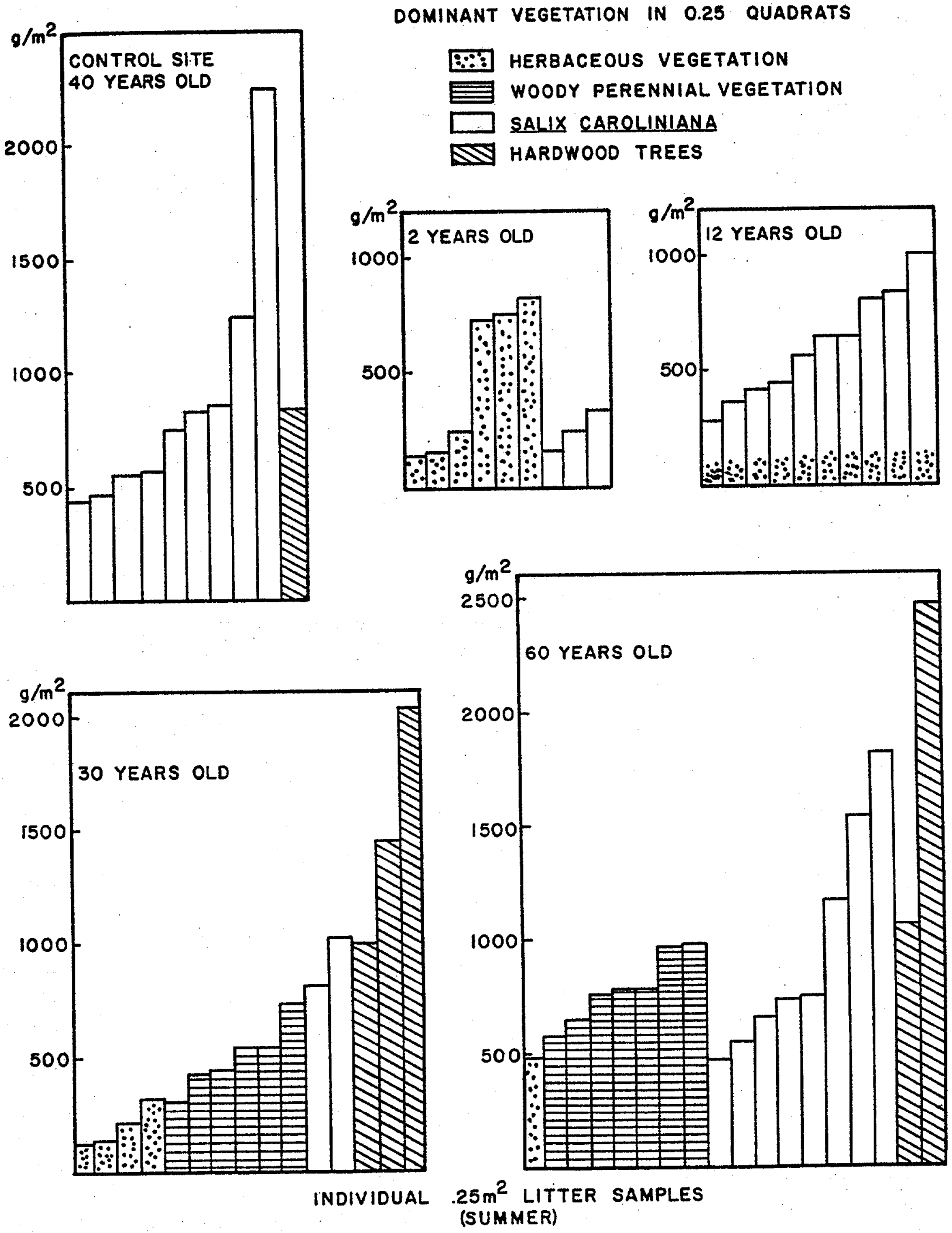


Figure 55. Litter accumulation in 0.25-m^2 quadrats compared by the dominant vegetation type found in the quadrat for the summer sampling period.

Table 12. Relative Importance Value Index (RIVI) above 10% for the various aged clay settling ponds and the control site for each 100-m transect.

		AGE OF SITE, YEARS					
		Clay Settling Ponds					Control Site
SIZE CLASS	SPECIES	2	12	30	60	60	40
TREE	*Salix caroliniana*	--	--	44.94	--	34.5	81.20
	Acer rubrum	--	--	30.68	--	32.71	18.80
	Quercus laurifolia	--	--	14.45	--	32.71	--
SHRUB	*Salix caroliniana*	--	93.80	17.70	88.84	60.53	69.39
	Myrica cerifera	--	--	45.47	--	11.55	--
	Sambucus simpsonii	--	--	15.08	--	--	--
	Cephalanthus occidentalis	--	--	--	--	19.58	19.90
HERB	*Salix caroliniana*	30.21	19.03	--	--	--	--
	Eichhornia crassipes	32.44	--	--	--	--	--
	Typha latifolia	16.62	--	--	--	--	--
	Sagittaria montevidensis	12.09	--	--	--	--	--
	Ludwigia peruviana	--	29.79	--	10.74	15.10	--
	Myrica cerifera	--	14.78	--	--	--	--
	Scirpus validus	--	10.70	--	--	--	--
	Clematis virginiana	--	--	17.67	--	--	--
	Parthenocissus quinquefolia	--	--	15.91	--	--	--
	Lygodium japonicum	--	--	13.72	--	--	--
	Rubus trivialis	--	--	--	35.79	--	--
	Hyptis alata	--	--	--	14.59	--	--
	Ampelopsis arborea	--	--	--	--	30.12	--
	Hydrocotyle verticillata	--	--	--	--	--	27.80
	Cladium jamaicense	--	--	--	--	--	15.84
	Acer rubrum	--	--	--	--	--	11.69
	Polygonum sp.	--	--	--	--	--	10.08

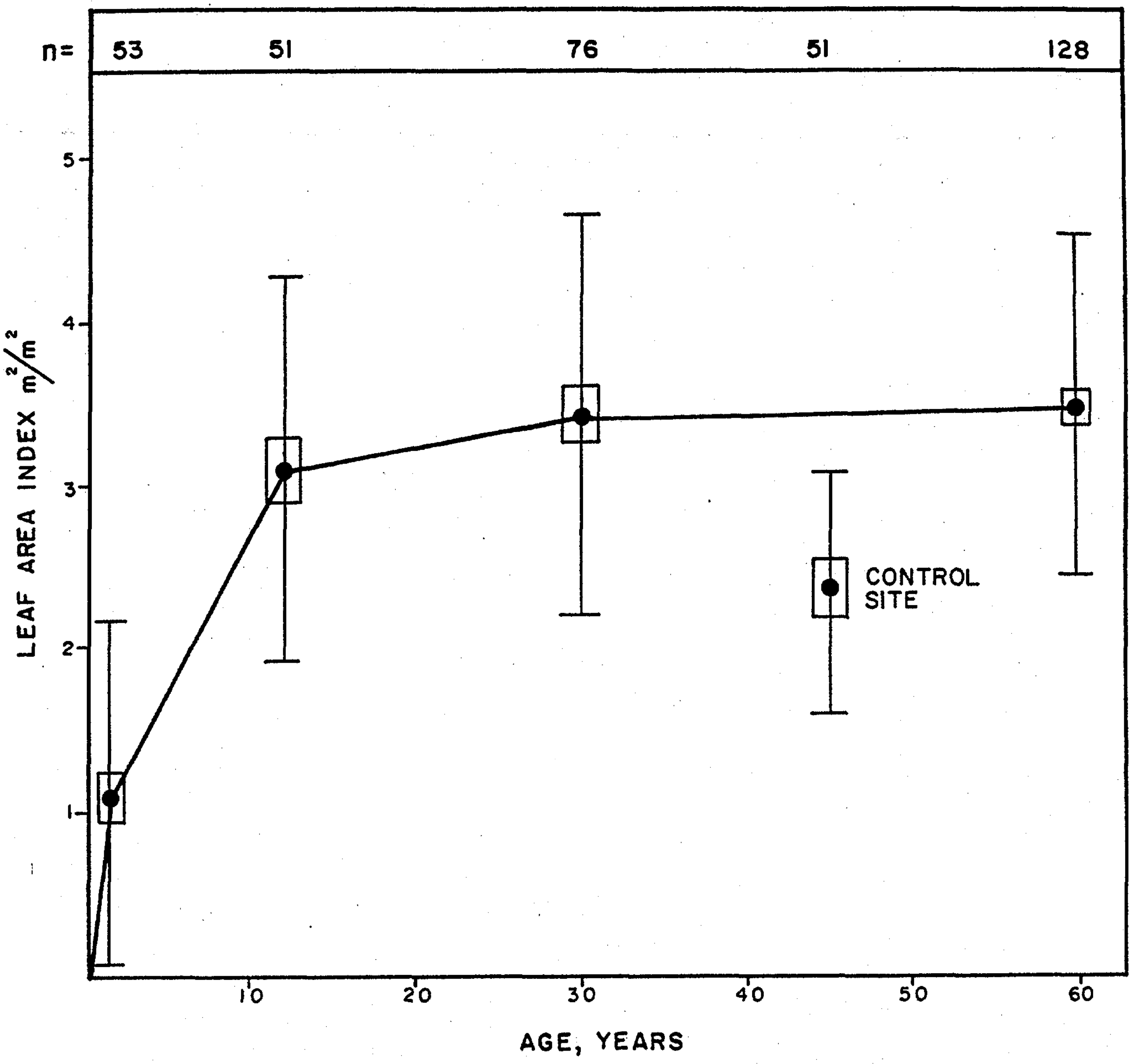


Figure 56. Comparison of Leaf Area Index (LAI) over time in phosphate clay settling areas and the control site. LAI counts one side of leaf. Connecting lines represent the arithmetic mean of all transects in each age group; the vertical lines are the standard deviations; the boxes are the standard error of the mean. The number of samples, n, for each site is listed across the top.

12 years and then a gradual leveling. This is consistent with the theory that leaf-surface areas of immature stands may be similar to, or sometimes larger than, those of mature forests (Whittaker and Woodwell 1967). The aberration of the control site is discussed below.

Vertical distribution of LAI for the 14 50-meter transects is shown graphically in Figure 57. The herbaceous layer from 0 to 2 meters remains the dominant vegetation type at all of the sites. Canopy structure may be developing at the 30-year-old site. Figure 58 also shows this relationship.

Water levels may also reduce LAI by reducing the low herbaceous layer. In Figure 59, LAI is plotted between sites where various levels of standing water were observed and those sites that were not flooded during July 1982 when the measurements were taken. This explains the much lower LAI at the control site at Lake Panasoffkee, which had been inundated for the previous 3 months, and the low LAI found for the wet transect at the 30-year-old site, which was under water at the time of measurement.

Optical density. The results for the optical density measurements are summarized in Table 13. The data from the computer printout are in Appendix F. The relationship between optical density readings and LAI are shown in Figure 60. Since it was first postulated by Monsi and Saeki (1953), many studies have suggested that optical density is linearly correlated with cumulative LAI. LAI measures vertical distribution and has a large variation from spot to spot where optical density with light from an angle averages biomass over a larger field.

The regression equation developed from the individual transects for optical density and LAI for this study show a poor correlation (r^2 = 0.50). The wetter sites as measured during LAI readings (transects 7, 8, 9, 15, and 18) are clustered at the lower end of the graph. The drier sites with variable amounts of understory vegetation show a more scattered pattern. This patchy nature is reflected by the number of sunflects and gaps as reported in Table 13. Whittaker (1966) found a strongly skewed log-normal distribution of light intensity on the forest floor from predominant shade to few sunflects. He recommended using a geometric mean.

Whether the sky was cloudy or clear is also reported in Table 13. Anderson (1964) reporting from the work of several investigators noted the total light received in a forest is greater on partially cloudy days than on clear or totally overcast days, although the percentage of total light in the open may fall. In this study cloudy readings did show higher transmittance. This may or may not have influenced the overall results.

The best correlation was obtained when the measurements from the transects in each site were averaged, then the regression equation of optical density to LAI is good (r^2 = 0.91) as seen in Figure 61.

Species composition and diversity. The individual plants counted for the different-aged clay settling ponds and the control site are listed in Table 14. The number of each species found in each 5-meter segment is in Appendix G. This latter grouping makes it possible to determine species that occur together on an environmental gradient and to analyze plant distribution. The common and botanical names of all species found in the study plots are listed in Appendix H.

Table 13. Optical density and leaf area index measured during the summer of 1982 in different age clay settling areas and the control site at Lake Panasoffkee. Values are expressed as the mean of n measurements ± 1 standard error.

	Light Penetration Measurements						Leaf Area	
Study site	Date 1982	Time	Sky	Gaps[a] % of n	n	Optical Density	n	LAI, m^2/m^2
Clear Springs-8								
(2 years old)								
Transect #6	—	-----	----	-	--	-----	26	0.69±0.15
Transect #7	7/11	1034-1400	Cloudy	30	75	0.33±0.02	25	1.52±0.57
Average							51	1.10±0.29
Noralyn 11A								
(12 years old)								
Transect #14	5/12	1022-1052	Cloudy	5	75	0.45±0.01	26	4.07±0.60
Transect #15	5/12	1055-1134	Cloudy	11	75	0.39±0.02	25	2.28±9.36
Average					150	0.42±0.01	51	3.18±0.36
Alderman Ford Ranch								
(30 years old)								
Transect #16	5/12	1325-1347	Clear	19	75	0.52±0.04	25	4.80±0.55
Transect #17	5/12	1355-1419	Clear	15	75	0.55±0.03	25	3.16±0.45
Transect #18	5/12	1500-1540	Cloudy	31	75	0.31±0.02	26	2.23±0.37
Average					225	0.46±0.02	76	3.37±0.29
Clark James								
(60 years old)								
Transect #1	5/11	1456-1523	Clear	16	75	0.49±0.03	26	3.07±0.48
Transect #2	5/11	0950-1040	Clear	9	75	0.40±0.02	26	4.46±0.47
Transect #3	5/11	1100-1135	Clear	8	75	0.47±0.02	25	3.60±0.37
Transect #4	5/11	1212-1247	Clear	15	75	0.60±0.03	26	2.85±0.33
Transect #5	5/11	1300-1337	Clear	7	75	0.67±0.02	23	3.70±0.39
Average					300	0.54±0.02	98	3.65±0.20
Control Site								
(45 years old)								
Transect #8	5/13	1000-1030	Cloudy	5	75	0.36±0.01	25	2.76±0.55
Transect #9	5/13	1032-1110	Cloudy	6	75	0.36±0.02	25	2.14±0.26
Average					150	0.36±0.01	50	2.37±0.21

[a] The percentage of the total number of readings taken in full sunlight because of gaps in the canopy or sunflects.

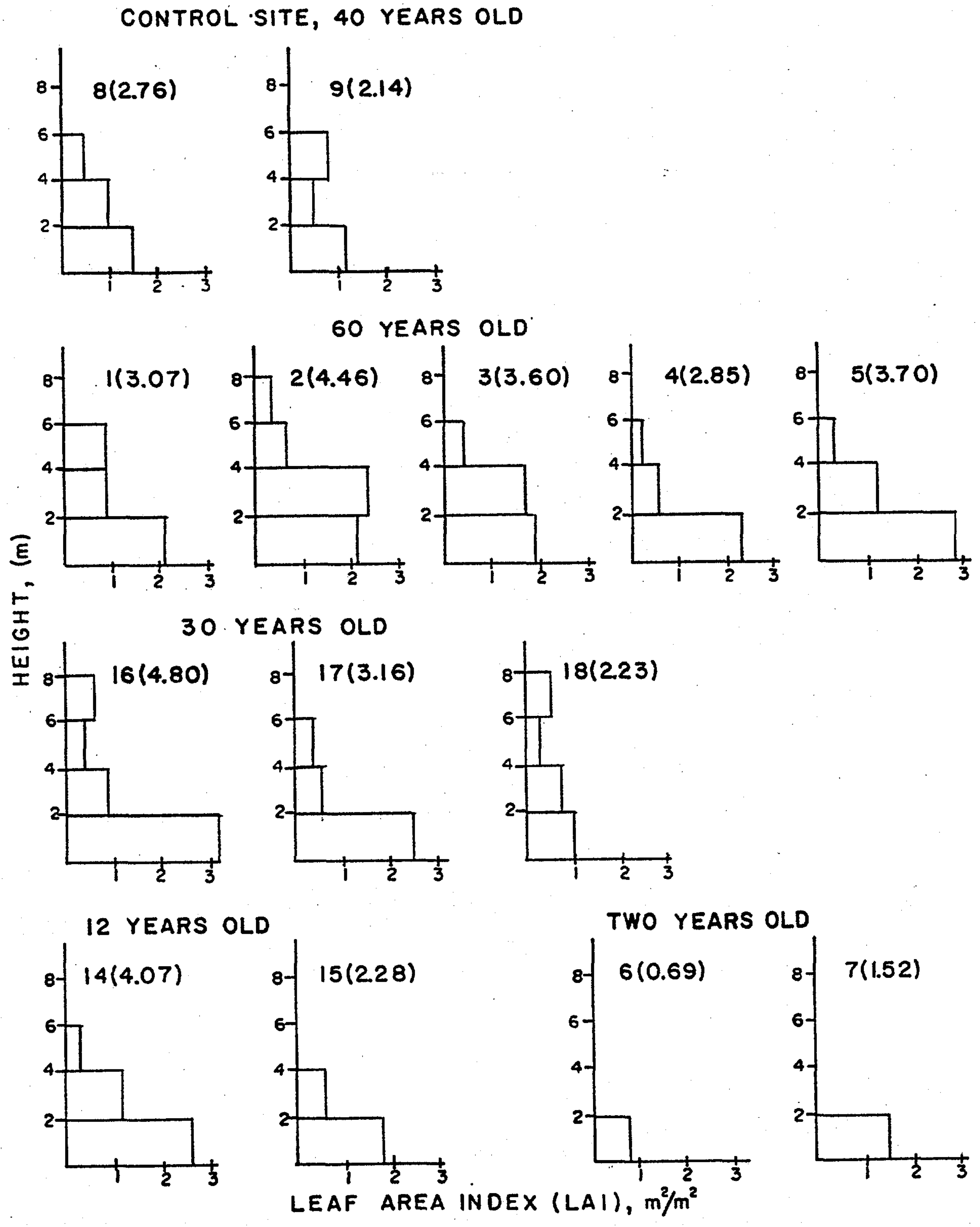


Figure 57. Vertical distribution of leaf area in phosphate clay settling areas of different ages and the control site at Lake Panasoffkee. The transect number and the leaf area index (in parentheses) accompany each diagram.

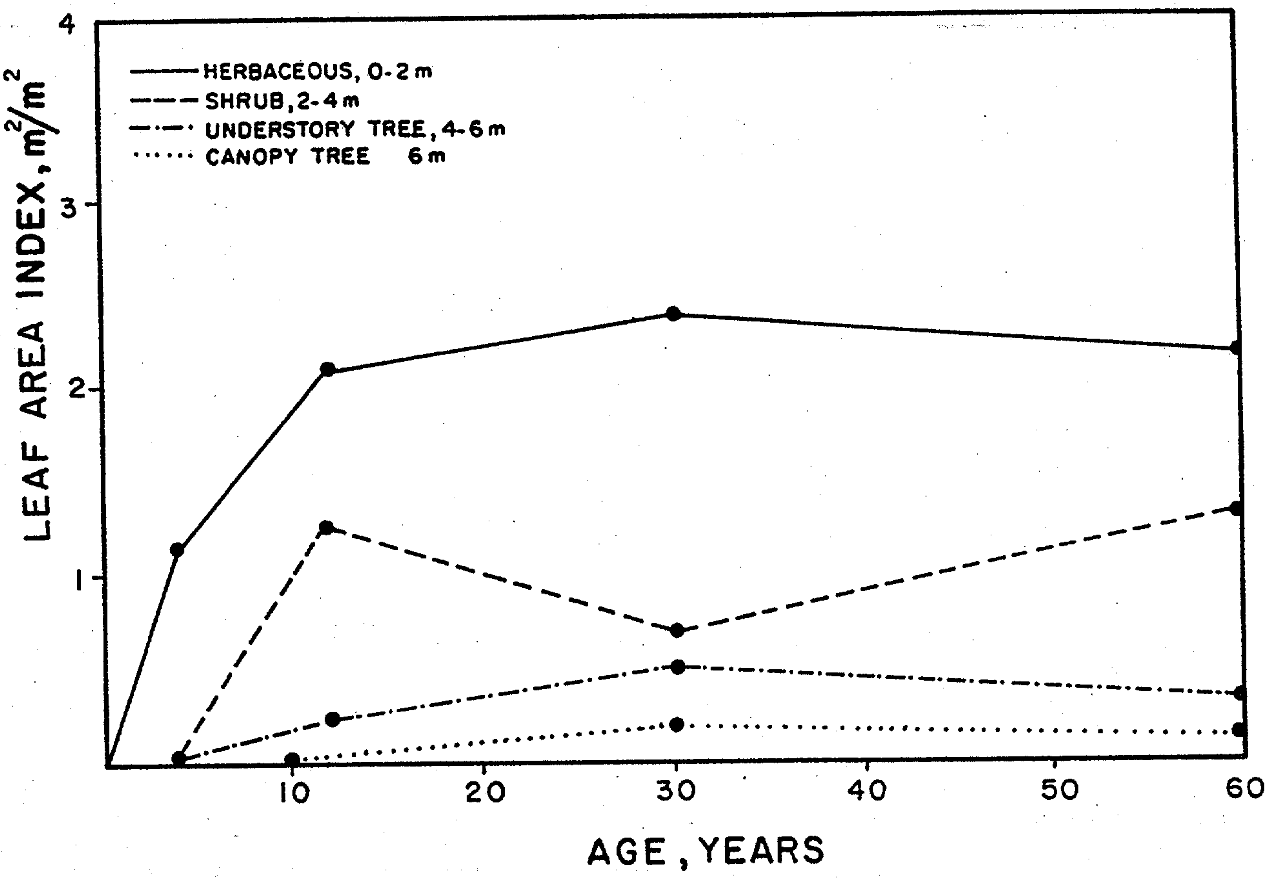


Figure 58. Leaf Area Index (LAI) of different strata in phosphate clay settling ponds over time.

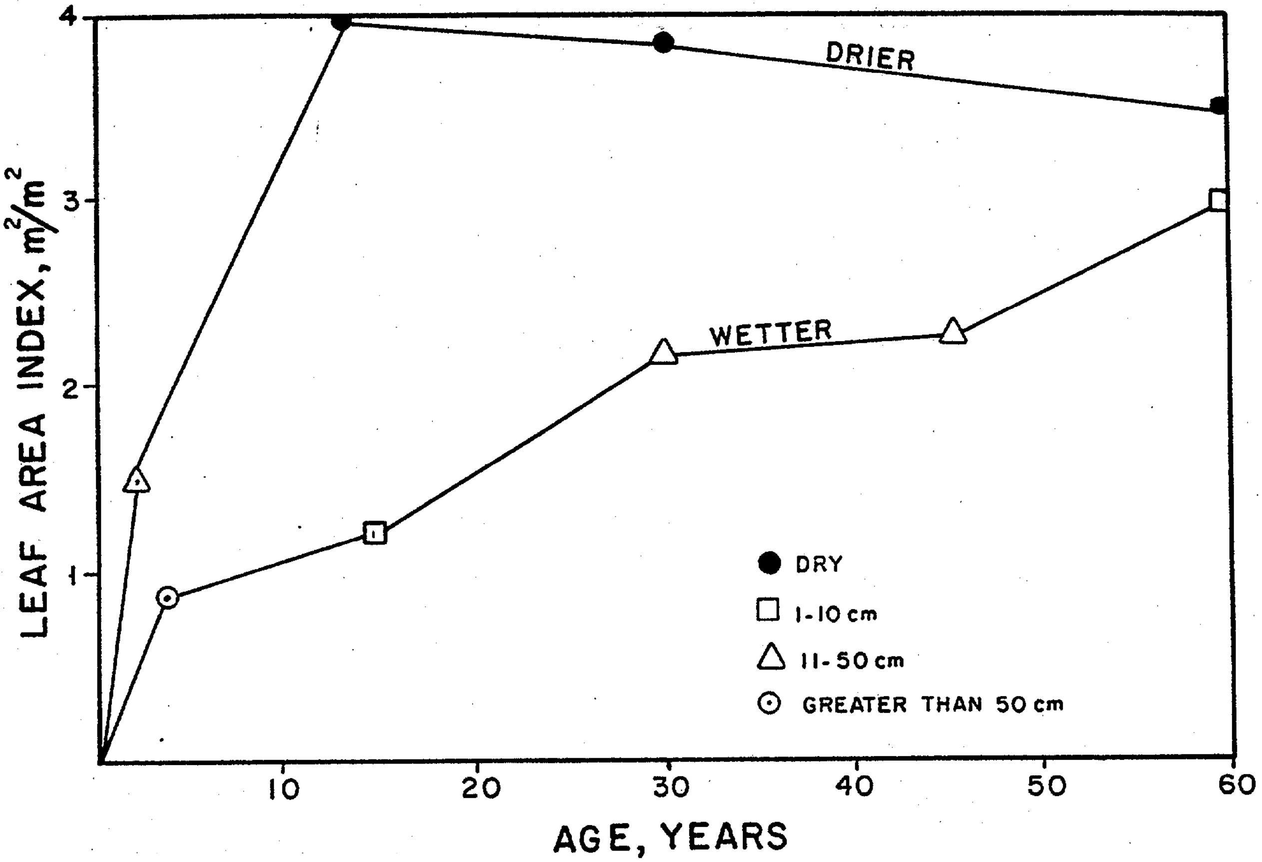


Figure 59. Leaf Area Index (LAI) in clay settling ponds and the control site compared to their relative moisture regimes. Water depths indicate the average water depths at the time measurements were made in July 1982.

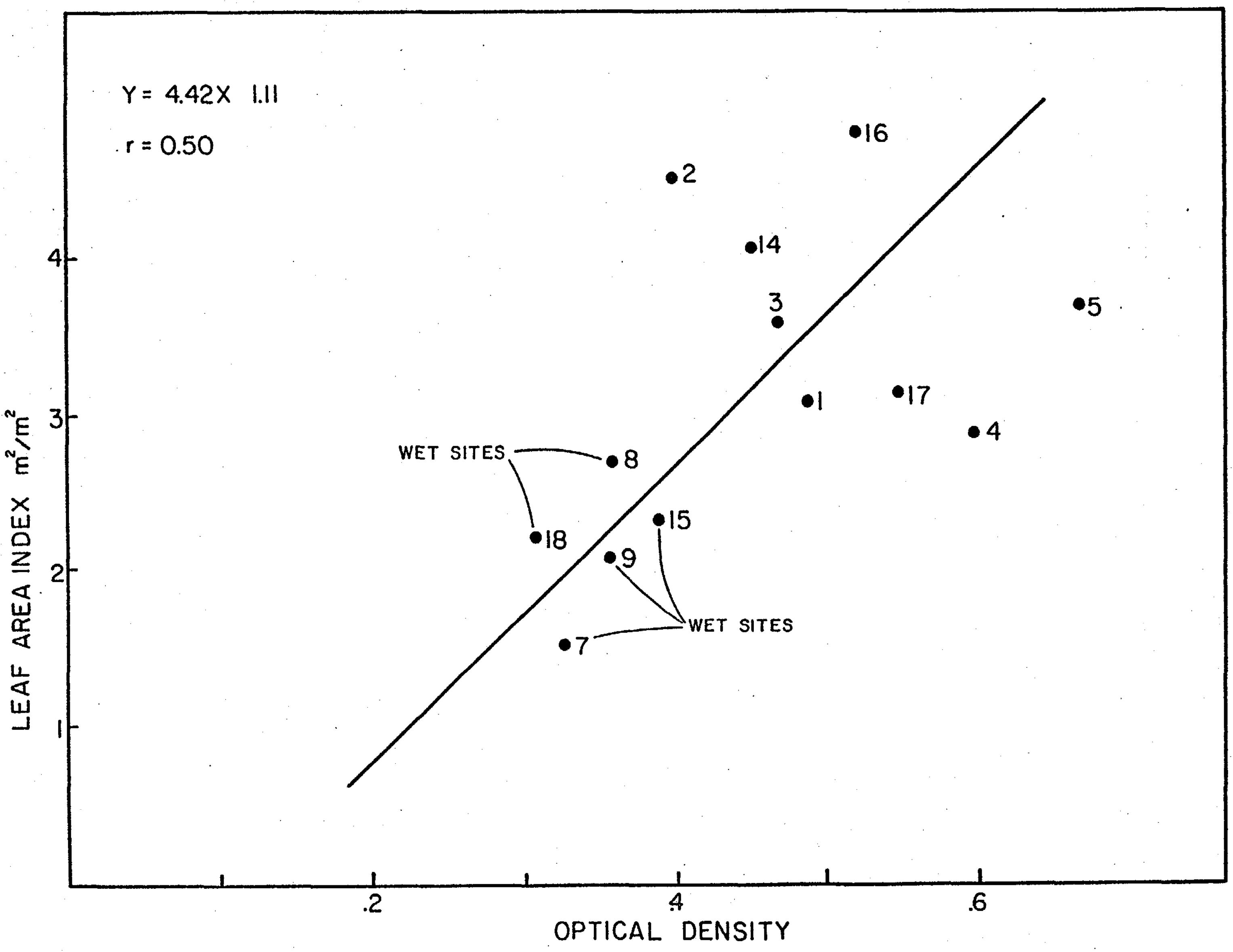


Figure 60. Relationship between cumulative leaf area index and optical density for each transect in four different aged clay settling areas and the control site at Lake Panasoffkee. Data from Table 13.

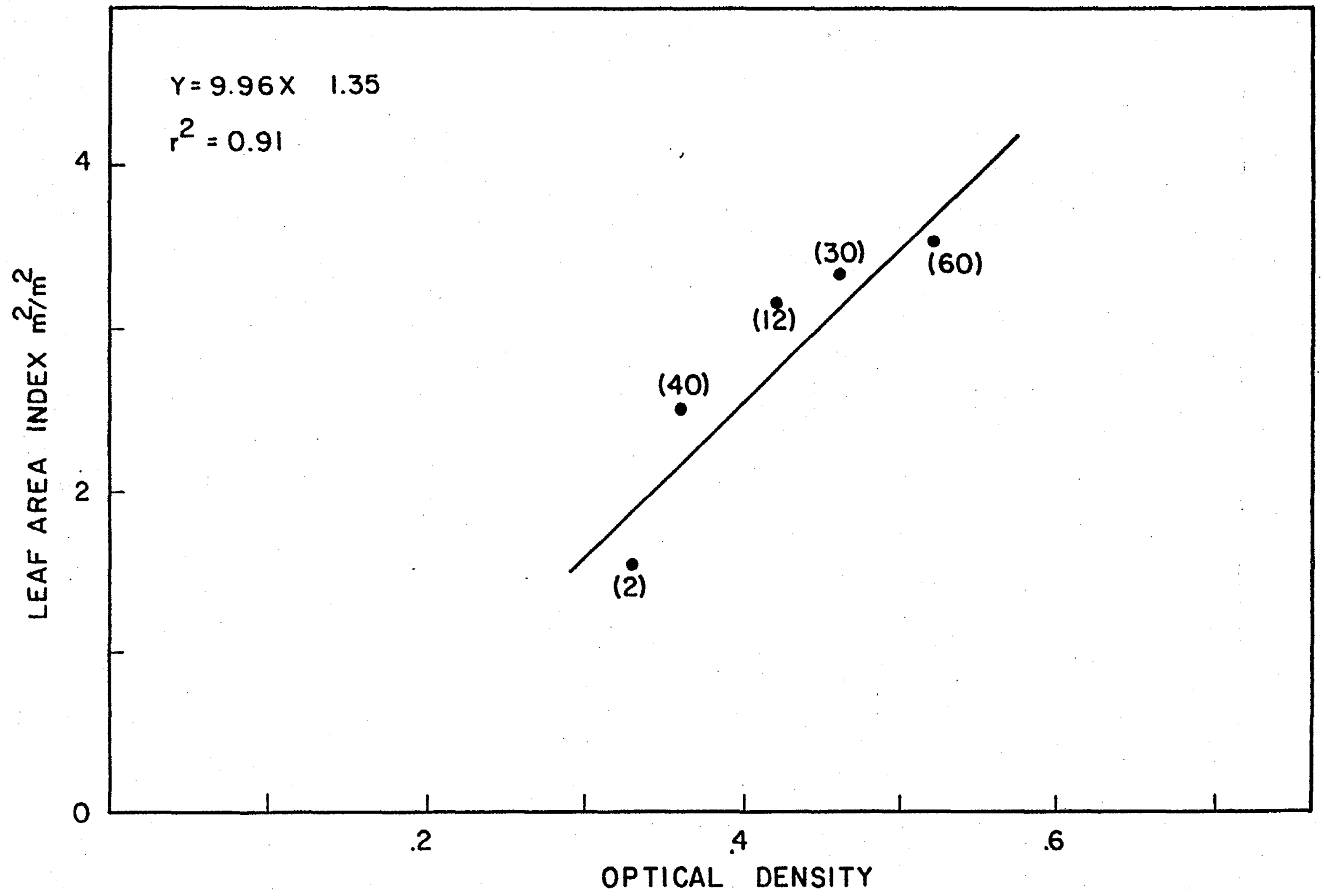


Figure 61. Relationship between cumulative leaf area index and optical density averaged for four different aged clay settling areas and the control site at Lake Panasoffkee. Data were averaged from the figures in Table 13. The age of the sites is in parentheses.

Table 14. Plant species found on four clay settling ponds and a control site with the abundance of each species for each 100-m transect.

	AGE OF SITE (YEARS)				
SPECIES	2	12	30	60	60	Control 40
TREES AND SHRUBS						
Acer rubrum	--	--	62	--	16	277
Baccharis halimifolia	108	13	9	54	36	11
Celtis laevigata	--	--	1	--	--	--
Cephalanthus occidentalis	--	--	--	6	152	9
Cinnamomum camphora	--	5	--	--	--	--
Cornus foemina	--	--	2	--	--	10
Fraxinus caroliniana	--	--	--	--	--	5
Liquidambar styraciflua	--	--	8	--	--	--
Magnolia virginiana	--	--	--	--	--	1
Myrica cerifera	--	104	106	2	3	28
Prunus caroliniana	--	--	--	--	--	1
Quercus laurifolia	--	--	15	--	1	1
Quercus nigra	--	--	4	--	2	--
Quercus virginiana	--	--	8	--	--	--
Quercus sp.	--	--	--	5	2	--
Rhus copallina	--	--	6	4	--	--
Rubus trivialis	--	--	170	124	57	1
Salix caroliniana	86	131	22	145	184	191
Sambucus simpsonii	--	--	100	74	55	91
Sapium sebiferum	--	3	--	--	--	--
Schinus terebinthifolius	--	--	--	1	2	--
Ulmus americana	--	--	15	--	--	1
VINES						
Ampelopsis arborea	--	--	33	21	107	6
Clematis virginiana	--	--	353	7	--	--
Ipomoea sp.	--	--	1	--	--	--
Lygodium japonicum	--	1	607	--	--	--
Melothira pendula	--	--	4	--	--	61
Mikania scandens	--	38	103	34	84	96
Momordica charantia	--	--	24	219	10	--
Parthenocissus quinquefolia	--	1	19	--	37	--
Passiflora incarnata	--	--	2	--	10	--
Smilax smallii	--	--	1	--	--	--
Toxicodendron radicans	--	--	43	--	1	70
Valeriana scandens	--	--	22	--	48	--
Vitis rotundifolia	--	--	2	1	--	1

Table 14. (continued)

	AGE OF SITE (YEARS)					
SPECIES	2	12	30	60	60	Control 40
HERBACEOUS VEGETATION						
Ambrosia artemisiifolia	--	--	5	--	--	7
Aster caroliniana	--	--	--	--	--	4
Boehmeria cylindrica	--	--	--	--	--	544
Callicarpa americana	--	--	2	2	--	--
Conyza parva	--	15	--	--	--	--
Desmodium sp.	--	--	2	--	--	--
Drymaria cordata	--	--	75	--	12	--
Erechtites hieracifolia	--	--	--	--	4	3
Eupatorium capillifolium	160	107	19	71	19	39
Eupatorium jucundum	--	--	--	--	15	--
Eupatorium sp.	--	--	12	2	2	--
Galactia sp.	--	--	1	--	3	--
Galium sp.	--	--	1	--	--	7
Hydrocotyle verticillata	--	--	--	22	2	125
Hyptis alata	--	3	8	19	10	--
Lantana camara	--	--	1	--	2	--
Ludwigia leptocarpa	63	--	--	--	--	--
Ludwigia peruviana	--	970	12	165	506	--
Lycopus rubellus	--	1	--	--	--	--
Lythrum lineare	--	394	--	--	--	--
Oxalix sp.	--	--	--	--	1	--
Physalis sp.	--	--	--	2	--	--
Phytolacca americana	--	--	1	2	7	--
Pluchea purpurascens	--	20	--	--	--	--
Polygonum sp.	--	--	3	777	369	69
Triadenum virginicum	--	--	--	4	--	--
Urena lobata	--	3	8	19	10	--
Unknown composite	--	--	2	--	--	--
OTHER						
Cladium jamaicense	--	--	--	--	--	133
Cyperus odoratus	3	--	--	--	--	--
Eichhornia crassipes	284	--	--	--	--	--
Osmunda cinnamomea	--	--	--	--	--	177
Osmunda regalis	--	--	--	--	--	11
Scirpus validus	--	87	2	--	2	--
Poaceae	--	107	32	1	1	--
Sagittaria montevidensis	128	--	--	--	--	--
Thelepteris normalis	--	--	27	5	3	--
Typha sp.	67	16	--	--	--	--

The 2-year-old site was dominated by marsh species except for an abundance of groundsel (Baccharis) and dog-fennel (Eupatorium), which had colonized during the dry summer of 1981, but was only evident around the edge in 1982.

The 12-year-old site had a large number of myrtle (Myrica cerifera) seedlings colonizing, especially the drier segments in transect 14. Primrose, willow (Ludwigia peruviana) was the dominant herbaceous species, and it became more abundant as the water table came closer to the surface in transect 15.

The most number of species was found at the 30-year-old dry site. Since transect 18 was under water, only the individuals in the drier transects (16 and 17) were counted. The plants at transects 16 and 17 are more characteristic of drier habitats than were most of the other clay ponds. The exotic fern vine (Lygodium japonicum) was the dominant herbaceous species and frequently formed dense mats. Tree seedlings were clustered close to parent trees. Where an American elm (Ulmus americana) tree was located, 11 seedlings were counted along the line transect within 10 meters, while only two were counted at a distance. Sweetgum (Liquidambar styraciflua) had six seedlings established along the line transect within 5 meters and only one at a distance of 20 meters. Oak (Quercus spp.) seedlings and red maple. (Acer rubrum) were more evenly spaced along the two transects, but so were the trees and saplings of these species.

The 60-year-old site had fewer species than the 30-year-old site. However, the drier transect (4) has almost as many species but many fewer tree seedlings. This may indicate a case of arrested succession because appropriate seeds for more mature wetlands were unable to migrate to the 60-year-old site.

Species diversity at the 40-year-old control site was measured after the dry summer of 1982. Greater numbers of red maple (Acer rubrum) and ash (Fraxinus caroliniana) seedlings were found at the beginning of transect 8, which was closest to the hardwood swamp. The most common herbaceous vegetation was sawgrass (Cladium jamaicense) and cinnamon fern (Osmunda cinnamomea) .

Some indices of species structure are found in Table 15 and Figure 62. One measure of a community's diversity is to try to count the number of species present. This is the method represented by the species per thousand individuals and the diversity graph in Figure 62. This is an unweighted measure analogous to the range (in a statistical sense) of a quantitative variant (Pielou 1975). To arrive at a weighted measure that includes relative abundance as well as the number of species, the Shannon Index was used. It counts rare species relatively less than common ones (Ricklefs 1979). This latter scheme gives a higher diversity to both the 2-year-old clay settling pond and the 40-year-old control site, since they were characterized by fewer, more evenly represented species.

Environmental gradients may also influence species diversity. Monk (1965) reported community types characterized by extremes in moisture are less diverse than those in middle moisture conditions. The drier 30-year-old site had the highest diversity, and it also had the greatest number of surviving tree seedlings. The 60-year-old dredge pits and the 40-year-old control site had lower diversity.

Soil texture analysis. The data on soil cores analyzed for particle size are summarized for each site in Tables 16-20. For most samples two depths were analyzed, 0-20 centimeters and 20-40 centimeters.

Table 15. Species diversity for four clay settling ponds and a control site.

Age of Site (Transect no.)	Number of Individuals counted	Species/1000 Individuals	Shannon Index Nat LOG_e	Shannon Index Bit LOG_2	Shannon Exponent
2 years (6)	899	7.8	1.83	2.64	10.10
12 years (14, 15)	2063	19.5	1.81	2.61	22.00
30 years (16, 17)	1956	36.1	2.51	3.62	49.74
60 years (2, 3)	1770	23.5	2.00	2.87	29.20
(4, 5)	1763	31.5	2.31	3.34	36.55
40 years Control site (8, 9)	1973	23.5	2.41	3.49	30.66

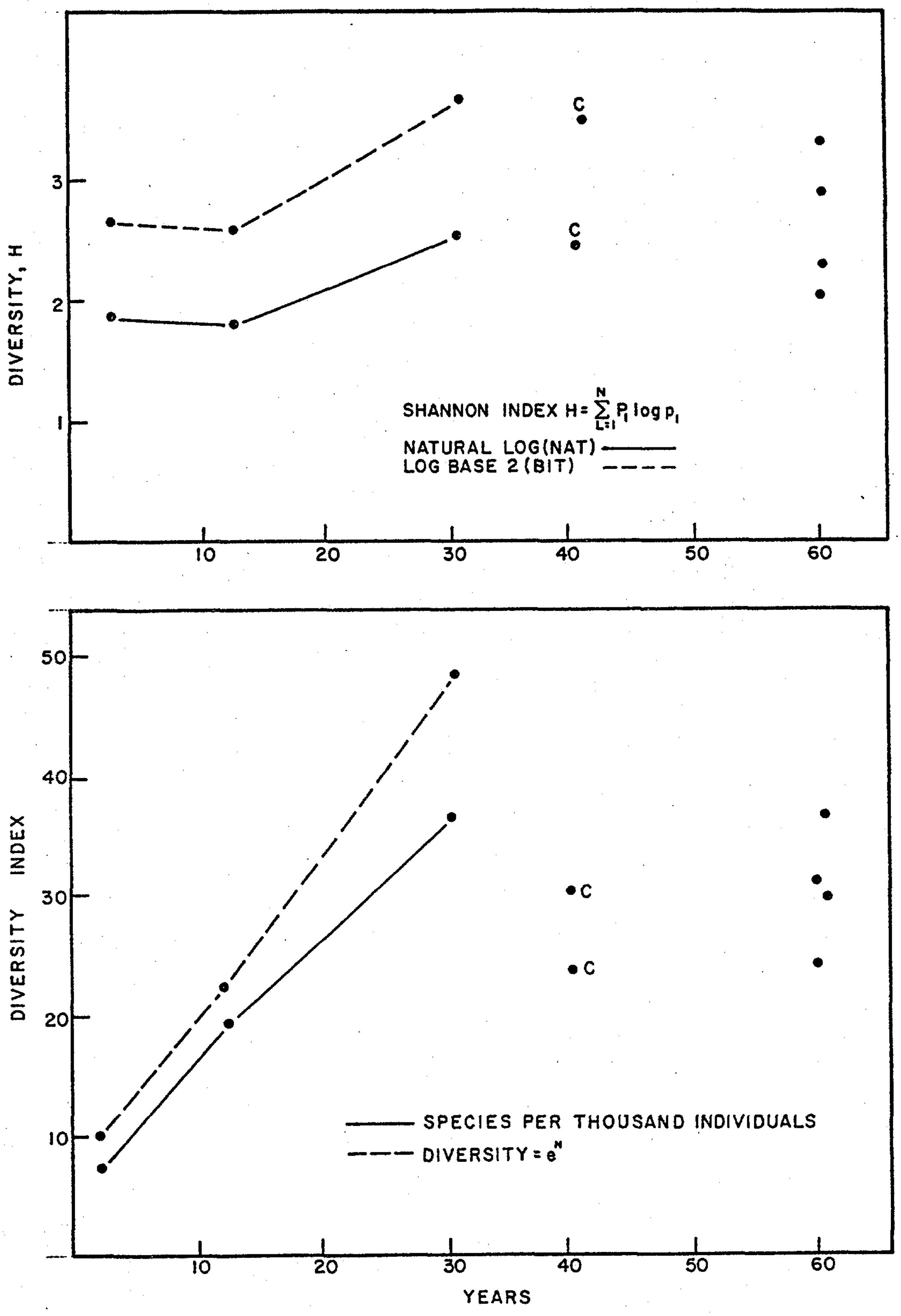


Figure 62. Changes in plant species diversity in clay settling ponds and a control site (C). The control and especially the 60-year-old site represent apparent anomolies influenced by highly variable moisture regimes and/or seed availability. Two quadrats were sampled at the 60-year-old site.

Table 16. Soil texture analysis in Clear Springs-8 (2 years old).*

Distance from Transect Start (Replicate Samples)	0–20 cm depth			20–40 cm depth			Average		
	% Sand	% Silt	% Clay	% Sand	% Silt	% Clay	% Sand	% Silt	% Clay
Transect 6									
20 meters (1)	9	29	62	--	--	--	14.50	24.50	61.00
20 meters (2)	20	20	60	--	--	--			
Transect 7									
40 meters (1)	0	29	71	--	--	--	3.00	26.50	70.5
40 meters (2)	6	24	70	--	--	--			

*Soil particle size analyses were divided into fractions according to the U.S. Dept. of Agriculture scheme (sand, >0.05 mm; silt, 0.05–0.002 mm; and clay, <0.002 mm)

Table 17. Soil texture analysis at Noralyn-11A site (12 years old).*

Distance from Transect Start (replicate samples)	0–20 cm depth			20–40 cm depth			Average		
	% Sand	% Silt	% Clay	% Sand	% Silt	% Clay	% Sand	% Silt	% Clay
Transect 14									
5 meters	20	37	43	--	--	--	20.00	37.00	43.00
15 meters (1)	13	29	58	13	35	52	11.50	36.50	47.25
15 meters (2)	9	36	55	11	46	43			
48 meters (1)	9	40	51	5	25	70	8.00	30.25	61.75
48 meters (2)	9	26	65	9	30	61			
Transect 15									
25 meters	10	28	62	7	15	78	8.50	21.50	70.00
48 meters	2	17	81	--	--	--	2.00	17.00	81.00
Seed transplant site #2	0	19	81	--	--	--	0.00	19.00	81.00

*Soil particle size analyses were divided into fractions according to the U.S. Dept. of Agriculture scheme (sand, >0.05 mm; silt, 0.05–0.002 cm; and clay, <0.002 mm).

Table 18. Soil texture analysis at Alderman Ford Ranch site (30 years old).*

Distance from Transect Start (Replicate Samples)	0–20 cm depth			20–40 cm depth			Average		
	% Sand	% Silt	% Clay	% Sand	% Silt	% Clay	% Sand	% Silt	% Clay
Transect 16									
5 meters (1)	1	19	81	0	17	83	1.75	16.75	81.75
5 meters (2)	1	16	83	5	15	80			
25 meters	1	13	86	0	14	86	0.50	13.5	86.00
Transect 17									
5 meters	0	15	85	0	17	83	0.00	16.00	84.00
42 meters (1)	0	16	84	0	16	84	1.00	16.00	83.00
42 meters (2)	3	13	84	1	19	80			
Top of berm between swales (cross section Fig. 63)									
	5	22	73	5	19	76	5.00	20.50	74.50
Next to dike (cross section Fig. 63)									
	0	13	87	--	--	--	0.00	13.00	87.00

*Soil particle size analyses were divided into fractions according to the U.S. Dept. of Agriculture scheme (sand, >0.05 mm; silt, 0.05–0.002 mm; and clay, <0.002 mm).

Table 19. Soil texture analysis at Clark James site (60 years old).*

Distance from Transect Start (Replicate Samples)	0–20 cm depth			20–40 cm depth			Average		
	% Sand	% Silt	% Clay	% Sand	% Silt	% Clay	% Sand	% Silt	% Clay
Transect 4									
5 meters (1)	42	16	42	96	1	3	74.75	5.75	19.50
5 meters (2)	66	3	31	95	3	2			
25 meters	0	13	87	0	24	76	0.00	18.50	81.50
40 meters	7	22	71	0	18	75	3.5	23.50	73.00
Transect 5									
5 meters	0	20	80	0	18	82	0.00	19.00	81.00

*Soil particle size analyses were divided into fractions according to the U.S. Dept. of Agriculture scheme (sand, >0.05 mm; silt, 0.05–0.002 mm; and clay, <0.002 mm).

Table 20. Soil texture analysis at Clark James site (60 years old).*

Distance from Transect Start (Replicate Samples)	0–20 cm depth			20–40 cm depth			Average		
	% Sand	% Silt	% Clay	% Sand	% Silt	% Clay	% Sand	% Silt	% Clay
Sand/clay deposition site									
(1)	96	3	1	38	14	48	81.75	5.00	13.24
(2)	97	1	2	96	2	2			
Transect 2									
5 meters (1)	20	11	69	60	7	32	42.50	7.75	49.50
5 meters (2)	7	12	81	83	1	16			
10 meters	4	12	84	4	14	82	4.00	13.00	83.00
Transect 3									
15 meters (1)	0	25	75	0	15	95	0.25	17.75	84.50
15 meters (2)	0	21	79	1	10	89			
45 meters (1)	4	21	75	1	5	94	4.75	12.00	83.25
45 meters (2)	14	15	71	0	7	93			

*Soil particle size analyses were divided into fractions according to the U.S. Dept. of Agriculture scheme (sand, >0.05 mm; silt, 0.05–0.002 mm; and clay, <0.002 mm).

The youngest sites had the least percent clay of all the clay sites sampled. This result may be an artifact of the location of these transects closer to the inflow pipe. They do show an increase in clay content as you move away from the deposition site. Hawkins (1973) also observed trends of increased clay content with increased time of settling in the field, which were attributed to differential settling.

Sand and clay were deposited together at the 60-year-old dredge pits. The deposition site shows the almost complete migration of clay out of the sand except for an occasional clay ball such as the one found in the 20-40-centimeter sample (1). The flow of sand and clay show clay on top of the sand in clearly defined layers at the sand/clay interface in transects 2 and 4.

The 30-year-old transects and the clay basins of the 60-year-old site had about the same amount of clay (81-85%). The 30-year-old site had the most uniform samples and the least differences between depths. At the other sites, soil with the higher clay content remained at the top near the upslope deposition sites, while the higher clay content soils tended to migrate to the deeper levels at the downslope locations.

Hardwood Seedlings

Establishment and survival. The results of the seedling plot measurements are presented in Table 21. The 30-year-old clay settling pond had the greatest number of seedlings germinate, and the drier site had the greatest survival rate. Although the 30-year-old wet site had the most seedlings in April, only those individuals survived that were tall enough to escape complete inundation during the wet season. The 60-year-old clay settling pond had many fewer seedlings overall and only two survivors. The 40-year-old control site had slightly fewer numbers of individuals established than the 30-year-old clay pond and less species diversity. An 8-month period of inundation at the control site may have eliminated all of the smaller individuals. However, the robust appearance of the survivors indicated flooding was not a serious setback. Red maple (*Acer rubrum*) was much more common than any of the other seedling species, indicating it may become the dominant during the next stage of succession at all but the 60-year-old site.

Soil plot transplant experiments. The results of the transplated soil plots are found in Table 22. More species germinated in the transplanted plots than are normally found in clay settling ponds. This suggests there may be a limitation to succession caused by an inadequate supply of seeds, microbes, or other essential components. Although this represents a limited sample, it indicates there may be a transport problem and other species are able to survive and thrive for at least 1 year at some locations. The 12-year-old site #1 in transect 14 with the water table 20-40 centimeters below the surface in January 1983 (see Figure 46) had the greatest success of the clay settling areas.

Water Depth and Vegetation

The graphs used to describe the quantitative measurements of community structure for each transect (Figures 49-52) were summarized with cross section sketches that relate water table and observed tree species for longer transects.

Table 21. Establishment and survival of hardwood seedlings.†

Site	April 1982		January 1983		
	Number of Stems/0.1 ha	Average Height, cm	Number of Stems/0.1 ha	Average Height, cm	Percent Survival
30-Year-Old Site					
Dry (Transects 16, 17)					
Acer rubrum (Red maple)	1275	27	900	29	71
Ulmus americana (American elm)	325	35	100	55	31
Celtis laevigata (Hackberry)	75	36	0	0	0
Liquidambar styraciflua (Sweetgum)	25	8	25	8	100
Quercus nigra (Water oak)	25	30	28	48	100
Wet (Transect 18)					
Acer rubrum (Red maple)	1800	29	200	70	2
Ulmus americana (American elm)	1250	37	50	94	4
Magnolia virginiana (Sweet bay)	50	60	0	0	0
Quercus laurifolia (Laurel oak)	50	40	0	0	0
60-Year-Old Site					
Transects 2, 3					
Quercus sp. (Oak)	5	27	0	0	0
Transects 4, 5					
Quercus sp. (Oak)	2	24	0	0	0
Acer rubrum (Red maple)	2	25	2	60	100
40-Year-Old Control Site					
Transects 8, 9					
Acer rubrum (Red maple)	1705	51	650	76	38
Cornus foemina (Stiff-cornell dogwood)	25	24	26	120	100

†Measured in ten 2 m x 2 m plots per 0.1-ha transect. In the 60-year-old site seedlings were measured in the entire 0.1-ha transect.

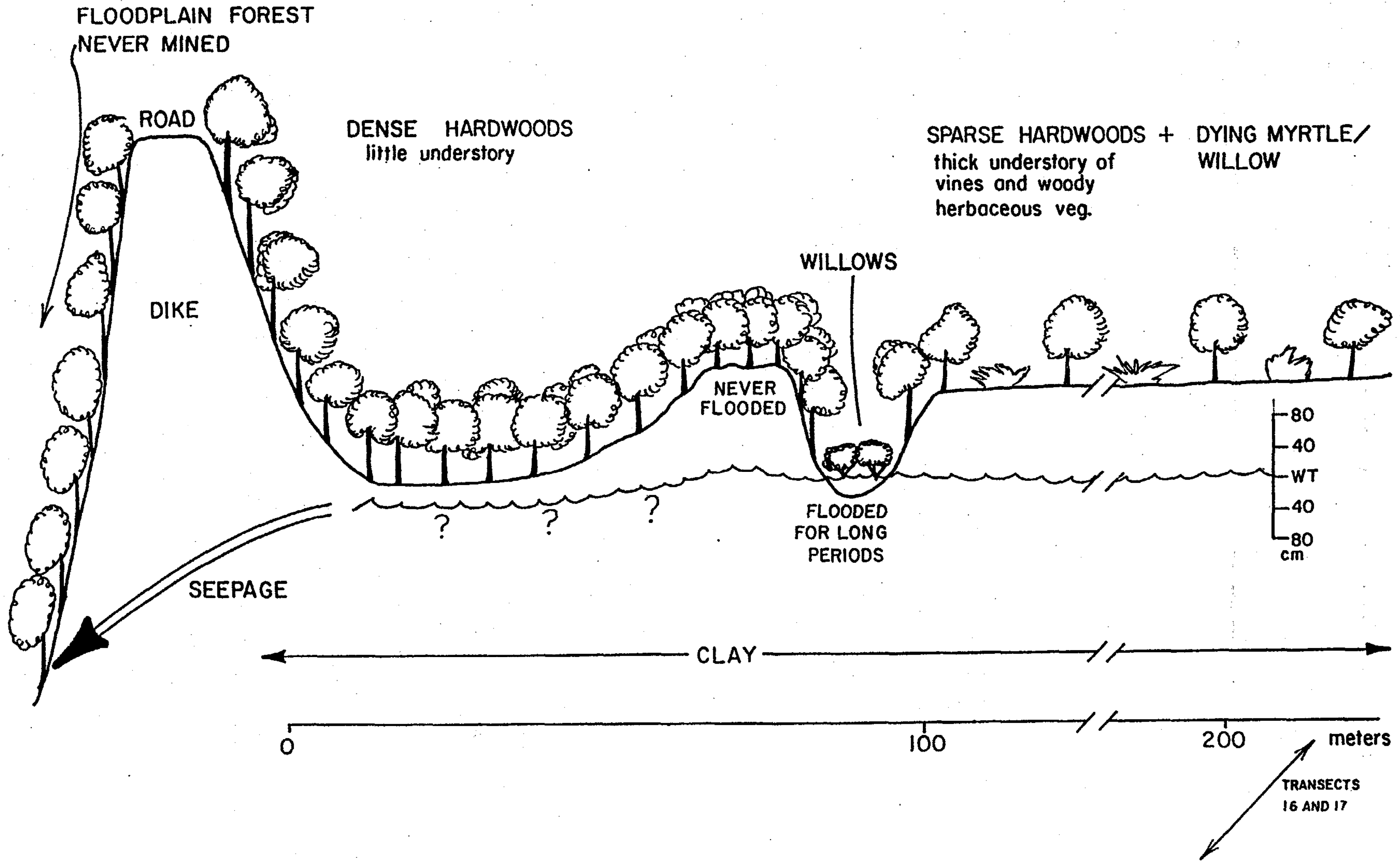
Table 22. Survival of tree and shrub seedlings in transplanted soil plots.†

Soil Plots Transplanted Dec. 28, 1982	Donor Sites			
	Oak Hammock	Floodplain Hardwood Swamp	Cypress Dome	Lake Hardwood Swamp
60-Year-Old Site				
May 28, 1982	1 *Quercus* (3)	None	None	2 *Cephalanthus* (18.0±2)
Jan. 7, 1983	None*	None*	None*	None*
12-Year-Old Site 1				
May 28, 1982	6 *Quercus* (8.3±1.4)	5 *Itea* (21.4±4.0) 1 *Cornus* (10)	None	---
Jan. 7, 1983	7 *Quercus* (13.2±2.5)	10 *Itea* (34.0±9.9) 1 *Cornus* (39)	None	---
12-Year-Old Site 2				
May 28, 1982	1 *Quercus* (3)	None	None	---
Jan. 7, 1983	None	None	None	---
Control				
May 28, 1982	36 *Quercus* (7.4±0.41)	5 *Itea* (45.4±6.2) 2 *Acer* (14.0±12.0)	None*	---
Jan. 7, 1982	40 *Quercus* (9.1±0.86)	6 *Itea* (52.7±6.7)	None*	---

†Thirteen soil plots (1 m x 1 m x 5 cm) were transplanted into several clay settling ponds and also back into the donor site as a control. Number of germinated seedlings are listed by genus, average heights (cm) and ± 1 standard errors are in parentheses. Species identified are oaks (*Quercus* spp.), Virginia willow (*Itea virginica*), stiff-cornel dogwood (*Cornus foemina*), buttonbush (*Cephalanthus occidentalis*), and red maple (*Acer rubrum*).

*Flooded

Figure 63. Alderman Ford Ranch, 30 years old. A hardwood hammock was found in the first swale and on top of the ridge. In the second swale there was a willow community similar to those found on other clay settling ponds. The interior of the site is a patchy vine covered hardwood community. Vertical exaggeration is approximately 1:13. Water table was measured January 1983.



For the Alderman Ford Ranch site, 30 years old, a 200-meter cross section perpendicular to the dike on the west and almost perpendicular to transects 16 and 17 on the east is shown in Figure 63. A hardwood hammock was observed developing in the first swale and also on top of the ridge. The inner swale supported a willow community similar to those found on other clay settling ponds. The interior was a patchy vine-covered hardwood community emerging from a stand of senescent willow (Salix caroliniana) and myrtle (Myrica cerifera). The thick vine and herbaceous vegetation and sparse tree cover made the interior of the site quite different from the part closer to the dike. Also the interior swale dominated by willows had been flooded for the entire year of observation, but the one next to the dike was only occasionally flooded. When the outside of the dike was inspected, seepage areas indicated increasing drainage and decreasing hydroperiod for the outside swale.

Another cross section (Figure 64) at the 30-year-old site showed definite zones of vegetation associated with topography. In general, willow (S. caroliniana) dominated the depressions, red maple (Acer rubrum) occupied the intermediate levels, and oaks (Quercus spp.) colonized the higher elevations. This site had been flooded for the past 6 months.

Some of the same vegetation patterns observed at the 30-year-old site were also seen at the 60-year-old dredge pits except the 60-year-old site had much less tree diversity and it appeared to be in a stage of arrested succession. The cross sections, Figures 65 and 66, extended from the sandy deposition site across the lower elevations, where the fine grained clay particles migrated, to the opposite bank. Willows and less frequently buttonbush (Cephalanthus occidentalis) occupied the deeper depressions. Myrtle and oak grew on the higher elevations and red maples grew in an intermediate zone in one of the transects. A few bay trees (Magnolia virginiana) occupied a seepage zone at the sand/clay interface. Thickets of vines and blackberries along with sparse tree cover surrounded the willow ponds on the gentler slopes.

The 40-year-old control site on the shore of Lake Panasoffkee was also dominated by a willow community. The cross section shown in Figure 67 extended from the hardwood swamp through a willow community to the existing ‘marsh growing in an old logging channel. Red maples and less frequently ash (Fraxinus caroliniana) were found widely scattered among the willows.

Discussion

Evidence from ecosystem measurements indicated several different patterns of adaptation and organization emerging in the new situation of clay settling ponds. Poor dispersal of species was an outside limiting function retarding succession in ail ponds. The 60-year-old site appeared, to be a case of arrested willow succession, whereas the 30-year-old site with a nearby seed source was developing a wetland hardwood forest. The 4O-year-old control site was making a transition to a lake border swamp. Case histories of the study sites indicated succession could be moving toward, several different kinds of vegetative communities.

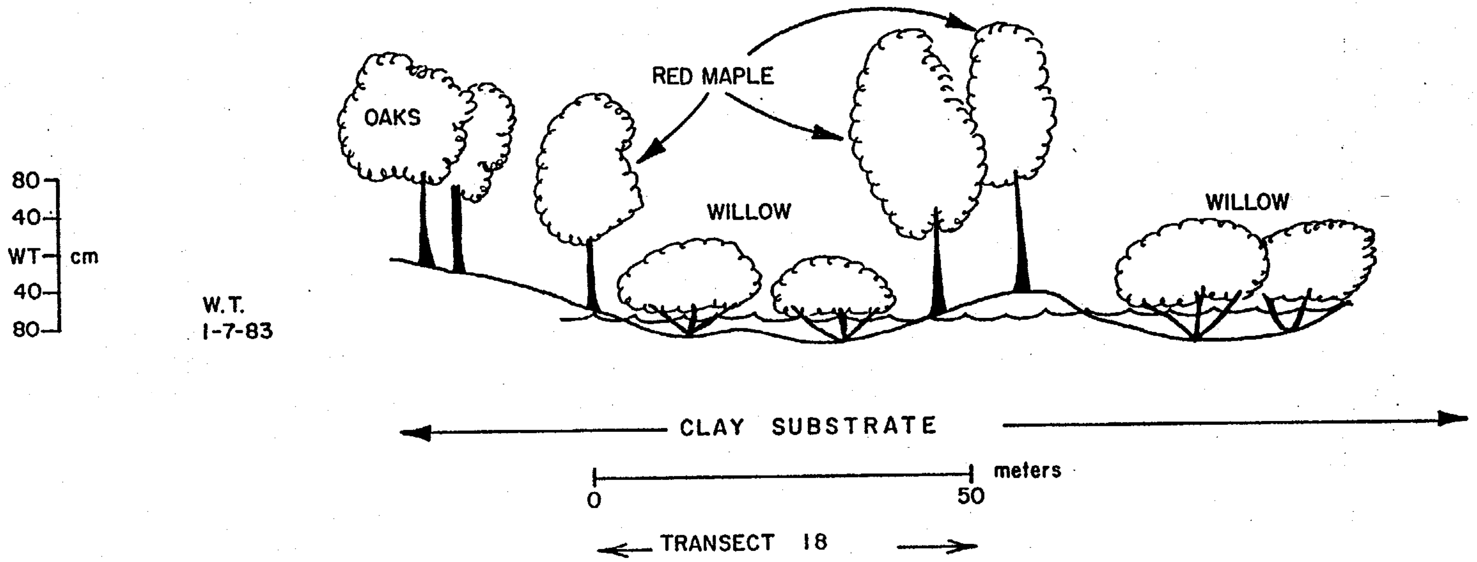
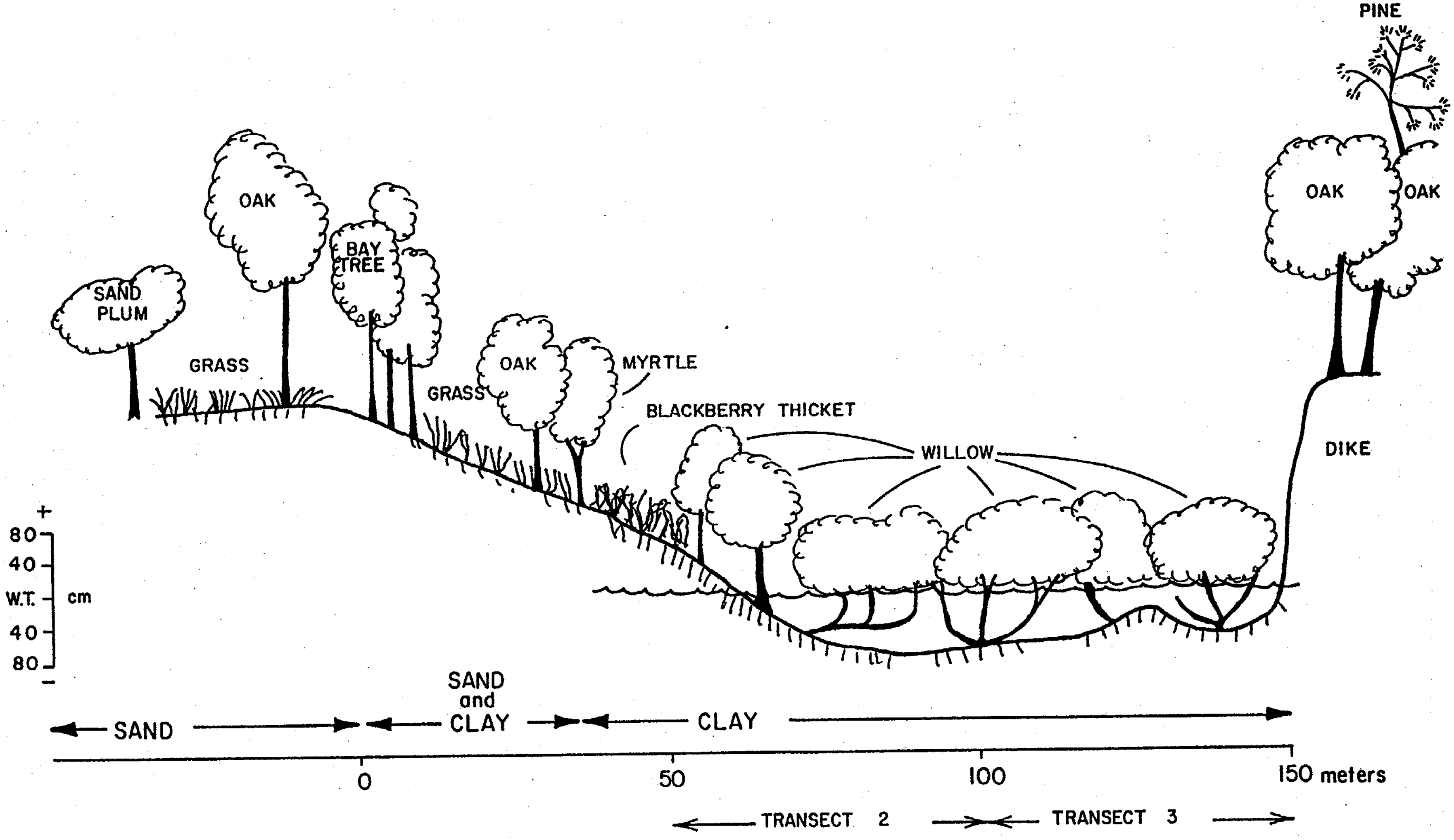


Figure 64. Alderman Ford Ranch. Cross section of a wet area within the 30-year-old site. Red maples and oaks were found on the higher elevations and willows dominate the depressions. Vertical exaggeration is 1:13. Water table measurements were taken 7 January 1983.

Figure 65. Clark James middle transects. A 60-year-old dredge pit backfilled with sand and clay. Willows grow in the depressions, the red maple is missing. Scattered oaks and myrtle with a thick understory of blackberries and grasses. A clump of bay trees was found on the upper boundary between sand and clay. Vertical exaggeration is 1:13. Water level was measured January 1983.



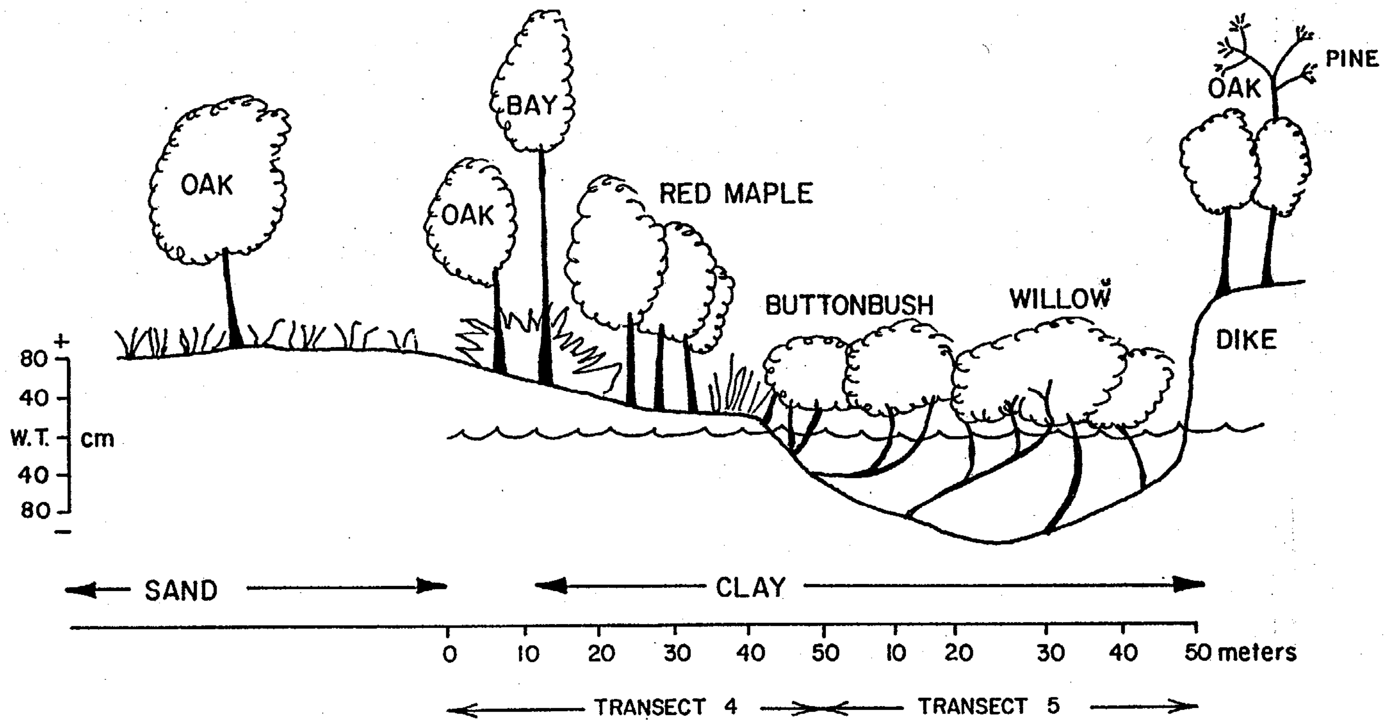


Figure 66. Clark James 60-year-old dredge pit backfilled with sand and clay, southern transects. Willows were found in the depressions, scattered red maples and primrose willow are in the next band, and oaks with pepper-vine cover the upper band. A lone bay tree is at the outer edge between sand and clay. Vertical exaggeration is 1:13. Water table measurements were taken in January 1983.

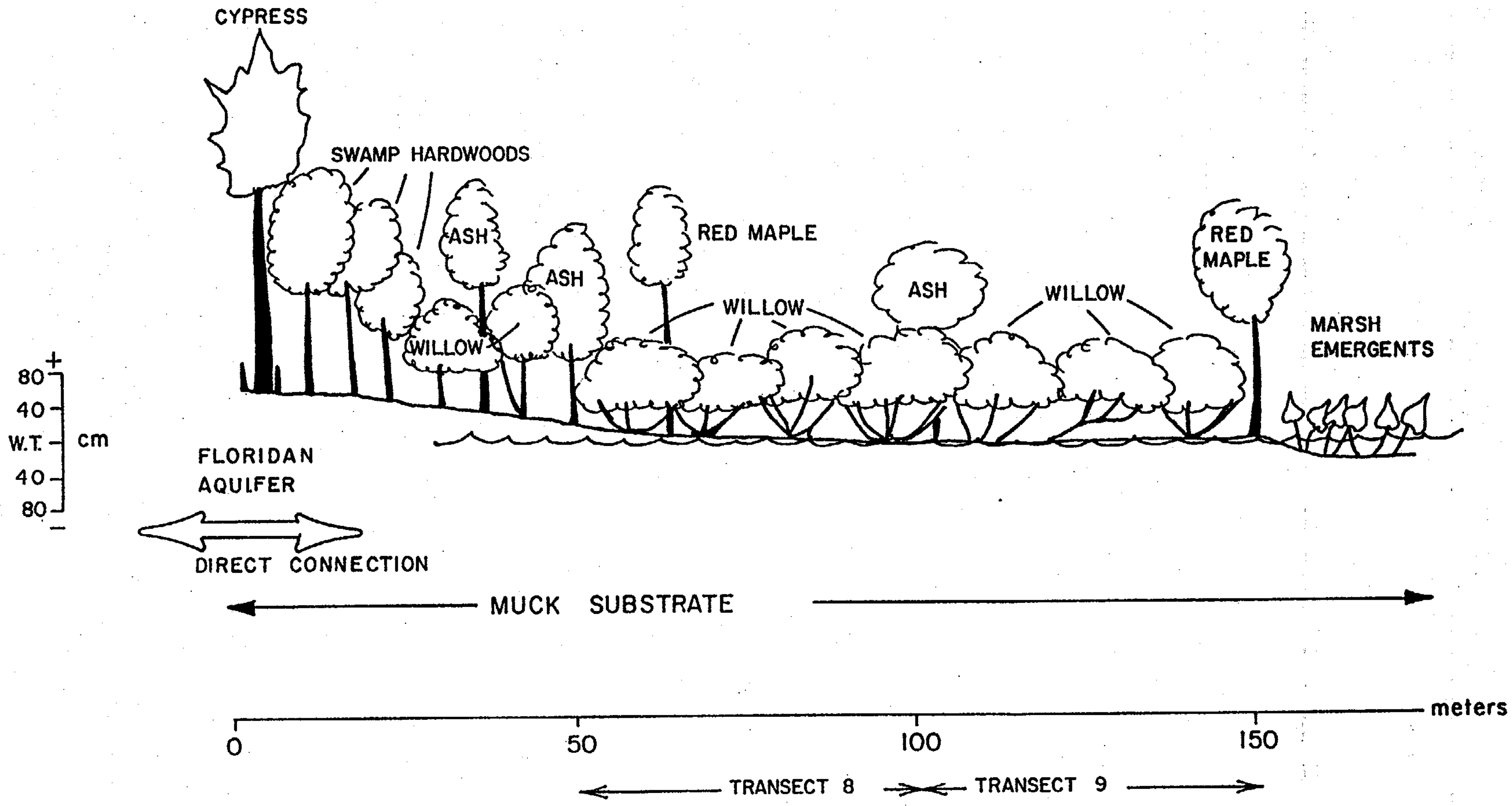


Figure 67. Lake Panasoffkee, a 40-year-old control site. It has changed from a marsh to a willow community over the past 40 years. A hardwood swamp is located at the upper end and a marsh is located at the other end. Vertical exaggeration is 1:13. Water table measurements were made January 1983.

Comparison of Study Sites

Shallow swamp transitional phase. The control site on the shore of Lake Panasoffkee has changed from a marsh to a mature willow community over the past 40 years. It fits the description of shallow freshwater swamps in its transitional phase (Penfound 1952; Shelford 1954; Putman et al. 1960). The willows have attained greater stature than in the clay settling ponds. Herbaceous vegetation was relatively sparse with most of the understory biomass contributed by saw grass (Cladium jamaicense) and tree seedlings. This resulted in an open canopy with good light penetration. Inundation appeared to be the factor controlling seedling survival. The individuals tall enough to escape drowning in the summer of 1982 were thriving in January 1983. It would be expected that litter biomass will gradually build up the forest floor to the elevation now seen in the adjacent bottomland swamp. From seedling and sapling information collected at the site, it appeared an Acer-Fraxinus-Cornus association will replace the Salix-Cephalanthus community. Policy decisions regulating flooding regimes at the dam could alter this pattern. Red maples are less tolerant of flooding than either ash *or* willow (Hosner and Boyce 1962), and a longer hydroperiod could shift succession toward a monospecific ash stand or back to the willow or even the marsh stage.

Emerging bottomland hardwood forest. The upper elevations of clay settling ponds, where water was measured 20-100 centimeters below the surface in January 1983, supported an emerging forest with some of the trees described for hardwood swamps (Putnam et al. 1960; Conner and Day 1976; Monk 1965). The growth forms for the willow trees (Salix caroliniana) in these transects *were* upright with single stems. Myrtle (Myrica cerifera) was also present as a conspicuous shrub species. Transects 16 and 17 at the 30-year-old site and transect 4 at the 60-year-old site are examples of this type of succession. Transect 14 at the 12-year-old site appears to be an earlier stage in this successional series.

In the 30-year-old site at Alderman Ford Ranch, the willows and myrtles were senescent, and scattered hardwood trees were present. Some had attained maturity and were available as a seed source. Between the scattered canopy the ground was covered with a thick mass of weeds, vines, and briers. Such brushpatch beginnings are typical of most southern hardwood forests, with the conditions most aggravated in the bottomlands (Putnam et al. 1960). Such a cover may be necessary to protect hardwood seedlings from extreme temperatures and browsing and for modifying soil conditions (Putnam et al. 1960). It is not unusual to find from 500 to 5000 seeds per hectare hidden among the tangle of herbaceous vegetation (Putnam et al. 1960). In transects 1.6 and 17 over 10,000 seedlings per hectare had survived after 10 months of growth (see Table 21).

In spite of heavy underbrush, light intensity as measured by the optical density readings was in the favorable range for seedlings present. This site appeared to be well on its way to the next stage in succession as it matures to a bottomland hardwood forest. It included many of the species found on the river floodplains of the region.

Transect 4 at the 60-year-old site also had a dense mat of undergrowth vegetation, a few hardwood species, and some myrtles, but here seedlings were scarce. It was overrun with the woody pepper-vine (Ampelopsis arborea), which is sometimes an indication of severely depleted and burned land (Putnam et al. 1960). Fire could explain the depauperate tree community since fire scars were also evident. An appropriate seed source and low light Intensity may also have retarded succession. This site did not show signs of advancing to a more mature system.

The bay trees located along the sand/clay interface at the 60-year-old site may indicate this species could become established on this type habitat. A sand/clay boundary which might produce a sufficient seepage zone is common on reclaimed clay ponds.

Transect 14, at the 12-year-old site, may be an earlier stage of a clay setting pond maturing to a bottomland hardwood forest. Although willows dominated this site, myrtles were found as a dominant seedling species during the species diversity measurements (see Tables 14 and G-2). Seedlings of camphor trees [Cinnamomum camphora), an exotic species, were also found here. This was the only location where the seedling transplant experiments (see Table 22) consisting of swamp hardwood species were a success. This may indicate seeding as a reclamation technique needs to be started early and species need to be matched with hydroperiod.

Arrested willow succession. The deeper depressions of the 30- and 60-year-old clay settling ponds, shown inundated during water table measurements in January 1983, supported a sprawling shrubby willow community. The tree forms in the depressions at the 60-year-old site, transects 2, 3, and 5, show 60-80% of the willows were multiple stem which indicated resprouting or coppicing and 10-30% were fallen over with the branches forming new trees. The growth habit of the willows in transect 15, at the 12-year-old clay settling pond, gives some insight into why trees in the wetter depressions appeared tortoured and stunted. In 24% of the willow shrubs here, the main branch was dead and two smaller branches had resprouted at the point of dieback. Stress, where trees are grown at the limits of their environmental range, is a common explanation for a shrubby or semi-dwarf growth habit (Brown 1977). Another factor at the older sites is the 60 years of dominance for willow trees, which is beyond the limits of their usual life span. Their survival may be explained by the lack of competition from better adapted tree species such as cypress and gum. The seeds of these later successional *trees* are generally spread by floodwater, which would be unable to reach these locations. Cypress and gum also have *very* specific requirements of wet and dry cycles for germination (Fowells 1965). Cypress trees planted on clay settling ponds have shown good growth after 2 years (Bob Goodrich, personal communication). Cypress or gum may be a viable reclamation alternative for the deeper depressions on clay settling areas.

Wetland regeneration in slime ponds. Can a slime pond be managed so as to constitute a permanent wetland, one that meets the need for replacing disturbed wetlands with reconstitued wetlands after mining? In at least one case wetland regeneration occurred in a short time. The 30-year-old site suggests that hydroperiod and seed source may be adjusted to regenerate a floodplain type wetland. In the first swale next to the natural floodplain of the Alafia River, succession was not arrested and the willow communities of clay settling areas did prepare the way for succession. A few stunted willows in this hardwood hammock indicated they were replaced by the swamp forest. The willows present in the wet inner swale adjacent to this site suggest that wetter hydroperiods lead to arrested willows if other species that could tolerate the deeper water such as cypress and gum are not seeded.

Plant Succession as a Mechanism for Reclamation

The period of willow, dominance. What processes have taken place during the 30-40-year period of willow dominance? Vegetation on clay settling ponds rapidly organizes a green cover in relation to minor differences in topography even before the active filling stage is terminated. The pattern of the system is arranged into open water habitat with floating macrophytes, rooted marsh vegetation in shallower water, and densely packed willow seedlings on the exposed soil surfaces. The process of increasing surface elevation through the deposition of dead organic matter coupled with the continued drainage of rainwater by the industry shifts the open water bodies to marsh and the higher elevations to a shrub community usually dominated by willows. The dominant pioneer plants are the same ones that colonize other disturbed habitats of the region.

A summary of vegetation measurements that have been reported from various aged clay settling ponds are listed with their relative importance values in Table 23. Species have been generally arranged from the most moisture tolerant to the least. The 2- and 4-year-old sites exhibit the shift to a more terrestrial system during this early successional stage. The 5-10-year-old site described by Schnoes and Humphrey (1981), was reported to have been burned 3 years before their study. Baccharis and Imperata cylindrica have also been observed to colonize other clay settling ponds after a fire. The 12-year-old site studied by Butner and Best (1981) had apparently received sand tailings in what may have been a reclamation attempt. This explains the predominance of old field species that prefer drier locations. The 15-20-year-old site also had received some sand tailings. This or a lower water table may explain the extensive colonization by myrtle.

At least two sites indicate willows and myrtles have reached maturity by the age of 25-30 years and may be replaced by hardwood species. Zellar-Williams and Conservation Consultants (1980) in a species list for the same 25-year-old Maine Ave. site studied by Butner and Best (1981) recorded the presence of numerous hardwood tree species including red maple Acer rubrum), red mulberry (Morus rubra), wax myrtle (Myrica cerifera), laurel oak (Quercus laurifolia), and live oak (Quercus virginiana). They also observed that the seedlings and saplings of trees to replace the willows were conspicuously absent and the site was mostly overgrown with woody vines. The 30-year-old site at Alderman Ford Ranch also has a drier patchy vine covered hardwood forest, but numerous seedlings were present. The 60-year-old sites at Clark James support a shrubby willow community that may be a case of arrested succession.

Comparison of willows with more mature wetland types. Storage of structure and its maintenance by one stage of succession is available as a material and energy resource to stages that follow. What communities might be expected to follow the willows on clay settling ponds? The structure and complexity of willow communities are compared to various vegetation types common to Florida in Table 24. These are divided into five categories: cypress-gum swamps, hardwood bottomland forests, the southern mixed hardwood climax forest, some scrub communities found in Florida, and the willow communities studied for this project.

Clay settling ponds at the end of 25 years are composed of senescent or dwarfed early successional species often overrun with weedy herbaceous vegetation. Are there mechanisms as discussed in the following section that might be

Table 23. Comparison of vegetation importance value indices for different aged clay settling ponds. Vegetation is generally organized from most to least moisture tolerant.

	AGE OF SITES (YEARS)											
Species	2[a]	4[b]	5–10[c]	12[a]	12[b]	12–15[c]	15–20[c]	18[b]	25[b]	30[a]	60[a]	60[a]
HERBS AND VINES												
Eichhornia crassipes	32.87	---	---	---	---	---	---	---	---	---	---	---
Sagittaria montevidensis	36.85	---	---	---	---	---	---	---	---	---	---	---
Typha	38.11	15.30	5.49	---	---	---	---	3.82	---	---	---	---
Paspalum sp.	---	9.23	---	---	---	---	---	---	---	---	---	---
Cyperus	2.15	2.58	---	---	---	---	---	---	---	---	---	---
Polygonum	---	6.16	---	---	---	47.13	---	4.82	---	---	---	7.59
Juncus	---	---	5.49	4.39	---	---	---	---	---	1.67	---	---
Ludwigia peruviana	---	2.28	2.19	59.80	---	24.65	---	---	---	4.26	11.40	2.40
Mikania scandens	---	22.70	---	---	---	---	---	---	---	12.01	---	---
Unknown vine	---	10.45	---	---	---	---	---	---	---	---	---	---
Unknown herb	---	---	---	---	---	31.33	---	---	---	1.84	---	---
Valerian scandens	---	---	---	---	---	---	---	---	---	2.55	---	5.80
Clematis virginiana	---	---	---	---	---	---	13.46	2.80	19.17	22.30	5.99	---
Momordica charantia	---	15.41	---	---	---	---	---	---	5.57	1.42	---	---
Drymaria cordata	---	---	---	---	---	---	---	---	---	11.42	---	27.49
Apios americana	---	---	---	---	---	0.82	---	---	---	---	---	---
Lythrum lineare	---	---	---	16.09	---	---	---	---	---	---	---	---
Thelepteris normalis	---	---	---	---	---	---	---	46.53	10.26	1.43	13.09	---
Eupatorium capillifolium	---	---	---	5.87	---	---	---	---	6.84	---	---	---
Rubus	---	---	---	---	14.80	---	---	---	29.11	7.54	40.09	---
Lygodium japonicum	---	12.81	---	---	---	---	---	7.90	---	15.15	---	---
Vitis rotundifolia	---	---	---	---	9.07	---	1.60	---	---	---	---	---
Conyza parva	---	---	---	3.05	9.46	---	---	---	---	---	---	---
Unknown vine	---	---	---	---	---	4.90	73.10	---	---	---	---	---
Hyptis alata	---	---	---	---	---	---	---	---	---	---	29.42	2.38
Ampelopsis arborea	---	---	---	---	---	0.54	0.96	---	5.74	1.67	---	36.08
Aeschynomene americana	---	---	---	---	6.49	---	---	---	---	---	---	---
Urena lobata	---	---	---	---	5.84	---	---	---	---	---	---	---
Cruciferacese	---	---	---	---	6.23	---	---	---	---	---	---	---
Parthenoicissus quinquefolia	---	---	---	---	---	---	10.25	4.05	21.60	1.39	---	---
Andropogon	---	---	8.24	---	25.92	---	---	---	---	---	---	---
Imperata cylindrica	---	---	78.02	10.73	---	---	---	---	---	4.62	---	---
Heterothica subaxillaris	---	---	---	---	7.66	---	---	---	---	---	---	---
Rhynchelytrum roseum	---	---	---	---	3.01	---	---	---	---	---	---	---
Indigofera hirsuta	---	---	---	---	12.83	---	---	---	---	---	---	---
Lantana camara	---	---	0.55	---	---	15.25	---	3.38	---	---	---	---
Callicarpa americana	---	---	---	---	---	---	0.64	---	---	---	---	---
Ambrosia artemisiifolia	---	---	---	---	---	---	---	---	---	2.59	---	---
TREES AND SHRUBS												
Salix caroliniana	100.00	81.06	71.22	93.20	34.00	100.00	42.26	53.33	21.66	38.10	88.84	60.36
Cephalanthus occidentalis	---	---	---	---	---	---	---	---	---	---	3.93	23.20
Sambucus simpsonii	---	---	---	---	---	---	1.76	---	40.00	3.78	5.69	1.20
Myrica cerifera	---	---	---	2.70	---	---	52.84	46.66	20.00	11.42	1.52	11.32
Baccharis halimifolia	---	3.9	28.77	4.10	44.00	---	---	---	---	---	---	3.95
Acer rubrum	---	---	---	---	---	---	---	---	---	24.01	---	0.98
Ulmus americana	---	---	---	---	---	---	---	---	6.00	4.98	---	---
Quercus nigra	---	---	---	---	---	---	---	---	---	1.19	---	---
Quercus laurifolia	---	---	---	---	---	---	---	---	---	13.04	---	1.56
Liquidambar styraciflua	---	---	---	---	---	---	---	---	---	4.08	---	---
Quercus virginiana	---	---	---	---	---	---	---	---	---	---	---	0.98

[a] This study. Importance values for trees and shrubs were combined using a weighted value based on basal area (m^2/ha) to make comparable to the other sites. Importance values for herbs and vines were calculated from summer 1982 data.

[b] Butner and Best (1981). Importance values for vines and herbs recalculated using the importance value index (Table 3 in their study) to make comparable to the other sites. Deadwood was not listed and the live tree values were not recalculated therefore the importance values for trees were not always 100%.

[c] Schnoes and Humphrey (1980). Importance values for trees and shrubs recalculated and weighted using basal area (m^2/ha) to make trees and shrubs comparable for all sites. Importance values calculated for trees, herbs, and shrubs <5 cm dbh using percent cover.

Table 24. Structural indices of willow communities, forested wetlands, scrub wetlands, and the southern hardwood climax forest in the southeastern United States for trees >2.5 cm dbh.

Community Types	Canopy Height m	Basal Area m^2/ha	Stems, #/ha	Herbs summer g/m^2	Litter summer g/m^2	LAI, m^2/m^2	Tree Species 0.1 ha	Optical Density summer
Willows[a]								
Clay ponds								
Arrested Succession	3.77	9.4	4950	144	940	3.7	5	0.53
Emerging Hardwoods	6.64	10.4	1286	244	652	3.4	7	0.46
Muck Lakeshore Transition	4.93	22.17	8060	186	951	2.4	6	0.36
Cypress								
Domes (Fla)[b]								
Small	15.00	53.10	2234	--	--	2.0	3	0.53
Large	20.20	70.80	3951	--	--	3.4	4	0.65
Sewage	11.70	41.40	2573	--	--	4.4	4	0.87
Bog Swamp (Ga)[d]	18.00	52.00	1465	11	274	2.9	9	--
With Tupelo (La)[c]	15.20	56.20	1235	20	--	--	9	--
Bottomland Hardwoods								
Louisiana Swamp[c]	9.2	24.30	1710	193	422	--	23	--
Floodplain (Fla)[b]	16.5	32.5	1644	--	--	8.5	7	1.04
Alluvial (NC)[f]	25.0	74.79	2590	11	--	--	3	0.68
Scrub Wetlands (Fla)								
Dwarf Cypress[g]	4.1	15.50	1465	6	344	0.5	2	0.36
Mangroves[h]	6.0	20.30	5960	--	559	3.3	4	--
Southern Hardwood Climax[i]	18.2	64.10	1141	--	819	6.2	26	--

[a] This study.
[b] Brown 1978.
[c] Connor and Day 1976.
[d] Schlesinger 1978, > 4 cm.
[f] Brinson 1977.
[g] Flohrschutz 1978.
[h] Snedaker and Lugo 1973.
[i] Lugo et al. 1971.

employed to enhance or accelerate ecological succession to a more mature forest type? Or are environmental constraints so severe that clay settling ponds will continue as scrub communities similar in structure to other stressed habitats in Florida?

Ecological theory and enhancing succession. Theories of succession (see introduction) suggest principles to follow to enhance succession. The land surfaces of clay settling ponds are organized into different habitats that may be suitable for a mosaic of landscape alternatives dependent upon environmental gradients. Early seeding of mature species in clay pond may reduce competition from pioneer species and accelerate succession. It may also prove beneficial to retain islands of more mature ecosystems within the complex of clay settling ponds to act as dispersal centers for the process of colonization from more mature to less mature systems. The new conditions of clay settling ponds may provide a unique environment for new community types or the establishment of wetland systems already found in Florida, but the choices (seeds) for selection to maximize the use of these, resources are not present and may be retarding succession.

Environmental Conditions Control Plant Communities

The composition of plant communities developing in the slime ponds was found to depend on hydrology, nutrients and soil, immigration and competition, and fire frequency.

Hydroperiod and community organization. Wetlands exist because they are periodically inundated. Relationships between species distribution and microtopography for floodplain vegetation have been reported by several investigators (Franz and Bazzaz 1977; Duever 1982; Harms et al. 1980). Wetland species become sorted along an environmental gradient of flooding regimes in relation to their specialized physiological and structural adaptations (Hook and Brown 1973), and the ability of seedlings to survive inundation (Hosner and Boyce 1962; McDermott 1953). The duration of flooding and the size of some tree species during the exceptionally wet year also influences survival (Harms et al. 1980).

Widely different hydroperiods were observed in the clay settling ponds during the year and a half duration of sampling. There was no standing water during 1981-1982, a dry year for Florida, while the 1982-1983 period, a wet year, produced flooding greater than a meter in depth (see cross section sketches in Figures 63-67). The slow infiltration rates of clays probably accentuates water table fluctuations. Duever (1982) noted water tables decline faster when below the ground surface because of the smaller volume of water that can be contained in the soil pore space. Successful vegetation seeding in the clay ponds will have to include species able to adapt to these widely fluctuating conditions. It should be noted that although the control site was inundated for a longer period of time, the water depth was never as great. Here the willow trees were more robust and hardwood seedling establishment and survival greater than the depressions of the clay settling ponds (Table 21).

The hydroperiod, where successful hardwood floodplain vegetation has become established on clay settling ponds in 30 years at Alderman Ford Ranch, would provide a useful model to determine flood management schedules.

Clay soils as a suitable substrate for forests. Vegetation as it undergoes succession organizes sedimentary raw material into soil. Initial material in the settling areas included particles of varying sizes and shapes. These have arbitrarily been divided into three textural classes, sand, silt, and clay, based on particle size. A sediment is classified as a clay if it contains more than 40% of the clay separate (Brady 1974). In the field, a clay is identified as hard when dry, and sticky and plastic when wet. For this study mechanical analysis (see Tables 16-20) confirmed the field evidence showing soils of clay settling ponds contain predominately clays (73-83%) and some silts (16-23%).

A moderate amount of clay organized in soil is beneficial to many species. The small size of clay particles and the consequent large surface area, coupled with strong ion-exchange activity are responsible for the importance of soil clay as the major source and reservoir of plant nutrients (Etherington 1976). They are also important in governing soil water relationships and aeration characteristics. It has been found that phosphatic clay slimes were of value when used as a soil amendment (Hawkins 1973). in a study of old field succession the number of dominants and speed of succession increased with increasing silt-clay percentage (36%) and nearness to the water table (E. P. Odum 1960). On the other hand, hardwood forests in the Piedmont, growing on shrink-swell clay sites showed the lowest productivity and biomass values compared to other forest environments (Peet 1981).

It has been noted that forest stands modify clay soils by increasing organic content to more nearly meet the requirements of more exacting climax species (Pritchett 1979). A study of productive, well-stocked, uneven-aged hardwood stand growing in Mississippi (Broadfoot 1967) showed almost as much clay (72-81%) and silt (15-20%) content as the clay settling ponds of central Florida. This evidence, coupled with the success of hardwood colonization at the 30-year-old Alderman Ford Ranch site in this study, indicates the large amount of silt-clay size particles may not impede forest succession. The major emphasis of Broadfoot's (1967) research demonstrated the importance of hydroperiod where impoundment of winter and spring rainfall significantly increased tree growth.

It appears to be the indirect influence of clay soils as they regulate drainage and root penetration that needs to be considered. Soil texture directly influences soil-water relationships, aeration, and penetrability through its relationship with interparticle pore space (Etherington 1976).

In summary, the control of hydroperiod and the incorporation of organic matter in the soil may be significant parameters in enhancing forest succession. The addition of seeds and seedlings may be an important mechanism for providing choices to accelerate the succession process. Cypress/gum may be suitable for the deeper depressions now in an arrested willow state, bay trees may grow in seepage zones where there is a sand-clay interface, and hardwood swamp species may be able to colonize habitats where the water table only occasionally floods the land surface.

6. A PRELIMINARY ANALYSIS OF THE EFFECTS OF DISTANCE AND DENSITY OF A SEED SOURCE ON THE FATE OF NATURAL SUCCESSION IN PHOSPHATE MINED LANDS

Tim McClanahan

Introduction

Reclamation of phosphate mined land by natural succession has been demonstrated to occur if the circumstances are favorable (Kangas 1979; Rushton 1983). Kangas showed that succession does occur on spoil mounds but that the time it takes may be variable. In a later model (Kangas 1983) he demonstrates that succession can be accelerated if the seeds are added at the proper time. As well, Rushton demonstrated that succession can occur on phosphatic clay settling ponds but that the development may be arrested due to a lack of seeds. Both of their conclusions emphasize the importance of seeds at the proper time.

This preliminary paper includes an analysis of the effects that the distance and density of a seed source around the mined site have on the outcome of succession on clay settling ponds and the way present mining practice may be inhibiting the rate at which succession occurs.

Methods

In order to estimate the vegetation changes on clay settling ponds, data were compiled from previous studies (Butner 1981; Schnoes and Humphrey 1980; Rushton 1983) for 11 clay settling ponds. These data were summarized into Relative Importance Values (RIVI)* normalized for the percentages of the tree species. For each site the percentage of the hardwood species, of tree size class, was summed to get the total RIVI percentage of hardwoods at each site. Hardwoods were classified to include the genera *Quercus*, *Acer*, *Ulmus*, and *Liquidambar*. The classification did not include the genera *Sambucus*, *Baccharis*, *Salix*, and *Myrica*. For each site the RIVI percentages were correlated with the age of the site (Figure 68).

In order to test the effects of the distance and density of the seed source on the RIVI percentages for hardwoods, four of the 11 settling ponds, three of which had hardwoods present, were analyzed by aerial photographs taken at the

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* RIVI = Relative Importance + Relative Density + Relative Dominance
Percent hardwoods = ($\sum$ Hardwood RIVI /. $\sum$ Total RIVI) x 100

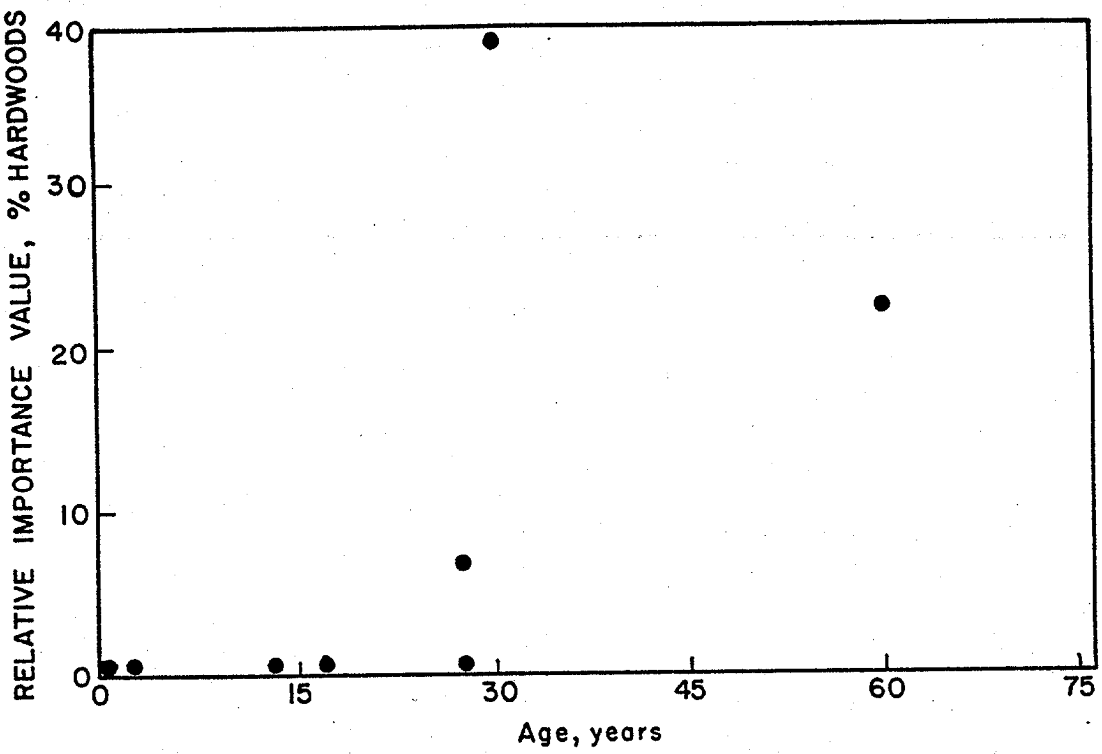


Figure 68. Plot of age versus the percent hardwoods (relative importance index) as a function of age.

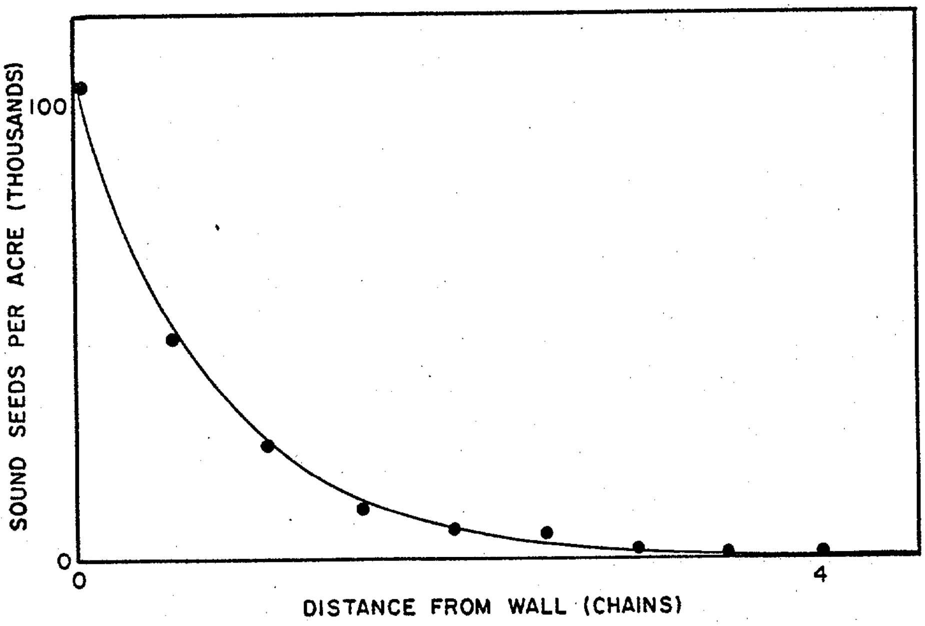


Figure 69. The dispersal of loblolly pine into a clear-cut (Boyer 1958); published with permission of Journal of Forestry.

time closest to the abandonment of these sites. From the aerial photographs the distance to the nearest trees in 16 compass directions was measured using 400 meters from the edge of the settling pond as the furthest distance measured. It was assumed that trees greater than 400 meters from the edge did not transport seeds in large enough numbers to effect succession of these sites substantially. This assumption can be supported by studies on the dispersal capacity of other hardwoods (Auclair and Cottam 1971; Boyer 1958; Johnson et al. 1981). An example is illustrated in Figure 69. The 16 distances were then averaged to get a relative measurement of distance and density (distance-density index) which was correlated with RIVI percentages (Figure 70a). A log and square root transformation were performed to see whether this curve was consistent with the theoretically expected curve (Figures 71 and 72).

Finally, aerial photographs were chosen from Polk and Hardee counties for 1968 and 1974. The aerial photographs with phosphate mined sites *were* then used to estimate the average distance-density index for any point within the mined area. This was accomplished by laying a grid with numbered intersections over the photograph. Using a random number table, intersections on the grid were chosen if the intersection fell within the boundary of a site being mined. From this intersection eight distances were measured as previously described. The distances were averaged in order to get the relative distance-density index of this point. This process was repeated for 30 points. A histogram of the samples is included in Figure 70b in order to juxtapose these sites with sites that have hardwoods present.

Results

The information on the 11 sites studied is summarized in Table 25. The statistical information for the four regressions is summarized in Table 26. The graphs and their equations are included in Figures 68, 70, 71, and 72. The relative distance/density for the 1968 and 1974 mined sites is presented in histogram form in Figure 70b along with the mean ($x = 302.88$) and standard deviation ($SD = 69.34$).

Discussion

Figure 71 suggests that the distance-density index to a seed source is a better predictor for natural succession than the age of the site alone. The slope of this line meets the axis at 275 distance-density meters. Seventy-six percent of the randomized points in the histogram lie beyond this point. This coincides very well with the absence of hardwoods in 72.7% of the settling ponds surveyed regardless of their age.

This survey is preliminary and further analysis may substantiate and improve the accuracy of these numbers. Nevertheless, these data suggest that natural succession to a climax state will be arrested on mined land if the needed seeds are not provided. As well, natural succession may not be a feasible alternative for the majority of the presently mined land unless seeds are added at the proper time.

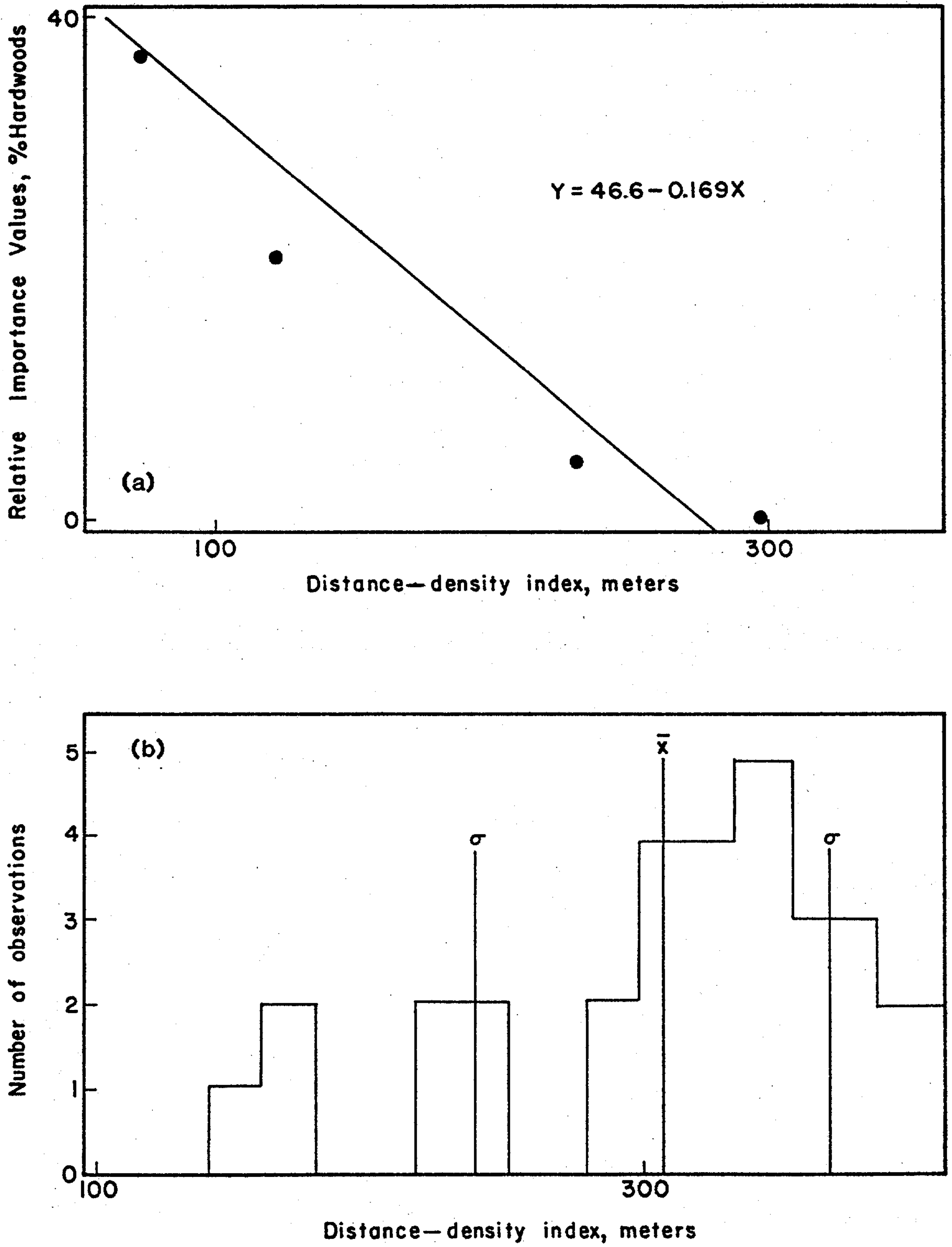
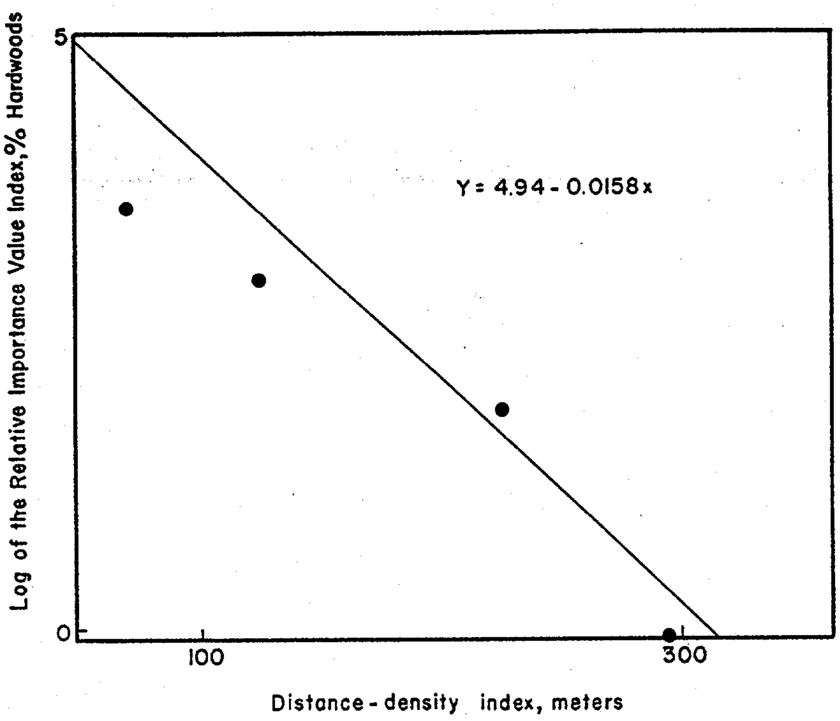


Figure 70. A comparison between sites where succession is occurring (a) and the distribution of mined sites in 1968 and 1974 in relation to a seed source (b).

Figure 71. Plot of the log of the Relative Importance Values vs. the distance-density index.



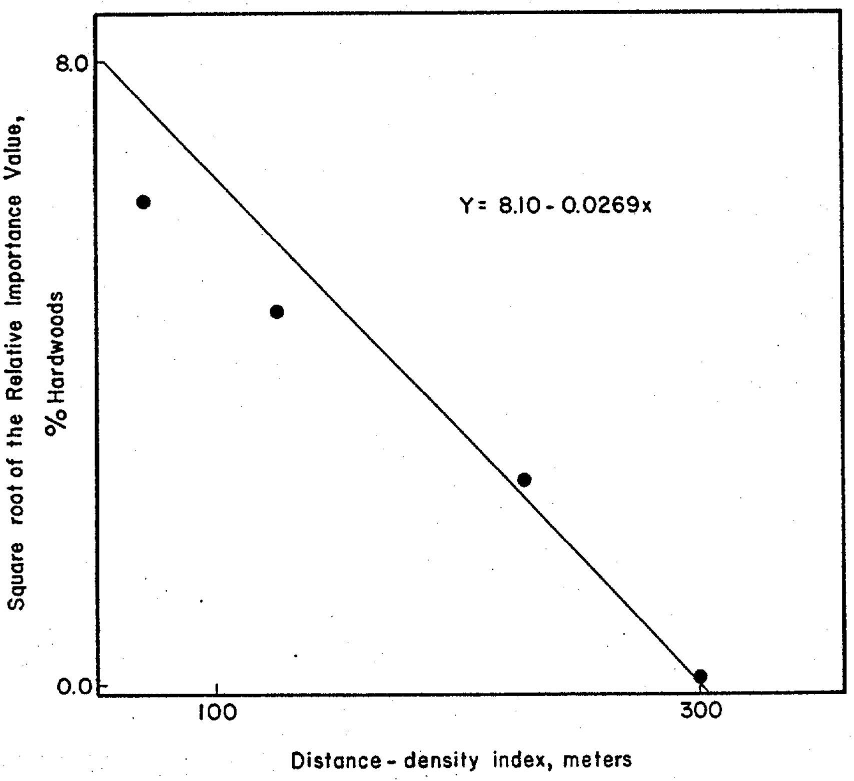


Figure 72. Plot of the square root of the Relative Importance Value Index vs. the distance-density index.

Table 25. Information on the age, successional status and literature source of the clay settling ponds.

Name	Age	RIVI, % Hardwoods*	Literature Source
Clear Springs	1	0	Rushton 1983
Noralyn 11A	12	0	Rushton 1983
Alderman Ford	30	38.8	Rushton 1983
Clark James	60	22.1	Rushton 1983
Agrico Mining	4	0	Butner 1981
Agrico Mining	12	0	Butner 1981
Maine Avenue	25	6.8	Butner 1981
Agrico Mining	18	0	Butner 1981
Swift Creek	5	0	Schnoes 1980
Noralyn 2	25	0	Schnoes 1980
A3	2	0	Schnoes 1980

*RIVI is the Relative Importance Value Index. Calculated as follows: RIVI = Relative Importance + Relative Density + Relative Dominance. RIVI, % Hardwoods = $(\Sigma\text{Hardwood RIVI}/\Sigma\text{Total RIVI}) \times 100$

Table 26. Statistical information for the tree correlations.

Correlation	Equation	r^2, %	Standard Deviation	Significance Level, %
Age vs RIVI, % Hardwoods	$y = -2.50 + 0.491x$	44.3	10.02	10.0
Distance-density index vs RIVI, % Hardwoods	$y = 46.6 - 0.169x$	95.4	4.537	2.50
Log of the RIVI, % Hardwoods vs the distance-density index	$y = 4.94 - 0.0158x$	95.2	0.4325	2.50
Square root of the RIVI, % Hardwoods vs the distance-density index	$y = 8.10 - 0.0269x$	98.8	0.3643	2.50

The best predictive line for succession is the square root of the RIVI vs. the distance-density index. This line is supported by other observations that the distribution of trees from their seed source decreases by the square root. This curve may be an example of an energy hierarchy of transport energies available. The majority of the seeds dispersed are moved a short distance by low energy dispersal (i.e., many mild breezes) and a few are dispersed long distances by a high energy dispersal (i.e., few strong winds). The location within this energy hierarchy that mined sites could be designed around for reclamation by natural succession will depend on the success of the seeds on the sites, the speed at which reclamation is desired, and the economic constraints of the mining process. These variables along with other considerations can be modeled in order to predict the outcome of succession and to choose a design that is best suited for the long term health of the region.

It may be more cost effective to the phosphate industry and to the whole region to design the present mining process with better seed access on a scale that would allow nature to reclaim the land at the least cost to man. A detailed energy and economic analysis of this proposal may indicate which measures may be most effective.

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