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SUCCESSIONAL DEVELOPMENT OF FORESTED WETLANDS ON RECLAIMED PHOSPHATE MINED LANDS IN FLORIDA

VOLUME II

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Karen J. Stewart

Florida Institute of Phosphate Research
1855 West Main Street
Bartow, Florida 33830
(863) 534-7160
Fax: (863) 534-7165
http://www.fipr.state.fl.us

SUCCESSIONAL DEVELOPMENT OF FORESTED WETLANDS ON RECLAIMED PHOSPHATE MINED LANDS IN FLORIDA

FINAL REPORT

VOLUME II

Mark T. Brown, Principal Investigator
and
Susan M. Carstenn, Project Manager

with

John Baker, B.J. Bukata, Tim Gysan, Kristina Jackson,
Kelly Chinners Reiss, and Melini Sloan,
Graduate Research Assistants

UNIVERSITY OF FLORIDA CENTER FOR WETLANDS
Department of Environmental Engineering Sciences
Gainesville, Florida 32611

Prepared for

FLORIDA INSTITUTE OF PHOSPHATE RESEARCH
1855 West Main Street
Bartow, Florida 33830 USA

FIPR Project Numbers: 95-03-117R and 98-03-131
Contact Manager: Steven G. Richardson

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DISCLAIMER

PERSPECTIVE

The FIPR research program has considered several issues related to wetland reconstruction on phosphate mined lands, including:

- How should we rebuild and manage wetlands, and what can Nature do on its own?
- How can we tell when wetlands are successfully restored?
- To what extent do we need to manage nuisance species, such as primrose willow, cattail and vines?

This research examined several factors that affect the development of forested wetlands on reclaimed phosphate mined lands. Part of the research was based on the premise that certain plants, e.g. primrose willow (*Ludwigia peruviana*) and cattail (*Typha spp.*), that have been designated as "nuisance" species by the Florida Department of Environmental Protection are really just early successional species that will be displaced by trees as the forest canopy develops. The project examined the effects of shade (shade cloth on frames to simulate a forest canopy) on primrose willow and cattail in the field, plus greenhouse work on the effects of nutrients and shade on competition of these species with sapling trees. Simultaneously, FIPR also conducted field experiments examining the effects of actual forest canopy on primrose willow (see Richardson and Kluson 1999, listed below). UF also studied the impact of vines on forested wetland development and looked at the importance of microtopographic relief (e.g. small mounds and depressions) on tree growth and understory species diversity in wetlands. The research also further documents the trends in development of various indicators of wetland functions in reclaimed forested wetland sites of various ages.

The reader is referred to the following related reports and papers:

Brown, M.T. and R.E. Tighe (eds.). 1991. Techniques and guidelines for reclamation of phosphate mined lands. FIPR Publication No. 03-044-095.

Crisman, T.L., W.J. Streever, J.H. Kiefer and D.L. Evans. 1997. An evaluation of plant community structure, fish and benthic meio- and macrofauna as success criteria for reclaimed wetlands. FIPR Publication No. 03-086-135.

Erwin, K.L., S.J. Doherty, M.T. Brown and G.R. Best. 1997. Evaluation of constructed wetlands on phosphate mined lands in Florida. FIPR Publication No. 03-103-139, Vols. I, II, III.

Richardson, S.G. and R.A. Kluson. 1999. Managing nuisance plant species in forested wetlands on reclaimed phosphate mined-lands in Florida. Proceedings of the 26th Annual Conference on Ecosystem Restoration and Creation, p. 104-118. Tampa, Florida, May 1999.

Steven G. Richardson
FIPR Reclamation Research Director

ABSTRACT

Studies of wetlands developing on phosphate mined lands and under controlled greenhouse conditions were conducted to evaluate the role of early successional species in ecosystem development. Persistence under reduced light, nutrient cycling, and nutrient sequestration were studied, as well as their role in developing and altering the physical environment (microtopography). Finally, measurable wetland attributes showing directional change with time were identified, and models of successional trajectories were established from attribute data.

These studies suggested that early successional species may facilitate ecosystem development and are not persistent within the developed wetland ecosystem. After three years under low light levels mimicking canopy closure (30% of available sunlight), primrose willow and cattails decreased in abundance and vigor. Cattail (*Typha spp.*) and primrose willow (*Ludwigia peruviana*) contributed greater nutrient sequestration than other common herbaceous species. Constructed wetlands dominated by primrose willow and by Carolina willow (*Salix caroliniana*) had higher microtopographic relief than systems where these species were not present. Native vines showed similar successional trends and may contribute rather than detract from ecosystem development.

Several wetland attributes exhibited sufficient directional change with time so that their trajectories show promise as a means of evaluating success. These include trajectories for tree height, dbh, canopy cover, soil organic matter content, and bulk density.

TABLE OF CONTENTS

VOLUME 2

TABLE OF CONTENTS (CONT.)

VOLUME 2

Chapter 5 (Cont.)

TABLE OF CONTENTS (CONT.)

VOLUME 2

Chapter 6 (Cont.)

APPENDIX

TABLE OF CONTENTS (CONT.)

VOLUME 2

Chapter 6 (Cont.)

APPENDIX

TABLE OF CONTENTS (CONT.)

VOLUME 2

Chapter 7 (Cont.)

TABLE OF CONTENTS (CONT.)

VOLUME 2

Chapter 7 (Cont.)

VOLUME 1

LIST OF FIGURES

VOLUME 2

Figure **Page**

Chapter 5

LIST OF FIGURES (CONT.)

VOLUME 2

Figure **Page**

Chapter 5 (Cont.)

LIST OF FIGURES (CONT.)

VOLUME 2

Figure **Page**

Chapter 6

LIST OF FIGURES (CONT.)

VOLUME 2

Figure **Page**

Chapter 6 (Cont.)

LIST OF FIGURES (CONT.)

VOLUME 2

Figure **Page**

Chapter 6 (Cont.)

LIST OF FIGURES (CONT.)

VOLUME 2

Figure **Page**

Chapter 6 (Cont.)

LIST OF FIGURES (CONT.)

VOLUME 2

Figure **Page**

Chapter 6 (Cont.)

Chapter 7

LIST OF FIGURES (CONT.)

VOLUME 2

Figure **Page**

Chapter 7 (Cont.)

LIST OF FIGURES (CONT.)

VOLUME 2

Figure **Page**

Chapter 7 (Cont.)

LIST OF FIGURES (CONT.)

VOLUME 2

Figure **Page**

Chapter 7 (Cont.)

LIST OF FIGURES (CONT.)

VOLUME 2

Figure **Page**

Chapter 7 (Cont.)

LIST OF TABLES

VOLUME 2

Table **Page**

Chapter 5

Chapter 6

LIST OF TABLES (CONT.)

VOLUME 2

Table **Page**

Chapter 6 (Cont.)

Chapter 7

CHAPTER 5

CHARACTERISTICS OF CONSTRUCTED HUMMOCKS IN CREATED WETLANDS

E. Tim Gysan, Susan Carstenn and John Baker

INTRODUCTION

HISTORICAL PERSPECTIVE

Microtopographic relief plays an important role in many wetland ecosystems. Microtopographic land surface variation causes conditions not found in flat landscapes, including variable hydrology, soil conditions, and wildlife habitats. Hummocks are one type of microtopography caused by natural events in wetlands. Hummocks form from organic matter accumulation around standing trees, brush, and wind-thrown trees (Hardin and Wistendahl 1983). Wetlands in the Canadian north contain hummocks formed by differential erosion (Munro and Shaw 1997), soil uplift by pressure created by the migration of the freezing interface towards permafrost inside mounds (Crampton 1977), and the upward displacement of soil caused by freeze-thaw of ice lenses (Mackay 1980). Hummocks can form by channel erosion and soil deposition in rivers and river deltas. One example of this phenomenon is the collection of large hummocks at Otter Island in St. Helena sound along the coast of South Carolina (South Carolina DNR and others 1996).

Wetland hydrologic conditions are the major influence on freshwater wetland structure and function. Hydrology directly affects biota through hydroperiod and depth of inundation. Hydrology indirectly affects biota by changing soil conditions such as nutrient availability, oxygen content, and pH. Wetlands are the transition between terrestrial and open water ecosystems and thus contain many species found in both systems. Small changes in hydrology can have great influence on the vegetation found in the wetland (Mitsch and Gosselink 1993). Conner and others (1981) suggest that flooding regime is an important controlling factor on vegetation, based on work in swamps in Louisiana. Joseph Hmielski (1994) found that in the hummocky transition and forest zones of flat transects occupying low elevations along brackish marsh-upland continua at the Virginia Coast Reserve/LTER, hummocks appear to allow glycophytic vegetation to colonize closer to the tidal creek thus increasing the width of transition zones. The effect is caused by the control of topographic variation, in the form of land slope and hummocks, on the position of vegetation zones through its effect on physiochemical variables.

The unique conditions found on hummocks can increase diversity within other natural wetlands (Vivian-Smith 1997). Hummocks favor seed germination and establishment of diverse vegetation including tree species (Titus 1990). Huenneke and Sharitz (1986) found that tree seedlings in natural and disturbed swamps were more likely to occur in areas of stabile substrate where they were able to escape inundation. Seedlings were much less dense in areas of unconsolidated soils with complete inundation during the growing season. Kozlowski (1984) showed that tree species are much more sensitive to environmental variations (such as water level fluctuations) as seedlings than they are as adults. Water most likely becomes a limiting factor in bottomland tree survivorship only on sites continuously flooded for long periods of time during the growing season (Hosner 1960). Lowry (1994) found that in swamps with flooding during more than 35% of the growing season, woody plants are restricted to mounds (hummocks). These studies have shown that varying hydrology and unique soil conditions created by microtopographic variations are valuable within a forested wetland.

SITE INFORMATION

The initial goal of this project was to incorporate microtopography, in the form of hummocks, into one or more constructed wetlands and to study the change in the hummocks over time, soils, vegetation, and hydrology to assess the effects on the wetland. Two reclamation projects were found and hummocks incorporated into their design. A final mature site, with constructed hummocks, served as a comparison to the immature sites. Figure 5.1 shows the location of the sites.

Agrifos L.L.C. and Janine Callahan, the reclamation coordinator for Agrifos, incorporated microtopography into the design of a current reclamation project. Eighteen hummocks were constructed; nine hummocks approximately 4m x 2m x 0.6m (length, width, and height) and nine hummocks approximately 4m x 2m x 0.9m. Hummocks were placed in-groups of three, with each group having one hummock constructed from each soil type. Soil materials used were sand tailings, mine overburden, and organic compost made from recycled yard waste in Sarasota. One pop ash (*Fraxinus caroliniana*) and one sweet bay (*Magnolia virginiana*) were planted on each hummock. No other vegetation was planted on the hummocks. Monitoring began after the site construction was completed in late March 1999 to establish baseline data for each hummock. Further monitoring took place bi-monthly. The site plan for the Agrifos wetland, including the hummock location and the hummock layout as constructed in the wetland, is shown in Figure 5.2.

Cargill Fertilizer, Inc. and reclamation coordinator Rosemarie Garcia also incorporated hummocks into a constructed wetland. Twelve hummocks were built in the wetland, half using mine overburden and half using harvested muck. Hummocks are approximately 6m x 6m x 0.9m. Sand tailings were not used in this project. Construction was completed in September 1999. One green ash (*Fraxinus caroliniana*), one sweet bay (*Persia borbonia*), and one bald cypress (*Taxodium distichum*) were planted on each hummock. No other vegetation was planted on the hummocks. Monitoring began in September 1999 and took place bi-monthly. The site plan for the Cargill Phase 7 reclamation is shown in Figure 5.3 along with the hummock placement and layout.

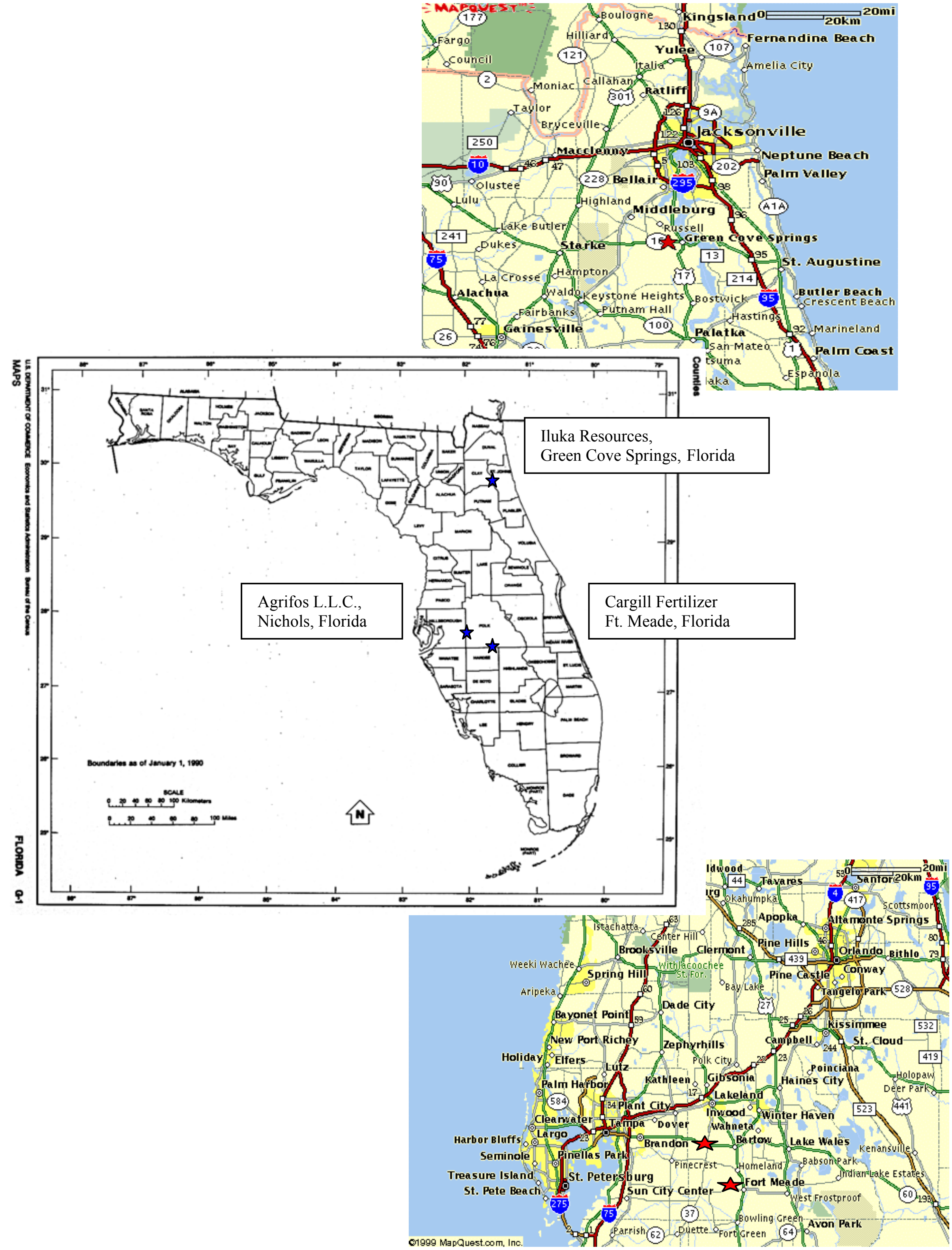


Figure 5.1. Constructed Wetland Site Locations.

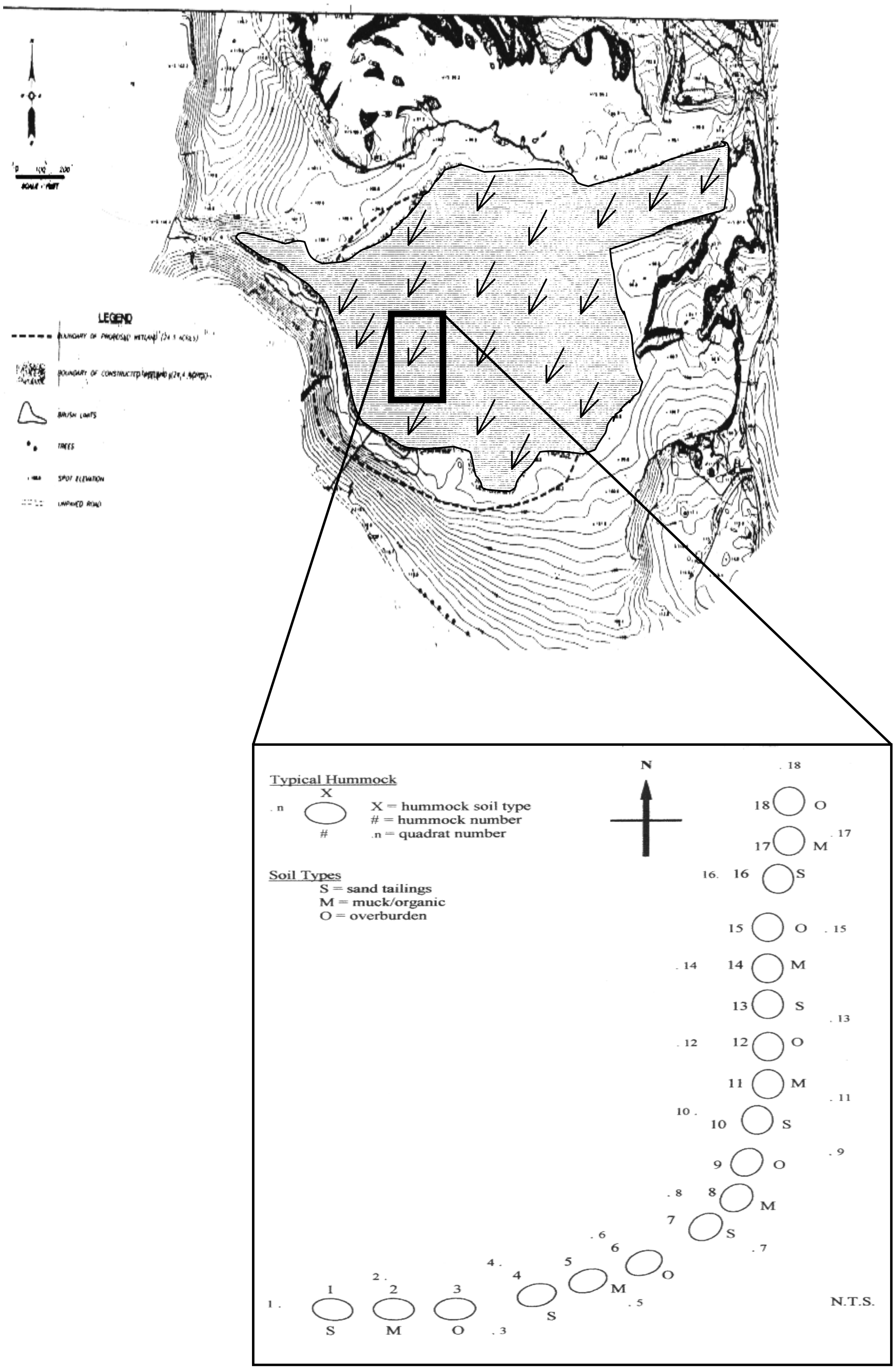


Figure 5.2. Agrifos Wetland As-Built Construction Plan with Location and Layout of the Constructed Hummocks.

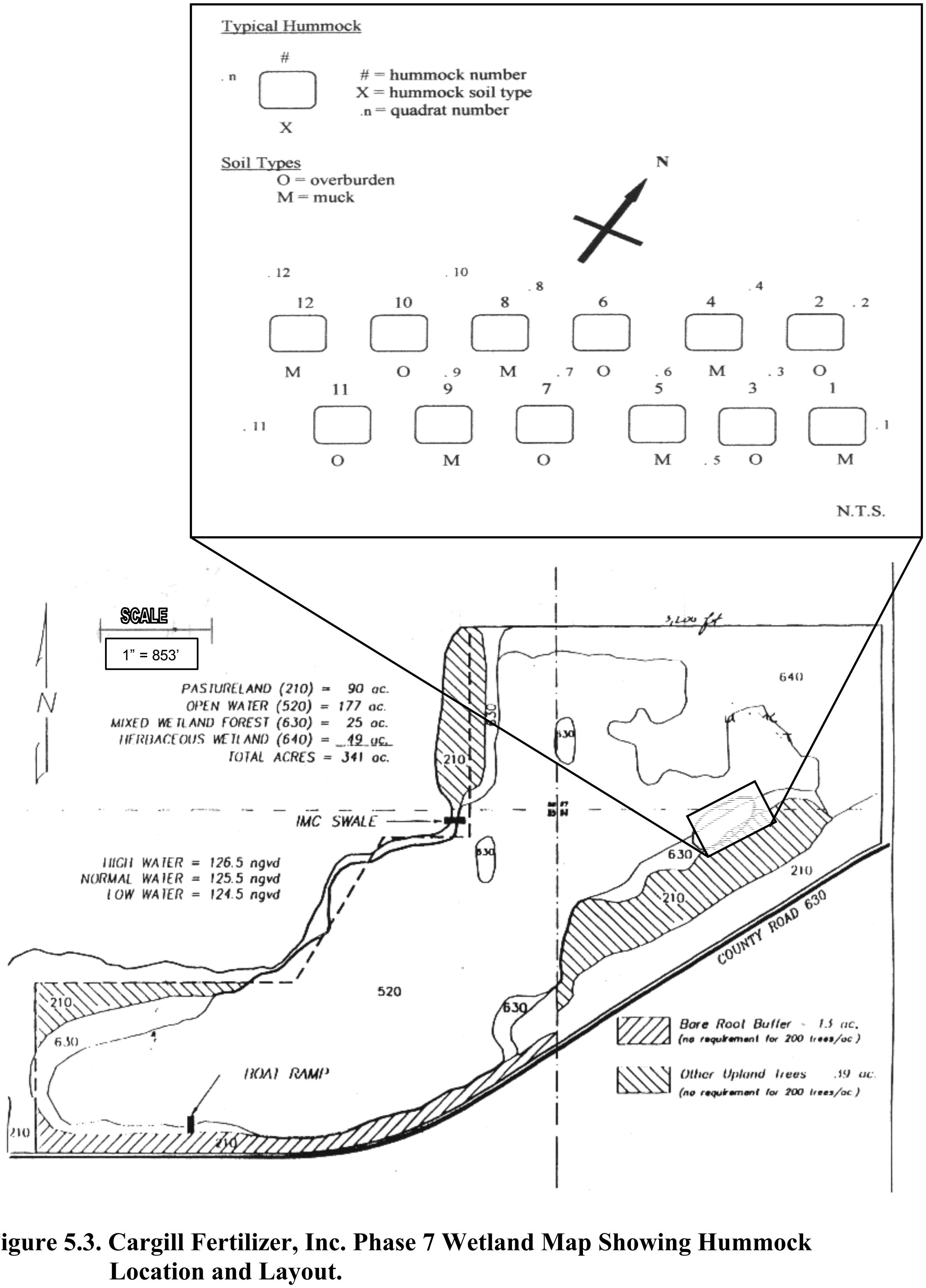


Figure 5.3. Cargill Fertilizer, Inc. Phase 7 Wetland Map Showing Hummock Location and Layout.

Ted Goodman at Iluka Resources in Green Cove Springs allowed hummock studies done in a reclaimed titanium mine site. The site was reclaimed in May 1993 and contains constructed hummocks made by topsoil replacement. The hummocks are not uniform in size.

The five hummocks randomly selected for the study range in size from 4m x 3m x 0.6m to 6.5m x 4m x 0.6m. The site has been deemed successful and released by the United States Army Corps of Engineers and the Florida Department of Environmental Protection. Cypress trees (*Taxodium distichum)* from the company's nursery were planted on each hummock. The site has a high density of herbaceous understory vegetation on the hummocks. The Site 7 wetland is shown in Figure 5.4 along with the study hummock location.

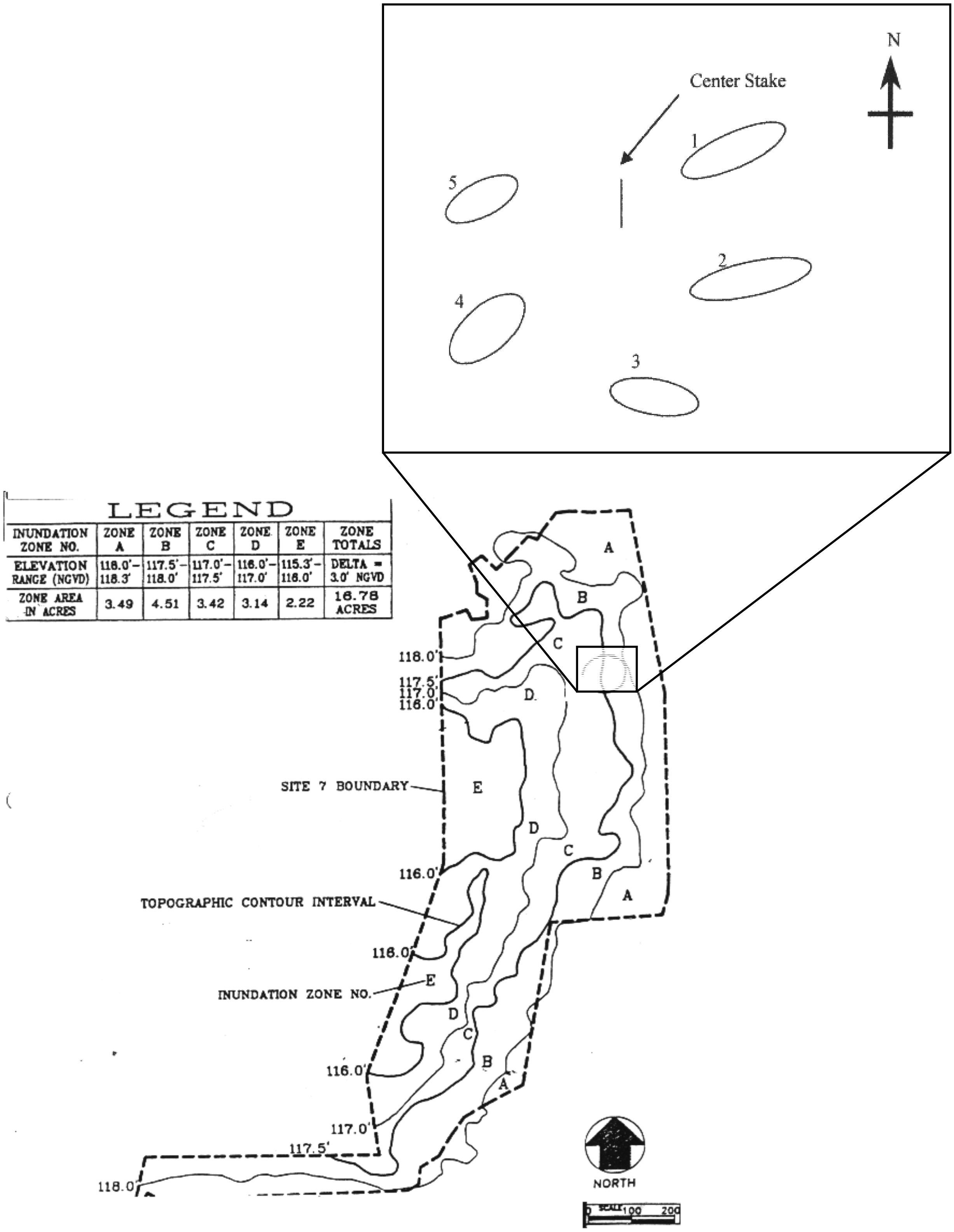
PURPOSE

Previous projects conducted on behalf of the Florida Institute of Phosphate Research by Mellini Sloan (1998) and Benjamin Bukata (1999) studied microtopographic relief in natural wetlands and its development in reclaimed wetlands. The preliminary work on the development of microtopography in the previous projects suggests that construction of hummocks may significantly increase tree growth and understory vegetation. The next step is to evaluate the design of relief and the contributions that relief can have in constructed forested wetlands. That evaluation was the purpose of this project.

Ultimately, the goal of this research was to understand the both methods of incorporating hummocks into constructed wetlands and the role they have in the enhancement of vegetation growth, vegetation survival and vegetation diversity, as well as hydrologic function.

Construction of hummocks in created wetlands requires consideration of the soils to be used, the size and shape of the hummock, and the height of the hummock peak above the water table. In this study, to understand structural characteristics of hummocks of varying sizes and soil composition, soil moisture and surface elevation were measured on each hummock. This study was set up to find trends between soil moisture conditions, changes in the hummock structure over time, facilitation of tree establishment and growth, and richness of species colonizing each hummock.

To determine the effects of standing water on hummock conditions, water level was correlated with soil moisture. To show the species richness each hummock type can support; species colonization was recorded. To document the role of hummocks in tree growth and survival, tree saplings were monitored to track establishment and growth both on and off the hummocks.



LEGEND

INUNDATION ZONE NO.	ZONE A	ZONE B	ZONE C	ZONE D	ZONE E	ZONE TOTALS
ELEVATION RANGE (NGVD)	118.0'–118.3'	117.5'–118.0'	117.0'–117.5'	116.0'–117.0'	115.3'–116.0'	DELTA = 3.0' NGVD
ZONE AREA IN ACRES	3.49	4.51	3.42	3.14	2.22	16.78 ACRES

Figure 5.4. Iluka Resources Site 7 Wetland Map with Hummock Location and Layout Shown.

METHODOLOGY

HUMMOCK ELEVATION MEASUREMENT

Establishment of Benchmarks

A benchmark was established in the Agrifos site by driving a 5-foot long (1.5m), ¼-inch (0.64 cm) steel rebar into the ground at a central point between the hummocks after construction. Four-foot (1.2m) lengths of ¼-inch (0.64cm) steel rebar were driven into the center of each hummock leaving a six-inch section above ground. Elevations, based on a surveyors benchmark elevation, were taken at the top of each rebar by surveyors during the as-built site survey. Benchmarks were established in the Cargill site using 5-foot (1.5m) lengths of ¼-inch (0.64cm) steel rebar. Rebar was driven into the center of each hummock leaving 1-foot (30.5cm) of rebar exposed above ground. Elevations were taken at the top of each rebar relative to the surveyors' benchmark. No benchmark was established in the Iluka site, as survey information was not available.

Elevation Measurements

A tape measurer was stretched across the length and width of each hummock horizontally from the center rebar to establish major and minor transects along the centerline. A typical hummock with transects is shown in Figure 5.5. Stake flags were placed at 30.5cm intervals to serve as permanent sampling locations in the Agrifos and Iluka wetlands. Permanent sampling locations were set up at 61cm intervals in the Cargill wetland because of larger hummock sizes. Heights were taken with a laser level placed at the benchmark point between the hummocks. The readings were given in feet and inches to the nearest tenth of an inch. Height measurements were taken at each sampling point. Height was also taken at the top of each rebar to provide a relationship with the benchmark elevation relative to mean sea level (MSL).

The top of the rebar was considered the zero point. Each hummock height was subtracted from the height at the top of that hummock's rebar to give a difference in height in feet at each point. The difference in height was subtracted from the known elevation at the top of the rebar to get the elevation above sea level. Elevation versus distance was then plotted using the Excel 97 spreadsheet.

Cross sectional areas along the major and minor transects were generated for each hummock (Figures A1-A35) by using multiple applications of Simpson's 1/3 Rule and Simpson's 3/8 Rule (Chapra and Canale 1988).

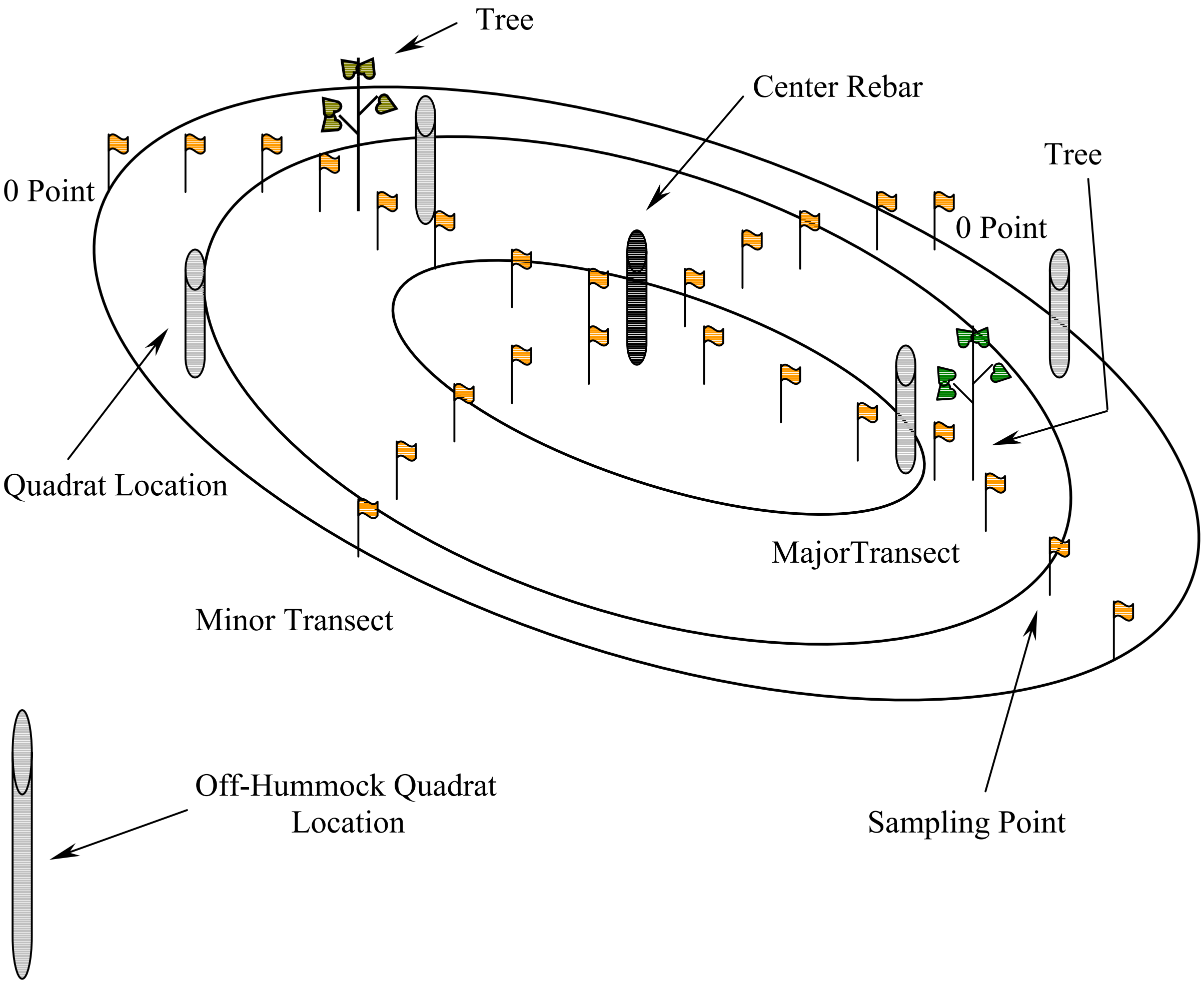


Figure 5.5. A Typical Hummock with Major and Minor Transects Shown as Flagged Sampling Points. Major Transects Cover the Length of the Hummock. Minor Transects Cover the Width of the Hummock.

Simpson's 1/3 Rule –

$I = (b-a)[(f(x_0) + 4\Sigma f(x_1) + 2\Sigma f(x_2) + f(x_n))/3n]$ [1]
I = area under the cross section curve
a = length at x = 0, tip of hummock
b = length at x = n, end of hummock
$f(x_{0,1,2,n})$ = value on y-axis, height of hummock
x_1 = the odd number points
x_2 = even number points up to , but excluding x_n
n = number of points

Simpson's 3/8 Rule

$I = (b-a)[(f(x_0) + 3f(x_1) + 3f(x_2) + f(x_3))/8]$ [2]
I = area under the curve
a = length value at x = 0, tip of hummock
b = length value at x = n, end of hummock
$f(x_{0,1,2,3})$ = value on y-axis, height of hummock

The change in area during each measurement period was used to calculate the percent change in hummock elevation. Percent change in area was determined by subtracting the new area from the original area and dividing the result by the original area.

Change in Area

% Change = $(A_0 - A_1)/A_0$ [3]
A_0 = original area
A_1 = new area

Cross sectional areas calculated for each hummock were compared to the original value to find changes over time. The changes indicate the amount of degradation in the hummock surface.

WATER LEVEL MEASUREMENT

Water level was recorded to relate the soil moisture in each hummock with the height of the water relative to each hummock. Stevens Type F water-level recorders Model 68 were installed in the Agrifos and the Cargill wetlands. Data were not collected during the first growing season however, because the recorders were not installed until mid-October. Water levels were determined by taking height readings at multiple points along the edge of the standing water. Elevations of the water surface were then determined using the same process as for hummock elevations.

SOIL MOISTURE MEASUREMENT

Soil moisture readings were taken using a TH_2O soil moisture meter. Readings of soil moisture were taken at each sampling point along the major and minor transects. Three outputs are possible with the TH_2O meter: direct output voltage, organic moisture, and mineral moisture. Direct probe output was used because of greater ease of calibration for specific soils.

Calibration curves for specific soils are based on the relationship between the dielectric constant (ε) sensed by the probe and the water content (θ). Specific calibration curves for each hummock soil type can be created. Soil moisture was calculated from the voltage read by the probe. Voltage (V) was related to ε by the following equation:

$$\sqrt{\varepsilon} = 1.07 + 6.4V - 6.4V^2 + 4.7V^3 \quad [4]$$

$\sqrt{\varepsilon}$ = square root of dielectric constant
V = voltage

The actual soil moisture was then calculated from the following equation (coefficients described in user manual):

$$\theta = [\sqrt{\varepsilon} - a_0] / a_1 \quad [5]$$

θ = volumetric water content (m^3/m^3)
a_0 = dry soil coefficient
a_1 = wet soil coefficient

A generalized curve for θ versus V is provided in the user manual and provides a typical error of $\pm 0.05\ m^3/m^3$. The coefficients for wet and dry soil are based on these curves. Perfect calibration decreases error to $\pm 0.02\ m^3/m^3$. Calibration was not done for this project because the trends seen in water content are more important to the hummock comparison than true values. The tendency of soils to compact and shift in the new wetlands changing the pore spaces prohibits accurate calibration. Water contents were taken on a bi-monthly basis throughout the growing season.

TREE MEASUREMENT

Tree heights were measured with a standard tape measurer. Heights were taken from the base of the tree to the highest point of the tallest branch. Heights were taken to the nearest 0.3cm. Basal diameter was measured using standard calipers. Diameters were taken to the nearest millimeter. Tree measurements were taken for 18 trees of each type planted on the hummocks in the Agrifos wetland. Nine trees of the same species off the hummock were originally supposed to be sampled to compare growth and survivorship with on hummock trees. However, only five ash trees were ever found off the hummocks, and no sweet bay trees were ever seen. These trees were measured at the beginning and end of the growing season. Due to the late construction of the Cargill wetland, only initial measurements were made of the 12 trees of each species on the hummock. Two ash, five bay, and five cypress trees were found off the hummocks. Tree measurements at the Iluka site were limited to diameter at breast height due to the extreme height of the trees. Height was not estimated for these trees.

VEGETATION MEASUREMENT

No species were initially planted on the Agrifos or Cargill hummocks to observe colonization. Plants were identified, and a percent cover for each species within a $0.25m^2$ circular quadrat was given. Four quadrats on each hummock were counted during each sampling period. Two quadrats were placed along the top of the hummock in lower moisture condition, and two were placed along the slope of the hummock at the soil/ water interface. Quadrats were placed in similar places on each hummock. Quadrats were placed at 18 points off the hummocks in the Agrifos wetland, 12 points in the Cargill wetland, and five points in the Iluka wetland to compare vegetation in differing growing conditions. Off hummock quadrats were randomly located. Quadrat sampling points were marked with 30.5cm sections of PVC pipe on the hummocks and with 90cm sections of PVC off the hummocks. The numbers of species (s) were counted as a simple diversity measurement. The *percent cover* (C_i) for each species (Brower and others 1990) within the quadrat was determined.

Percent Cover- $C_i = a_i / A * 100$ [6]

a_i = total area covered by a species

A = total area sampled

The richness and relative coverage was correlated to show the value of each species in the hummock community. The Shannon diversity index (Brower and others 1990) was used to determine diversity as each quadrat is considered a random sample of the entire community.

Shannon Diversity Index- $H' = -\Sigma p_i * \log_{10}(p_i)$ [7]

H' = Shannon diversity

$p_i = n_i/N$

N = number of individuals total

n_i = number of individuals in a given species

Because understory vegetation was not sampled by individual, relative coverage was used to determine p_i by calculating the probability a species would be sampled in a quadrat.

Weighted Probability – $p_i = P/\Sigma P$ [8]

where $P = n_i/n$

P = probability a species will be sampled

n = total number of quadrats

n_i = number of times a species is sampled

An evenness index was also calculated to provide a truer idea of the vegetation found on each hummock.

Shannon Evenness – $J' = H'/H'_{max}$ [9]
where $H'_{max} = \log s$
H'_{max} = maximum Shannon diversity
J' = evenness of species distribution
s = number of species

Community similarities were calculated for habitat on and off the hummocks. The Sorensen coefficient of community similarity (CC_s) was used for comparison because of interest in only the presence or absence of species (Brower and others 1990).

Sorensen Coefficient – $CC_s = 2c/(s_1 + s_2)$ [10]
c = number of species similar to both communities
s_1 = number of species in community 1
s_2 = number of species in community 2

PHOTOGRAPHIC RECORD

A photographic record has been kept of the Agrifos wetland system starting at construction. Bi-monthly pictures were taken from permanent photo stations marked in the wetland. A 1.5m section of PVC pipe was placed in the wetland next to the benchmark point and at similar position between the last 9 hummocks. All photos from within the wetland were taken from that five-foot height. Photos include images of each group of three hummocks and from a point elevated above the wetland. Similar photographic records were kept for the Cargill and Iluka sites.

RESULTS

HUMMOCK-TO-HUMMOCK COMPARISON

Change in Cross-Sectional Area

The change in cross-sectional area of each hummock measured along the major and minor transects was intended to show the amount of erosion or settling in each soil type used in hummock construction. Figure 5.6 shows the percent change in cross-sectional area for the hummocks in the Agrifos wetland. The changes shown are averages for each hummock type. A decrease in percent change from the first sampling period to the last sampling period indicates a continued soil shifting throughout the first growing season after construction. The hummocks constructed from organic matter show the largest decrease in cross-sectional area along both the major and minor transects. By the last sampling period (1999), the organic hummocks showed a change around –6.00% from the original height. Overburden hummocks were next, with a change of around –4.00%. Sand hummocks showed the least amount of change with a shift of –2.50%. Sampling during the summer of 2000 revealed continued decreases in cross-sectional area. Organic hummocks still showed the greatest decrease at –16.0%. Sand hummocks showed an average decrease of slightly greater than 6.0%. Although still decreasing in cross-sectional area, the magnitude of the change decreased in overburden hummocks (less than –2.0%).

Figure 5.7 shows the percent change in cross-sectional area for the Cargill wetland. After the first season, there was little difference between organic and overburden hummocks. After the second season, there appears to be larger decreases in overburden hummocks than organic hummocks. This is particularly apparent along the minor transect.

Figure 5.8 shows percent change in cross-sectional area for the Iluka Resources wetland. This mature site has hummocks constructed only from overburden. These appear to show a slight increase in area by the end of the growing season. Along the major transect, the increase is about 1.00%. Along the minor transect, the increase is around 4.00%. The purpose of this figure is to that show after the initial negative shifting of the hummock soil seen in above figures, a growth or stability of the hummock occurs.

Species Diversity

Species diversity indices were intended to show the differences in the ability of hummocks to support understory vegetation. Table 5.1 shows the species diversity as a simple species count and as a Shannon index for each hummock type and each sampling period. Included is a percent cover of vegetation on the hummocks. In the Agrifos wetland, the overburden hummocks have the highest number of species during the first

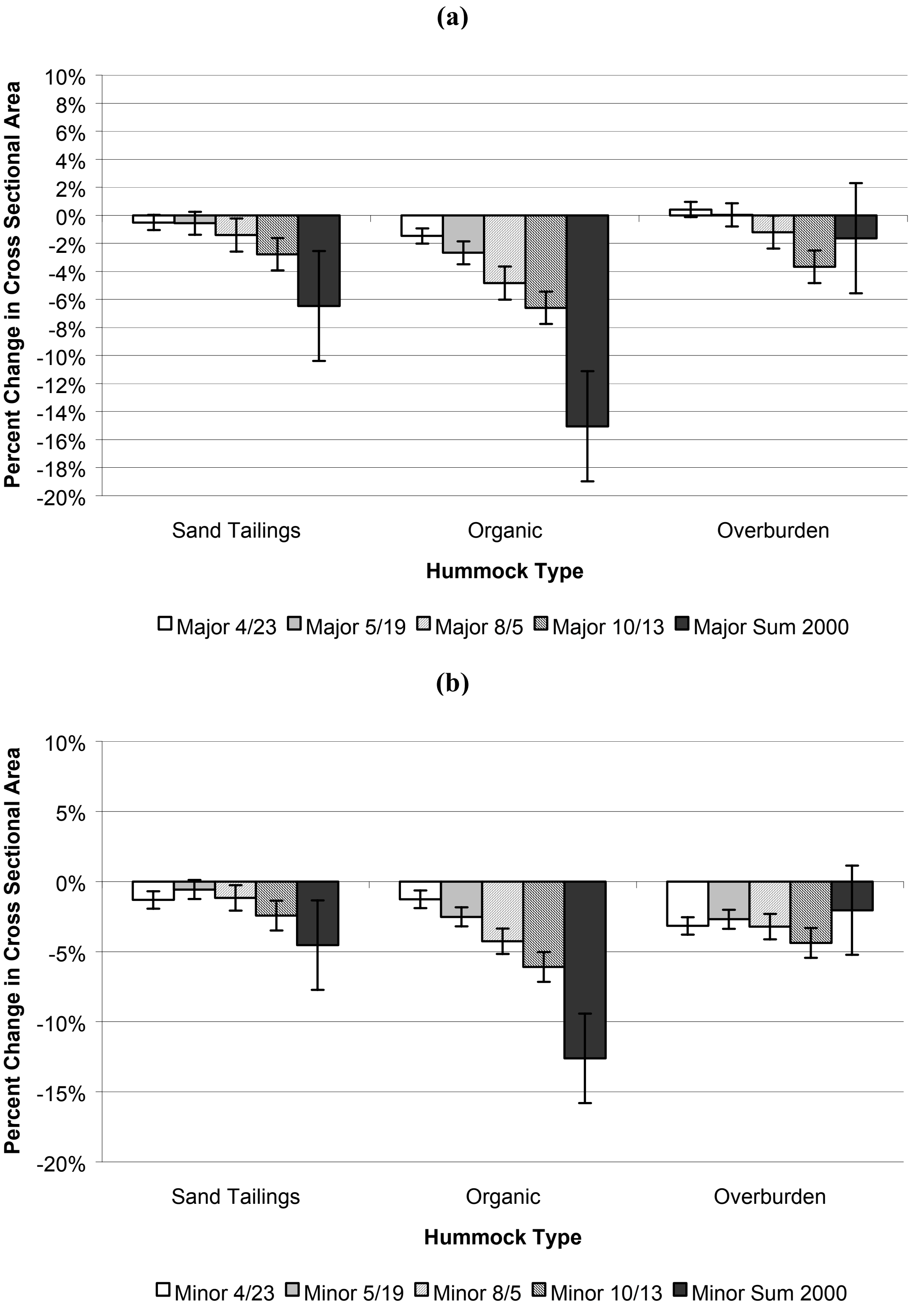


Figure 5.6. Changes in Cross-Sectional Areas for (a) Major and (b) Minor Transects in the Agrifos Wetland. Standard Error Bars Are Calculated Using the Excel 97 Chart Wizard.

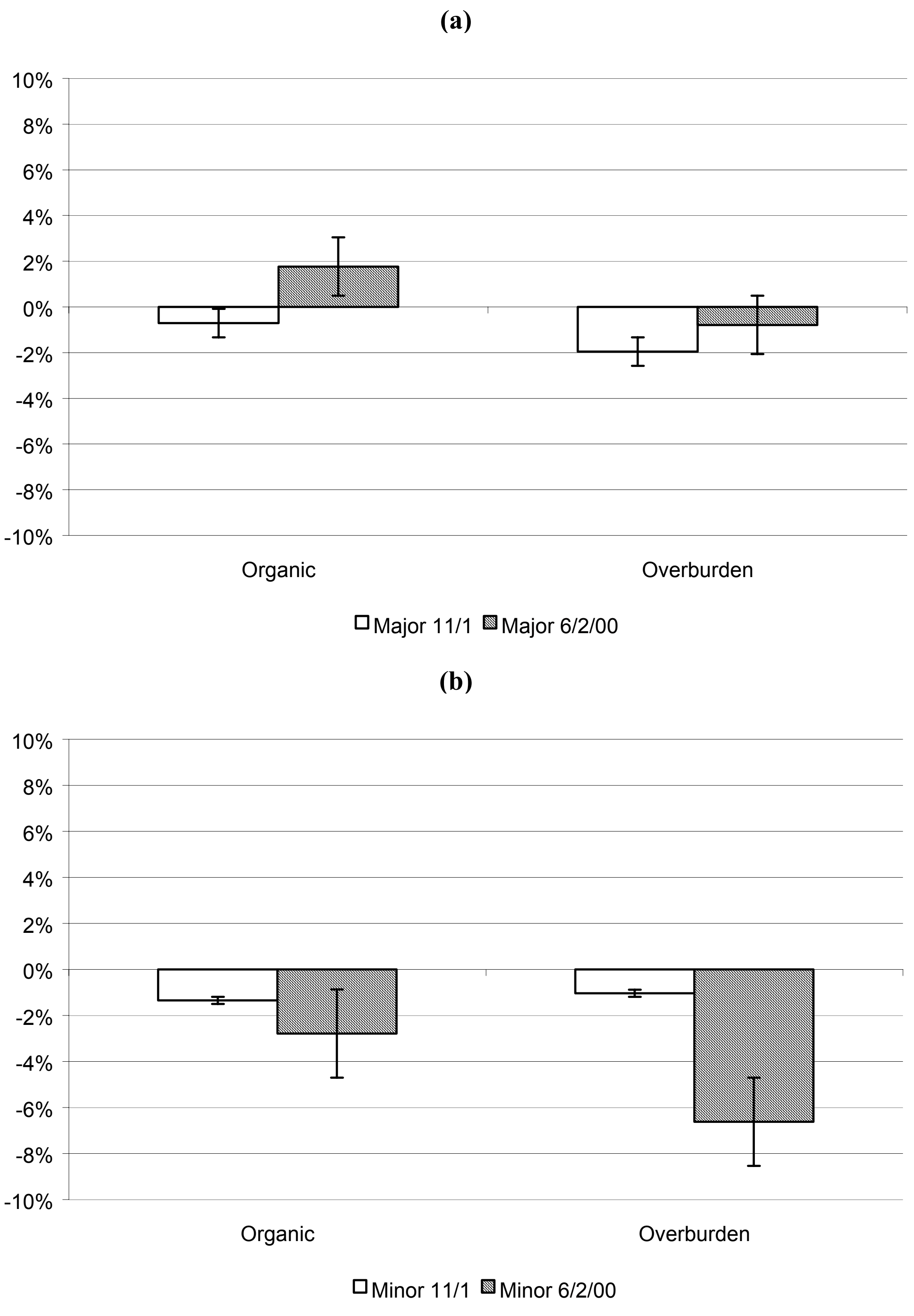


Figure 5.7. Changes in Cross-Sectional Areas for (a) Major and (b) Minor Transects in the Cargill Wetland. Standard Error Bars Are Calculated Using the Excel 97 Chart Wizard.

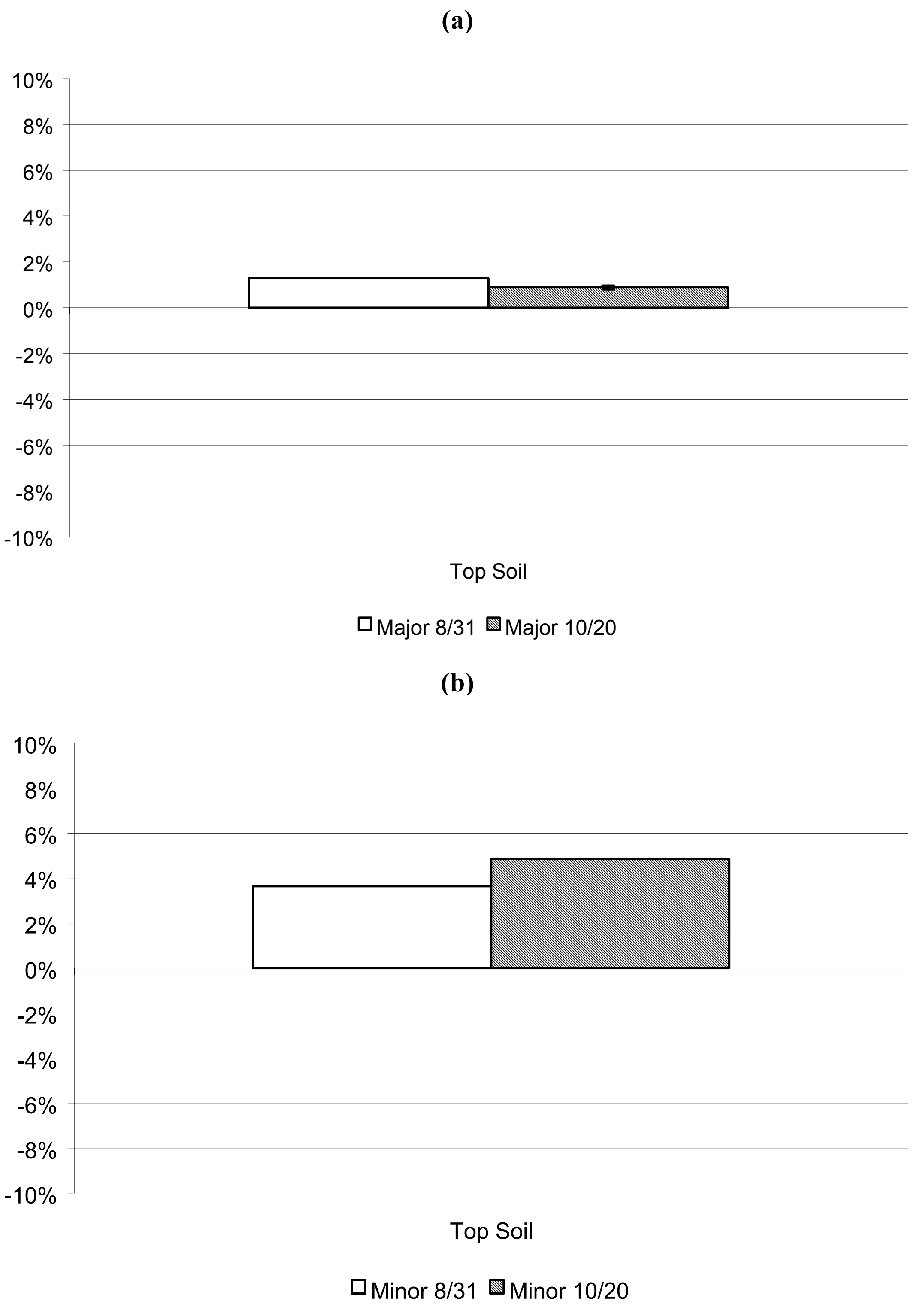


Figure 5.8. Changes in Cross-Sectional Areas for (a) Major and (b) Minor Transects in the Iluka Resources Wetland. Standard Error Bars Are Calculated Using the Excel 97 Chart Wizard.

Table 5.1. Hummock Comparison Based on Species Diversity Indices for Agrifos, Cargill, and Iluka Wetlands.

Wetland Location	Date Sampled	Hummock Soil Type	Number of Species (s)	Shannon Diversity (H')	Shannon Evenness (J')	% Cover
Agrifos	5/19/99	Sand	12	0.90	0.84	17
		Organic	8	0.70	0.78	12
		Overburden	17	1.06	0.86	24
Agrifos	8/5/99	Sand	16	1.07	0.89	24
		Organic	16	1.00	0.83	90
		Overburden	19	1.15	0.90	34
Agrifos	10/13/99	Sand	19	1.17	0.91	24
		Organic	18	1.11	0.88	56
		Overburden	17	1.08	0.88	27
Agrifos	Sum2000	Sand	23	1.23	0.90	35
		Organic	15	0.96	0.81	78
		Overburden	30	1.33	0.90	42
Cargill	9/13/99	Organic	13	0.98	0.88	37
		Overburden	10	0.81	0.81	34
Cargill	11/1/99	Organic	19	1.00	0.78	55
		Overburden	13	0.90	0.81	46
Cargill	Sum2000	Organic	46	1.49	0.90	86
		Overburden	43	1.50	0.92	86
Iluka	5/4/99	Top Soil	16	1.08	0.89	38
Iluka	8/31/99	Top Soil	21	1.19	0.90	45
Iluka	10/20/99	Top Soil	21	1.19	0.90	36

two sampling periods with 17 and 19 species recorded. The overburden hummocks also have the highest Shannon diversity and evenness during the first two sampling periods with 1.06 (0.86) and 1.15 (0.90). The organic hummocks have the lowest number of species and the lowest Shannon indices for the first two sampling periods. At the last sampling period of 1999, the sand hummocks have the highest number of species (19) and highest Shannon index (1.17). While organic hummocks generally had lower diversities, they had the highest percent cover during the last two periods with 90% and 56% cover. Overburden hummocks had higher percent cover than sand hummocks in each sampling period of 1999. High diversity with low percent cover indicates that, while a soil type may have conditions suitable for many different plants, not many are actually growing. The Cargill wetland has a higher number of species growing on the organic hummocks (13 and 19) than on the overburden hummocks (10 and 13). The organic hummocks also show a higher Shannon diversities during both sampling periods and have higher percent covers. The mature Iluka site, having topsoil hummocks, has the highest overall number of species (21) and the highest Shannon diversity (1.19). The Iluka hummocks had a percent cover above 35% for each sampling period.

Species richness was greater on overburden and sand hummocks than on organic hummocks. Both, diversity and evenness were greater on the sand and hummocks than on organic hummocks. However, percent cover was greatest on organic hummocks.

Tree Growth

Tree growth and survivorship provides an indication of the potential for hummocks to be used as planting sites for tree seedlings within a wetland. Figure 5.9 shows the survivorship of tree seedlings within the Agrifos wetland. Every tree seedling survived the first growing season on the overburden hummocks. Only one tree died on the sand hummocks, a *Magnolia virginiana*. The organic hummocks had the lowest survivorship, with only one *Fraxinus caroliniana* and two *M. virginiana* living the entire growing season.

Figure 5.10 shows the changes in height and basal diameter for the trees planted on hummocks in the Agrifos wetland. Among the *F. caroliniana*, trees planted on the sand hummocks had the highest growth for both height (5% increase) and basal diameter (28% increase). Overburden hummocks had the next highest growth with height increase of 5% average and diameter increase of 21%. Sand hummocks, again, had a higher increase in basal diameter for *M. virginiana* with growth of 6%. Overburden hummocks had the highest increase in tree height at 5%.

Tree growth data from the 2000 field sampling season is not included because tree survival was minimal in the Agrifos wetland with only one tree surviving. This is attributed to severe drought conditions. In the Cargill wetland, more trees were found on the hummocks in 2000 than were planted in 1999. None of the trees was small enough to suggest natural recruitment. With no record of their planting, it was impossible to analyze tree growth at this wetland.

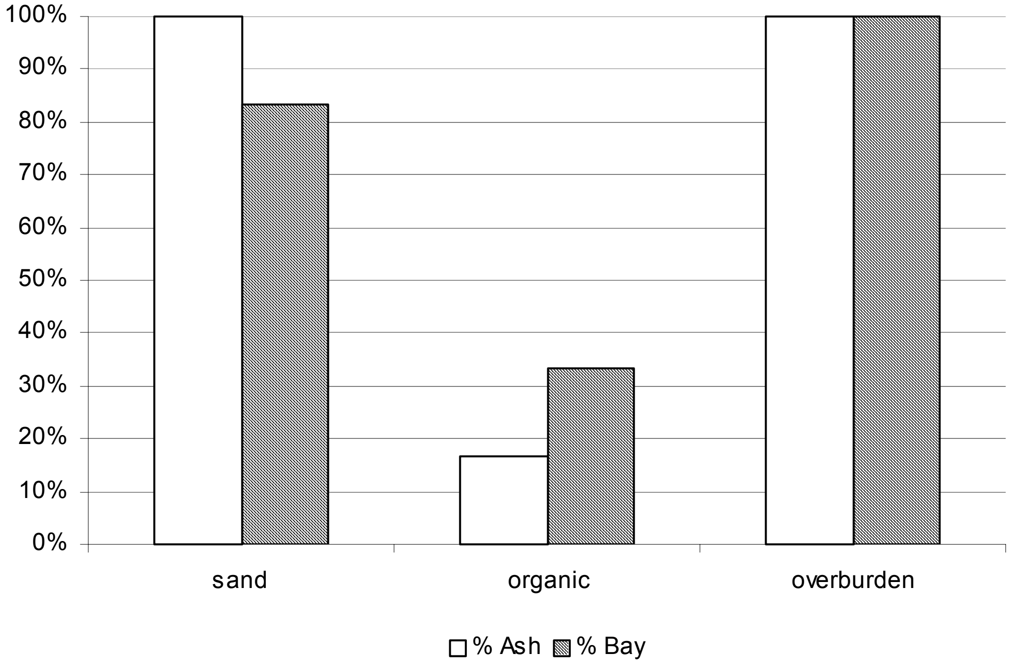


Figure 5.9. Percentage of Trees Surviving After One Growing Season in the Agrifos Wetland. Six Trees of Each Species Were Originally Planted for Each Hummock Soil Type.

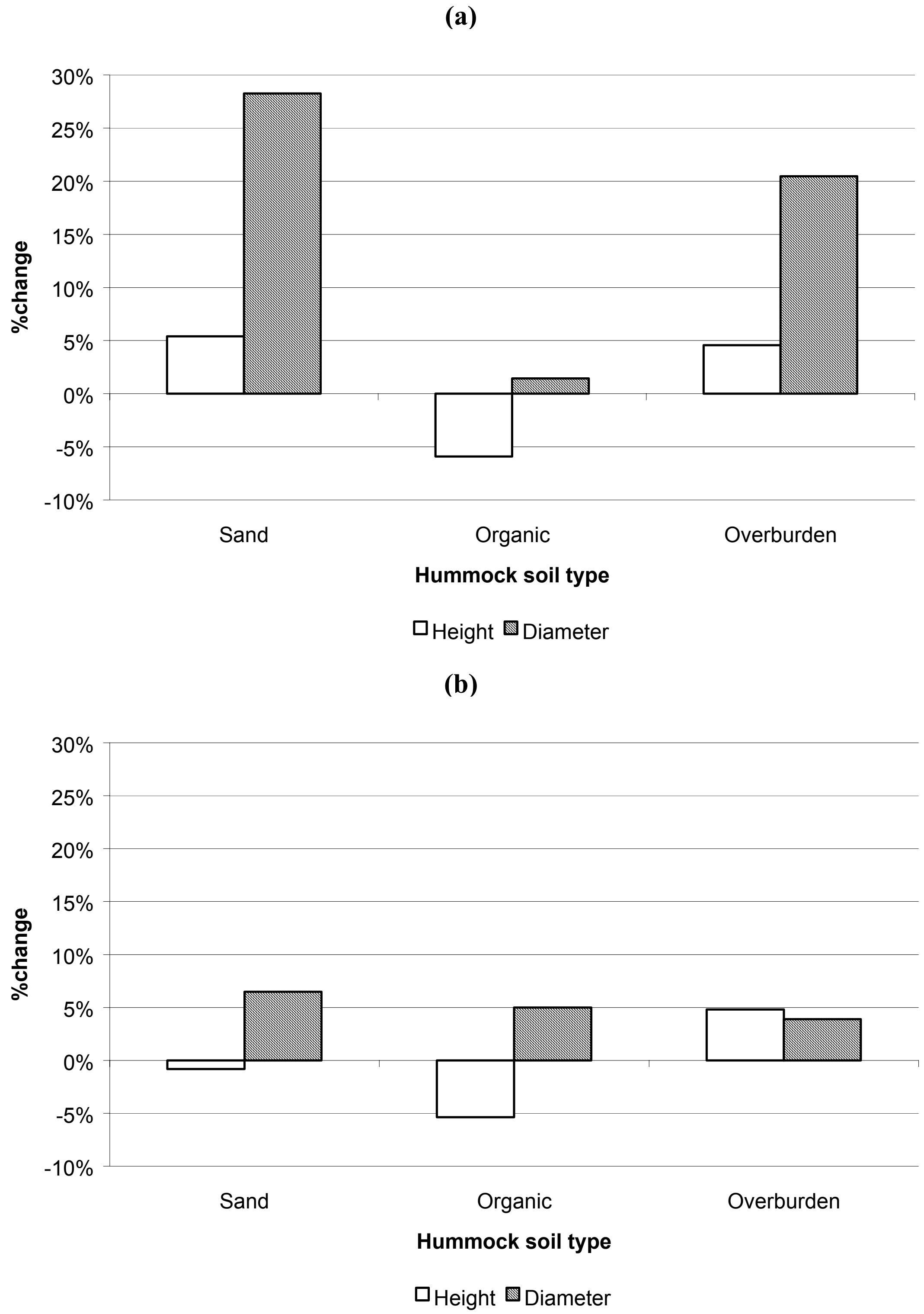


Figure 5.10. Changes in Tree Height and Basal Diameter for (a) *Fraxinus caroliniana* and (b) *Magnolia virginiana*. Measured on the Hummocks at the Beginning and End of the Growing Season in the Agrifos Wetland.

Volumetric Water Content

Volumetric water contents (one expression of soil moisture) of hummock soils can be used as an indication of the available microhabitats for vegetation growth. Figures 5.11-5.15 have the volumetric water content plotted against hummock elevation for each soil type in the Agrifos wetland for each sampling period. A best-fit line has been drawn through each group of points, and an r^2 value determined. A steeper slope of the best-fit line indicates a higher range of moisture values from the highest elevation to the lowest. In each sampling period, the organic soils have the steepest slope and therefore the highest range of moisture from the lowest to highest elevation. Overburden hummocks appear to have the shallowest slopes, indicating a more even distribution of moisture from lowest to highest elevation. From the first to the last sampling period, the r^2 values steadily increase for each soil type throughout 1999. Organic soil values increase from 0.58 to 0.87. Sandy soil values increase from 0.37 to 0.88. Overburden soil values increase from 0.33 to 0.92.

Figures 5.16, 5.17 and 5.18 show the volumetric water contents plotted against elevation for the hummocks in the Cargill wetland. The organic soils and overburden soils have similar slopes, indicating close ranges in moisture values. The increasing r^2 values are again seen for these soil types in 1999. The organic values increase from 0.35 to 0.75, and the overburden values increase from 0.47 to 0.81.

Figures 5.19-5.23 show the average volumetric water content for each hummock in the Agrifos wetland. The maximum and minimum values for volumetric water content are also plotted to show the range of micro-sites. A line has been drawn connecting the average values to show the trend for each soil type. Figure 5.19 presents data from the first sampling period. The organic hummocks, plotted in the middle of the graph, have higher averages and wider ranges of water contents than overburden and sand hummocks. Overburden hummocks have higher averages than the sand hummocks. The overburden hummocks also appear to have a similar width of ranges as the sand hummocks, but with higher minimum and maximum values. The same trend appears in each of the next three figures, which contain data for the other sampling periods.

Figures 5.24. 5.25 and 5.26 show similar data from the Cargill wetland. Again, the trend shows organic hummocks to have higher average volumetric water content than the overburden hummocks. Organic soils also have a wider range of values than the overburden soil, indicating more available micro-sites for vegetation.

HUMMOCK TO OFF-HUMMOCK COMPARISON

Species Diversity

The ability of hummocks to provide microhabitat for vegetation growth not found in other areas of a wetland would be a major attraction of incorporating hummocks into

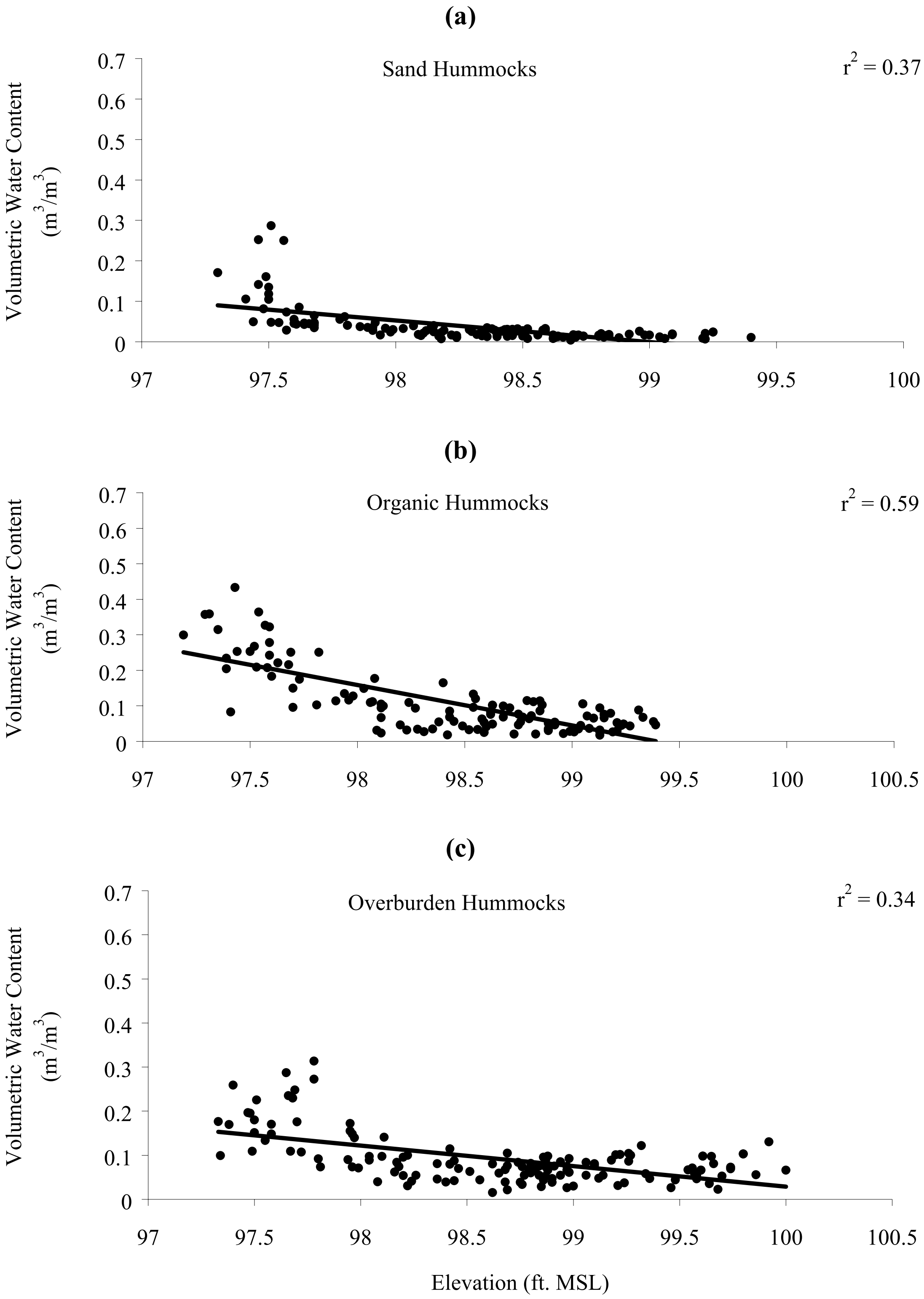


Figure 5.11. Volumetric Water Content Graphed Versus Elevation for Each Sampling Point on April 23, 1999, in the Agrifos Wetland. Water Level Measured at 96.94 Ft. MSL.

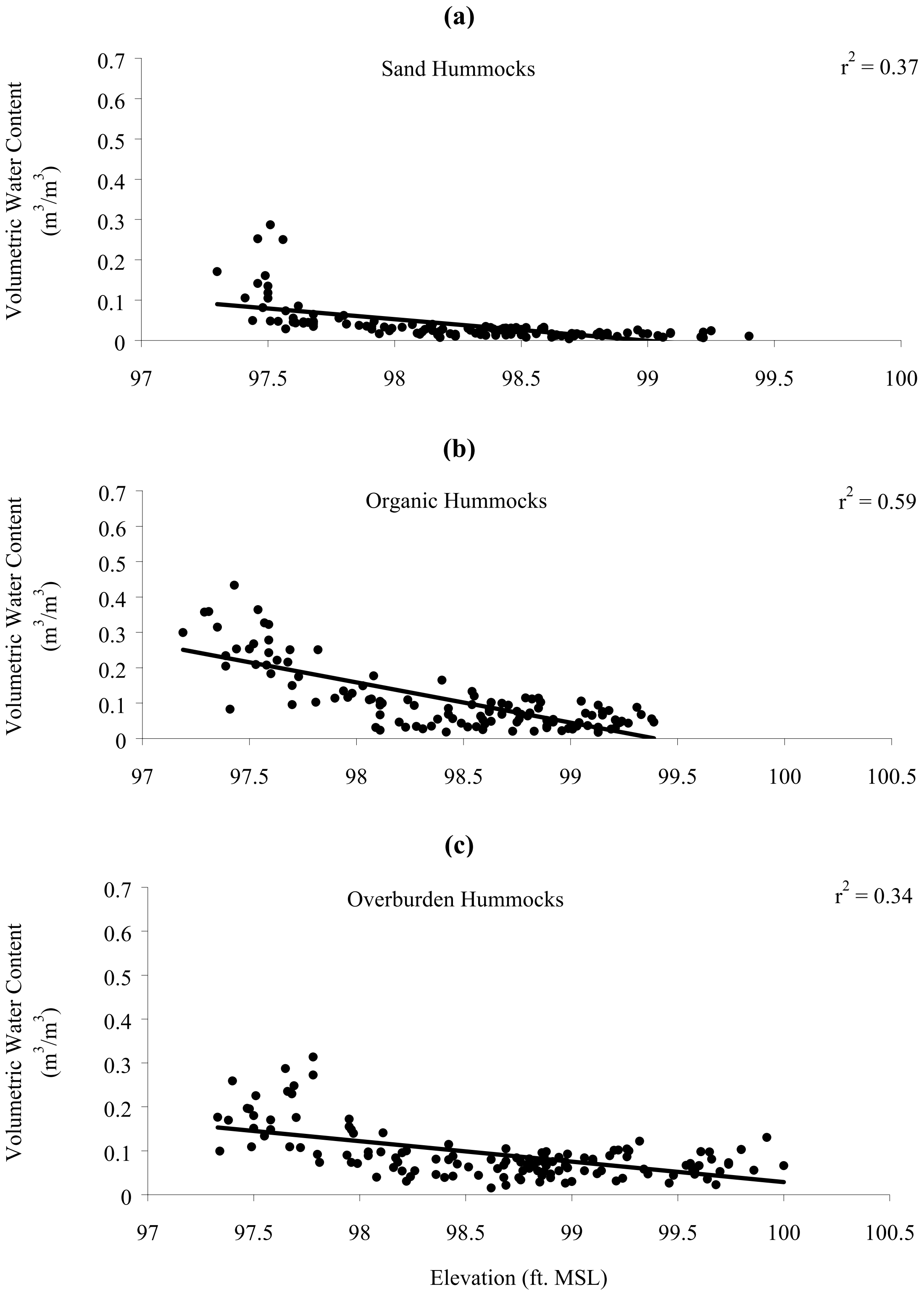


Figure 5.12. Volumetric Water Content Graphed Versus Elevation for Each Sampling Point on May 19, 1999, in the Agrifos Wetland. Water Level Measured at 97.28 Ft. MSL.

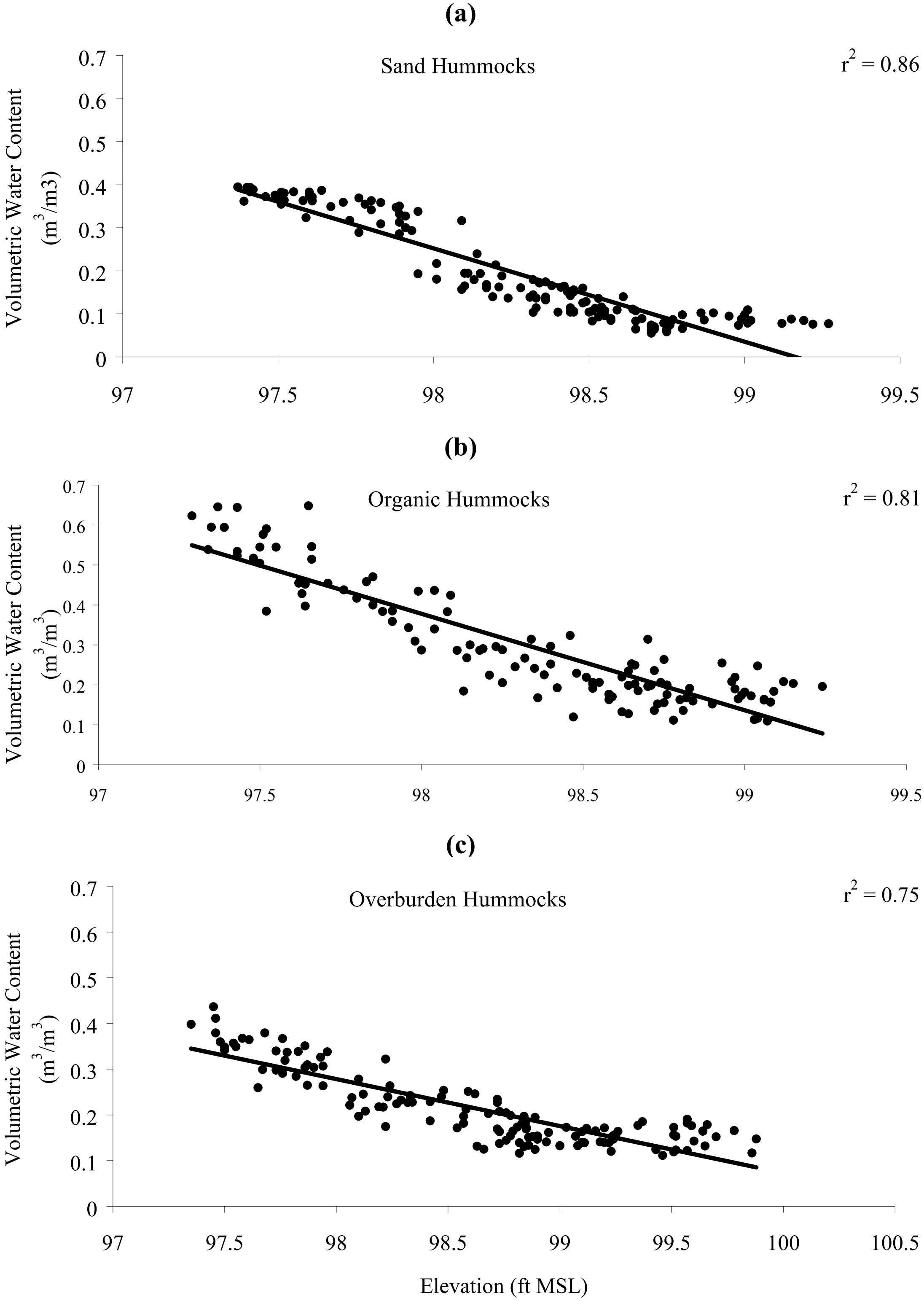


Figure 5.13. Volumetric Water Content Graphed Versus Elevation for Each Sampling Point on August 5, 1999, in the Agrifos Wetland. Water Level Measured at 97.33 Ft. MSL.

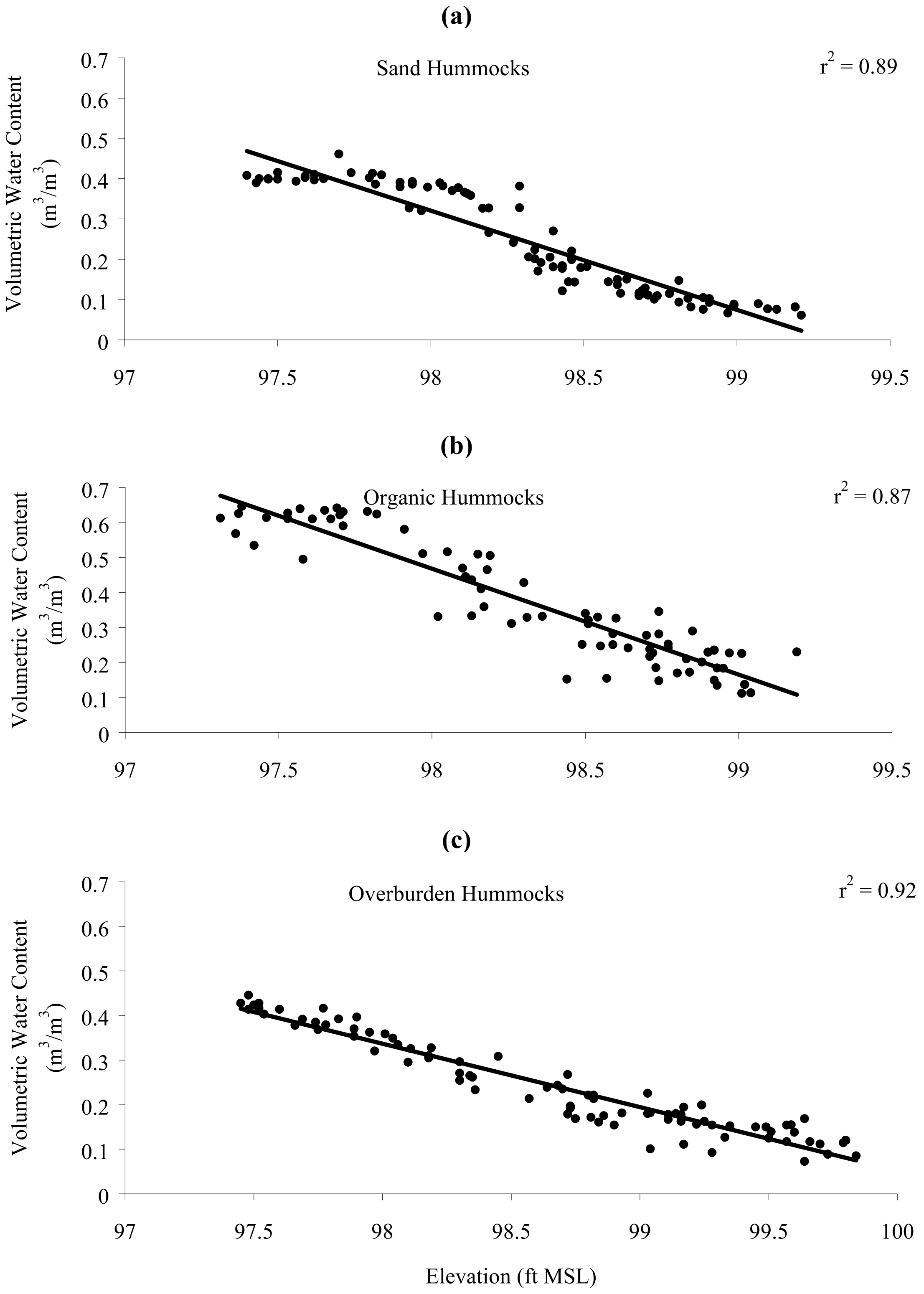


Figure 5.14. Volumetric Water Content Graphed Versus Elevation for Each Sampling Point on October 13, 1999, in the Agrifos Wetland. Water Level Measured at 97.42 Ft. MSL.

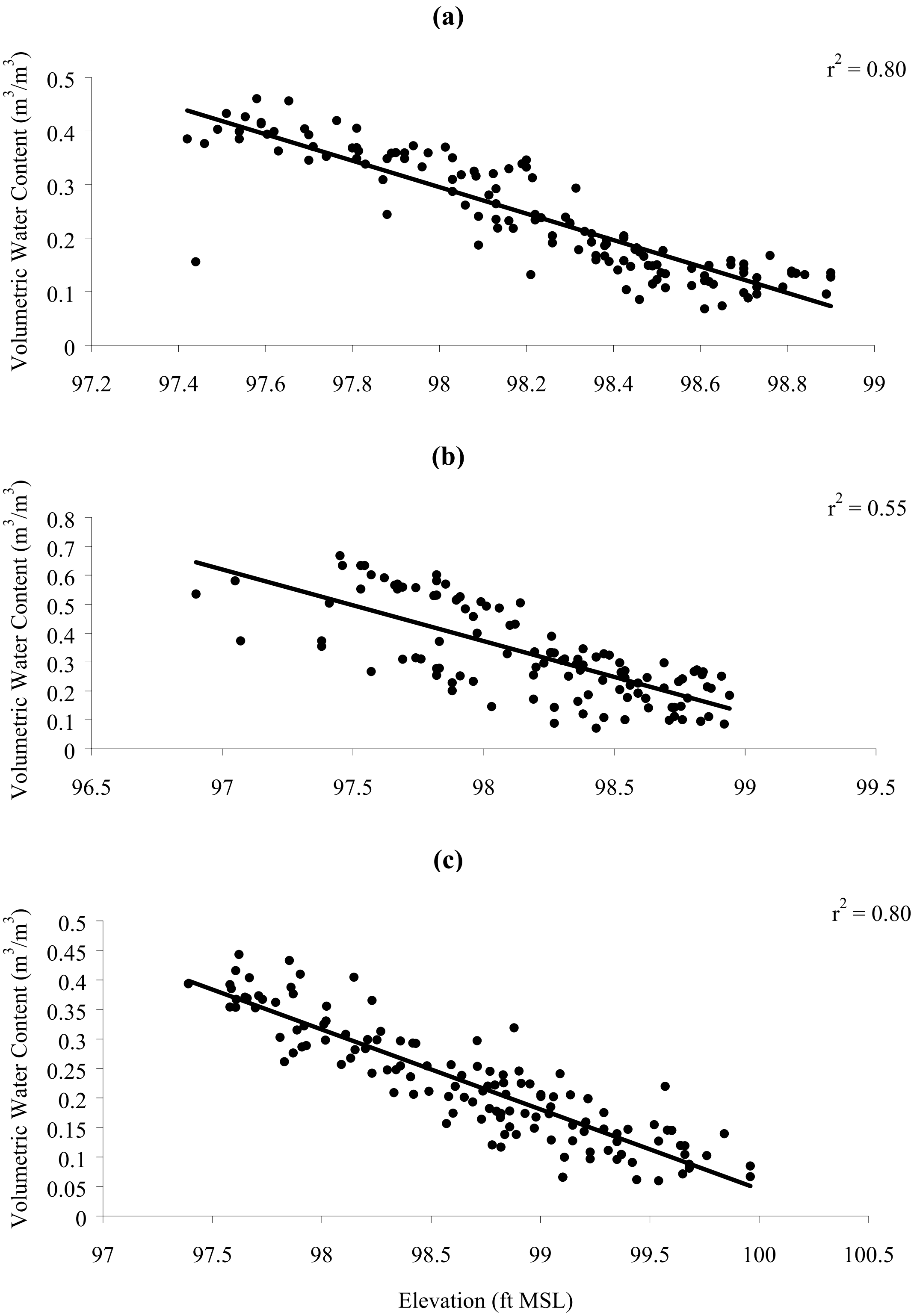
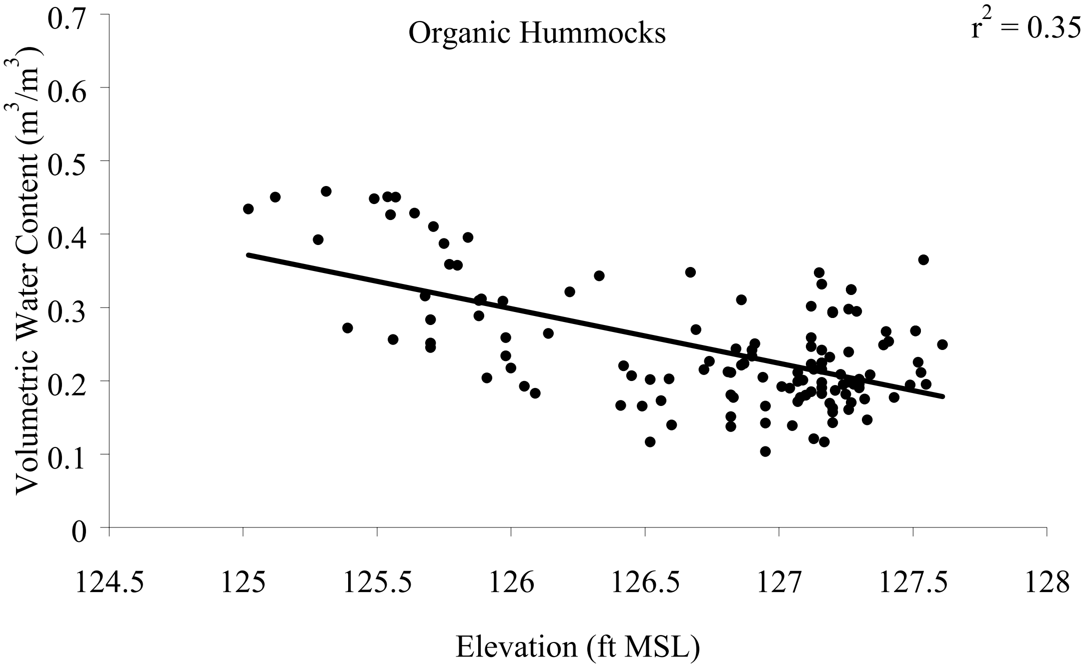


Figure 5.15. Volumetric Water Content Graphed Versus Elevation for Each Sampling Point During Summer 2000 in the Agrifos Wetland. Water Level Measured at 97.52 and 98.15 Ft. MSL.

(a)



(b)

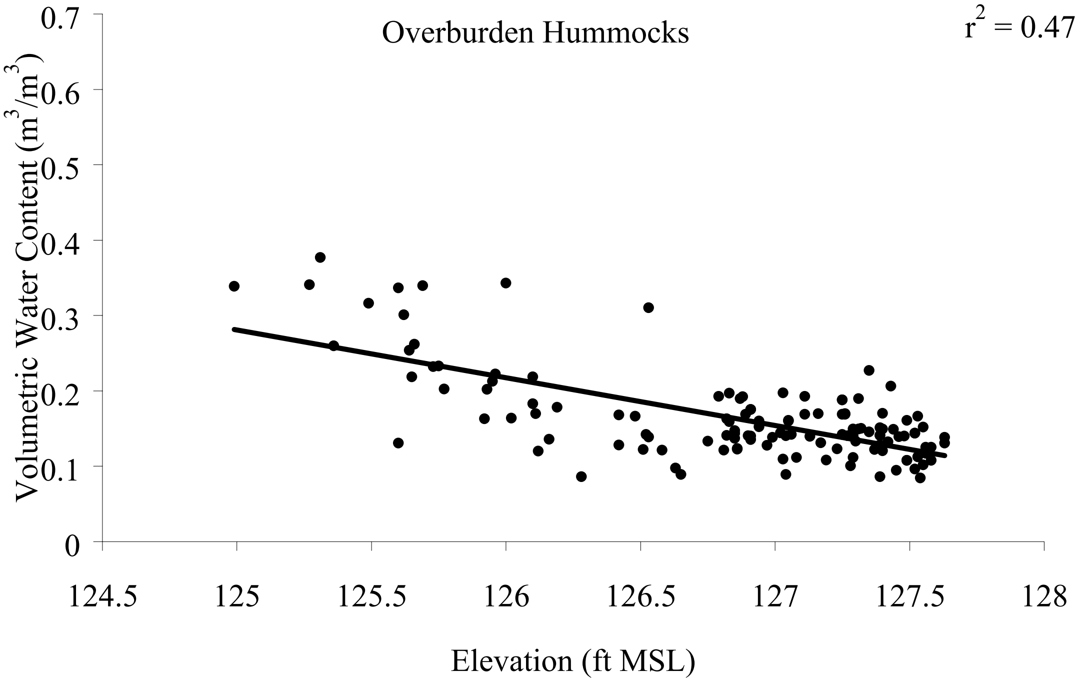


Figure 5.16. Volumetric Water Content Graphed Versus Elevation for Each Sampling Point on September 13, 1999, in the Cargill Wetland. Water Level Measured at 125.15 Ft. MSL.

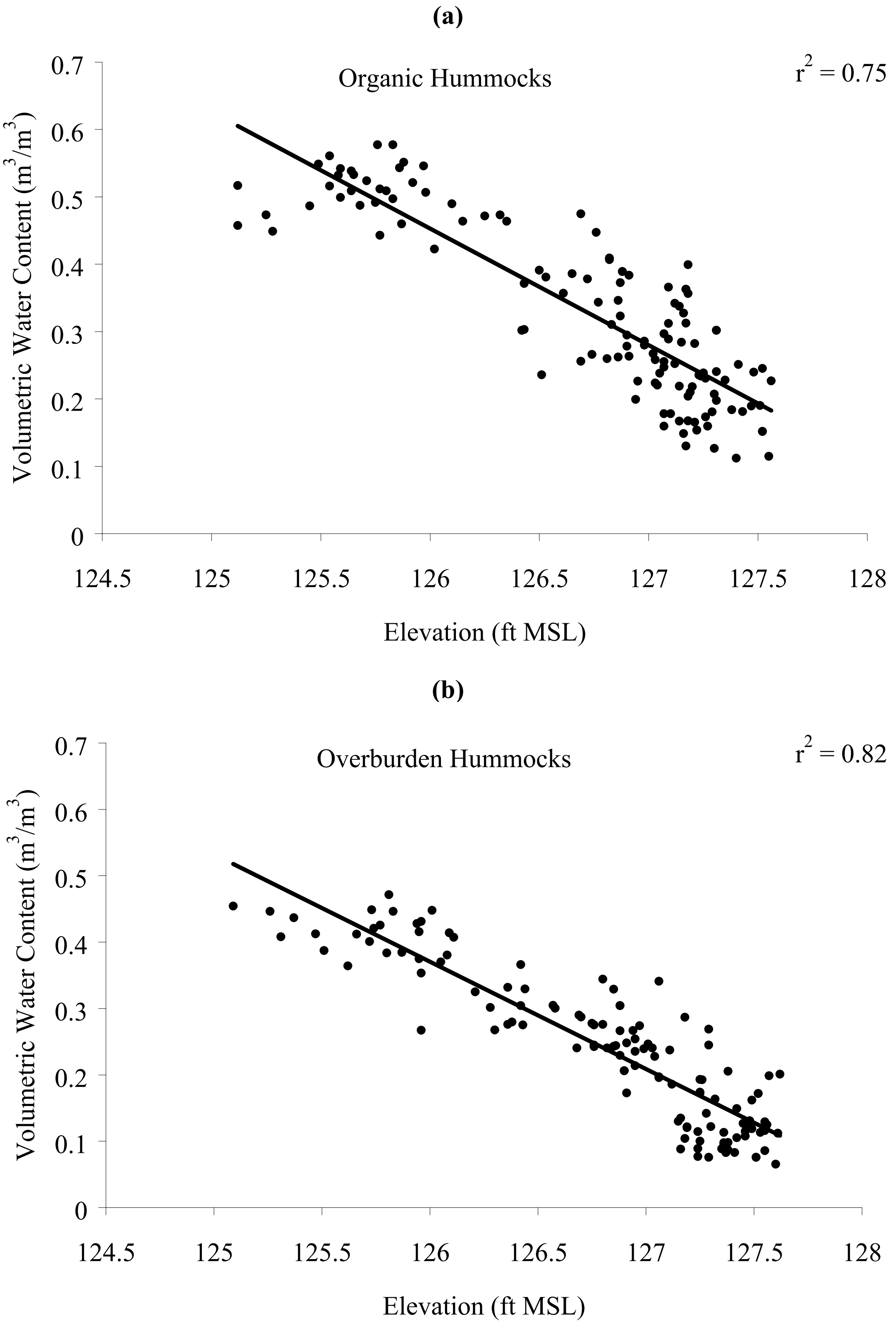


Figure 5.17. Volumetric Water Content Graphed Versus Elevation for Each Sampling Point on November 1, 1999, in the Cargill Wetland. Water Level Measured at 125.88 Ft. MSL.

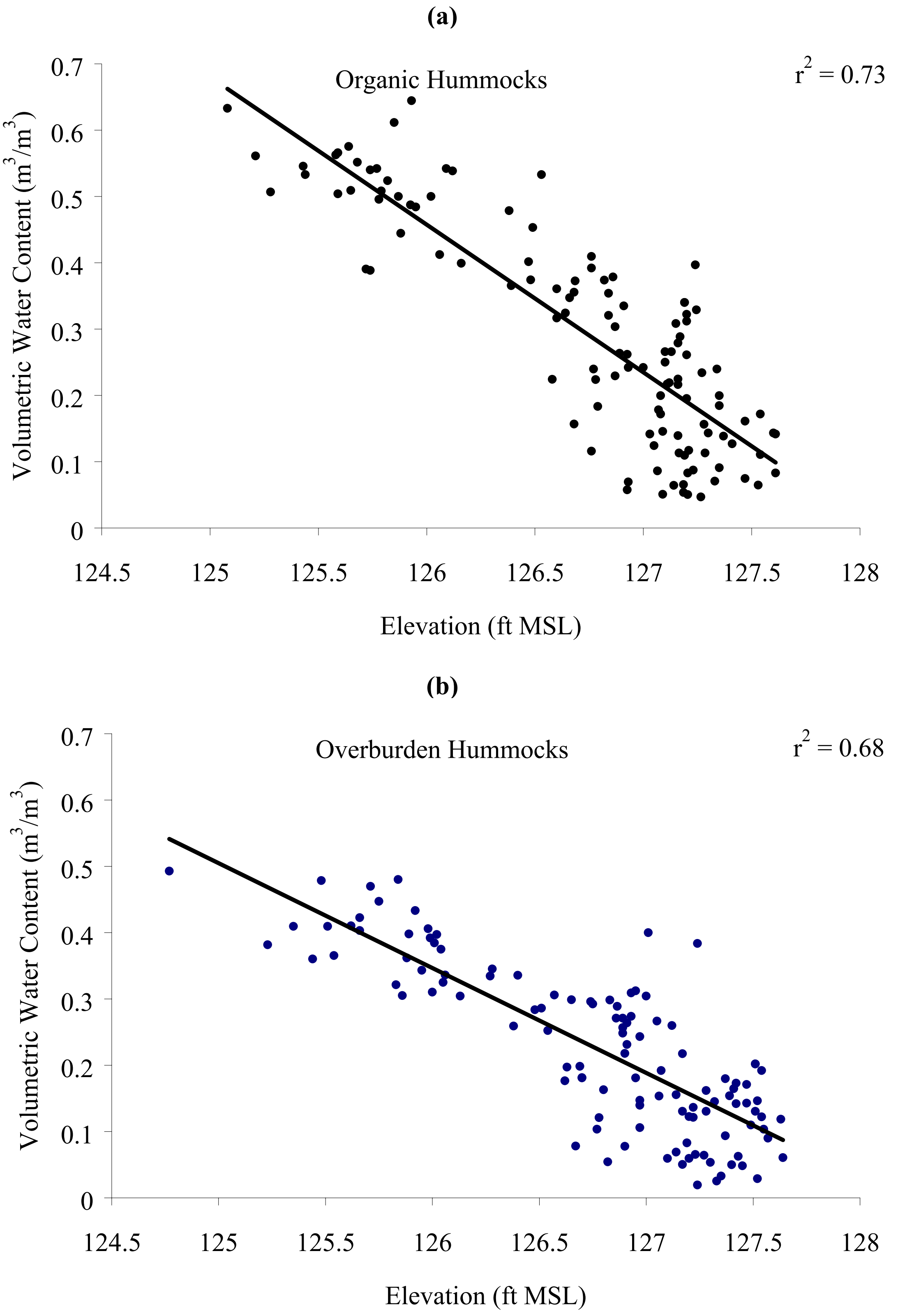


Figure 5.18. Volumetric Water Content Graphed Versus Elevation for Each Sampling Point on June 2000 in the Cargill Wetland. Water Level Measured at 125.62 Ft. MSL.

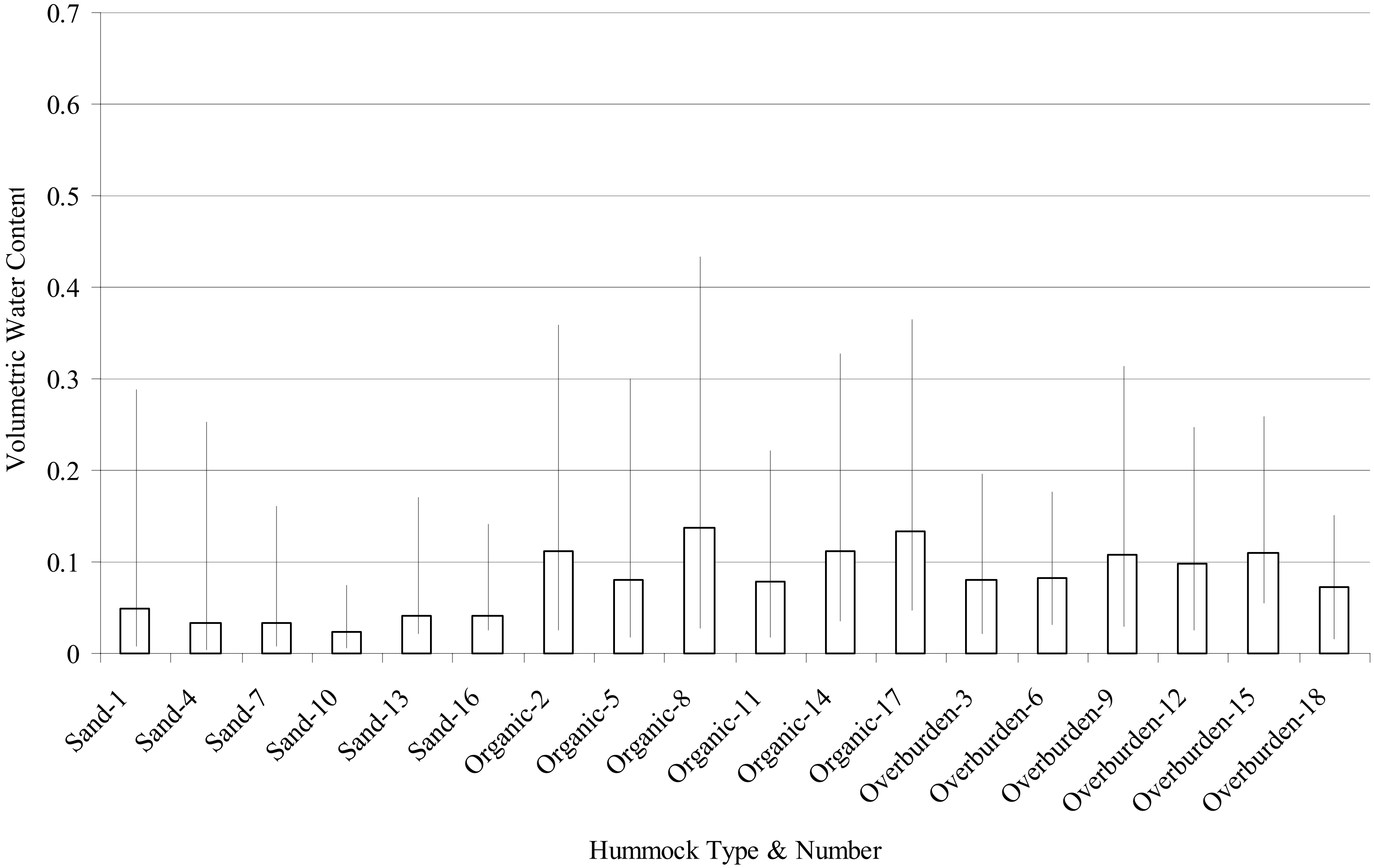


Figure 5.19. Values for Average Volumetric Water Content Plotted with Minimum and Maximum Values for Each Hummock in the Agrifos Wetland on April 23, 1999.

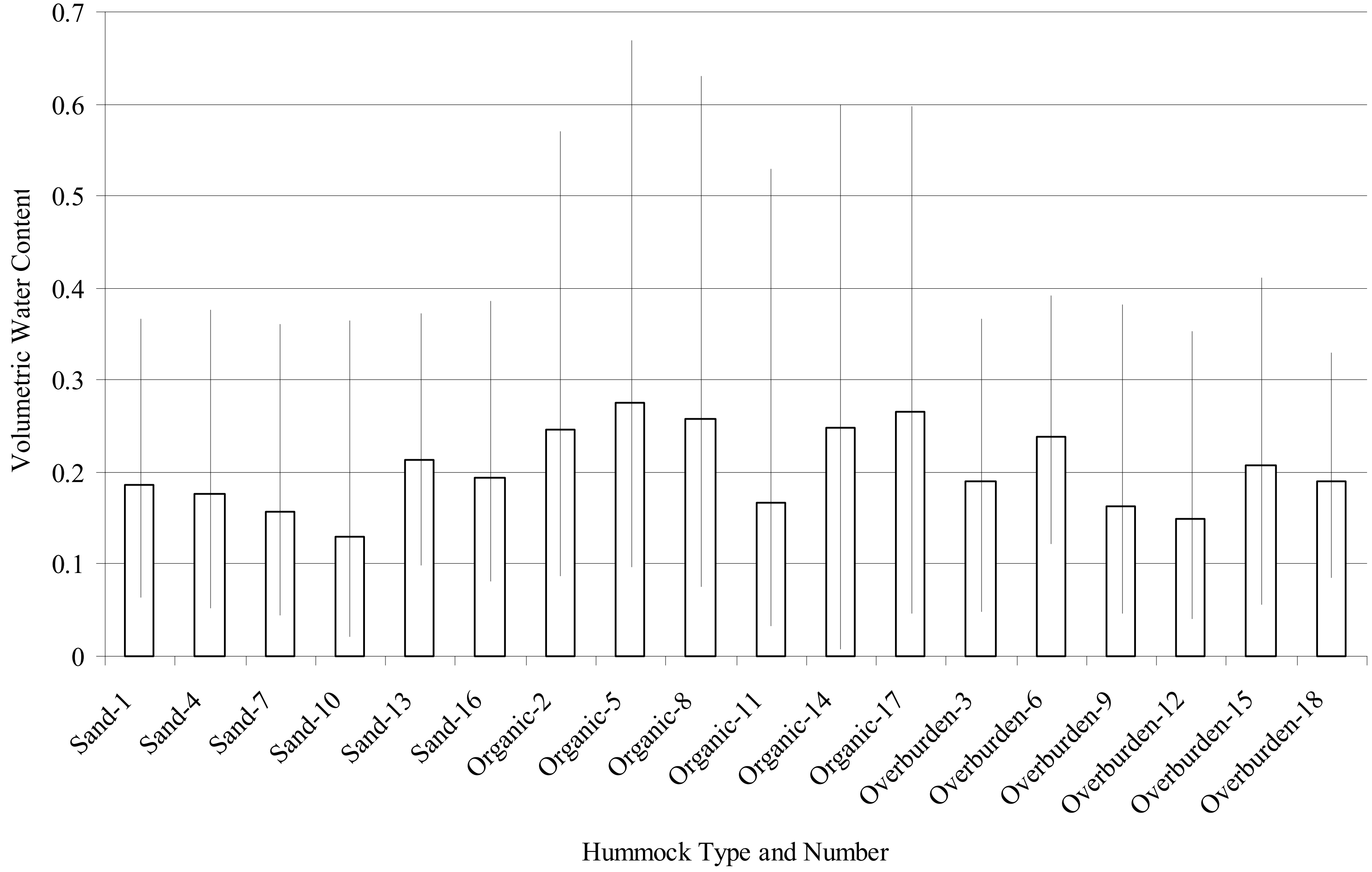


Figure 5.20. Values for Average Volumetric Water Content Plotted with Minimum and Maximum Values for Each Hummock in the Agrifos Wetland on May 19, 1999.

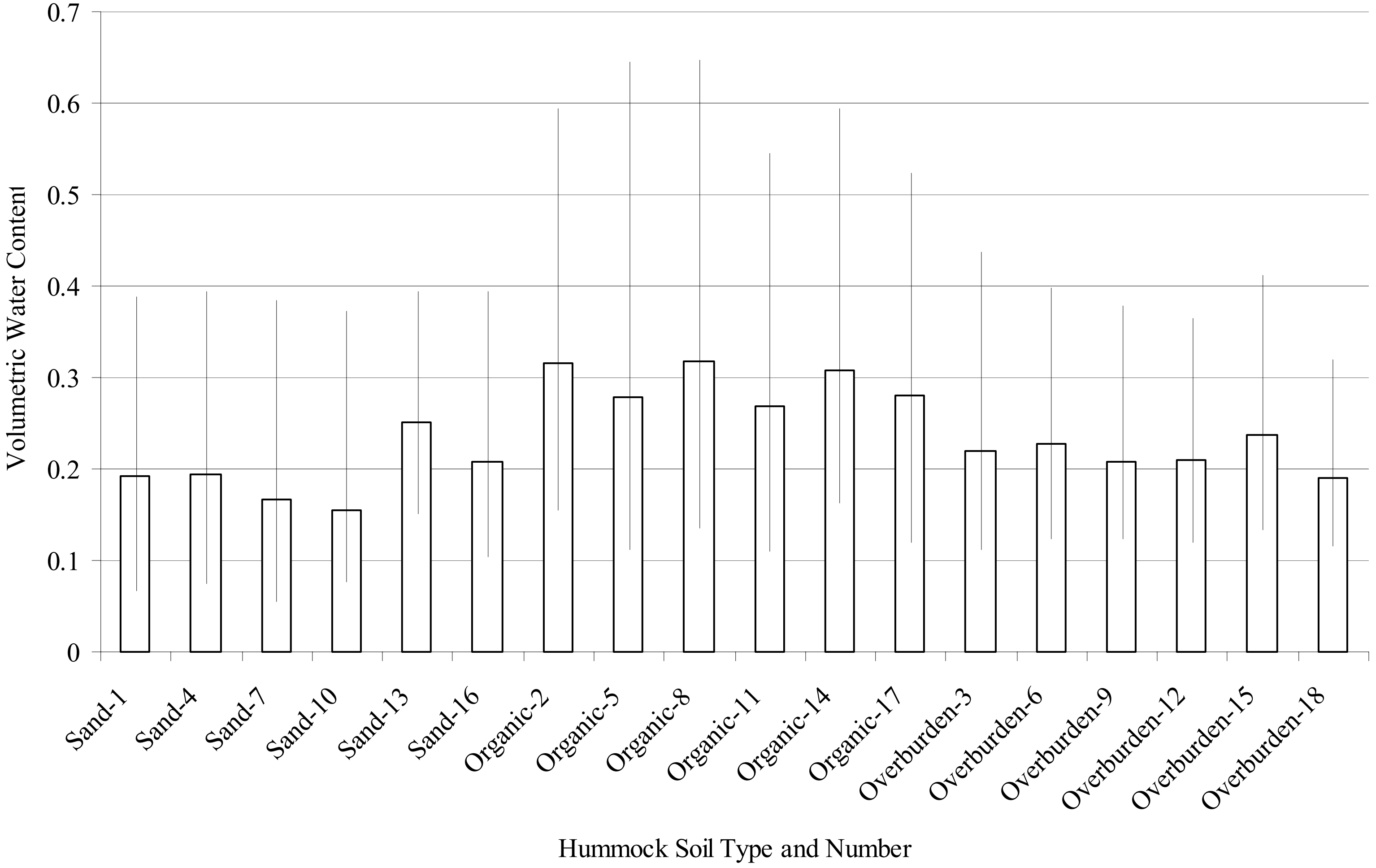


Figure 5.21. Values for Average Volumetric Water Content Plotted with Minimum and Maximum Values for Each Hummock in the Agrifos Wetland on August 5, 1999.

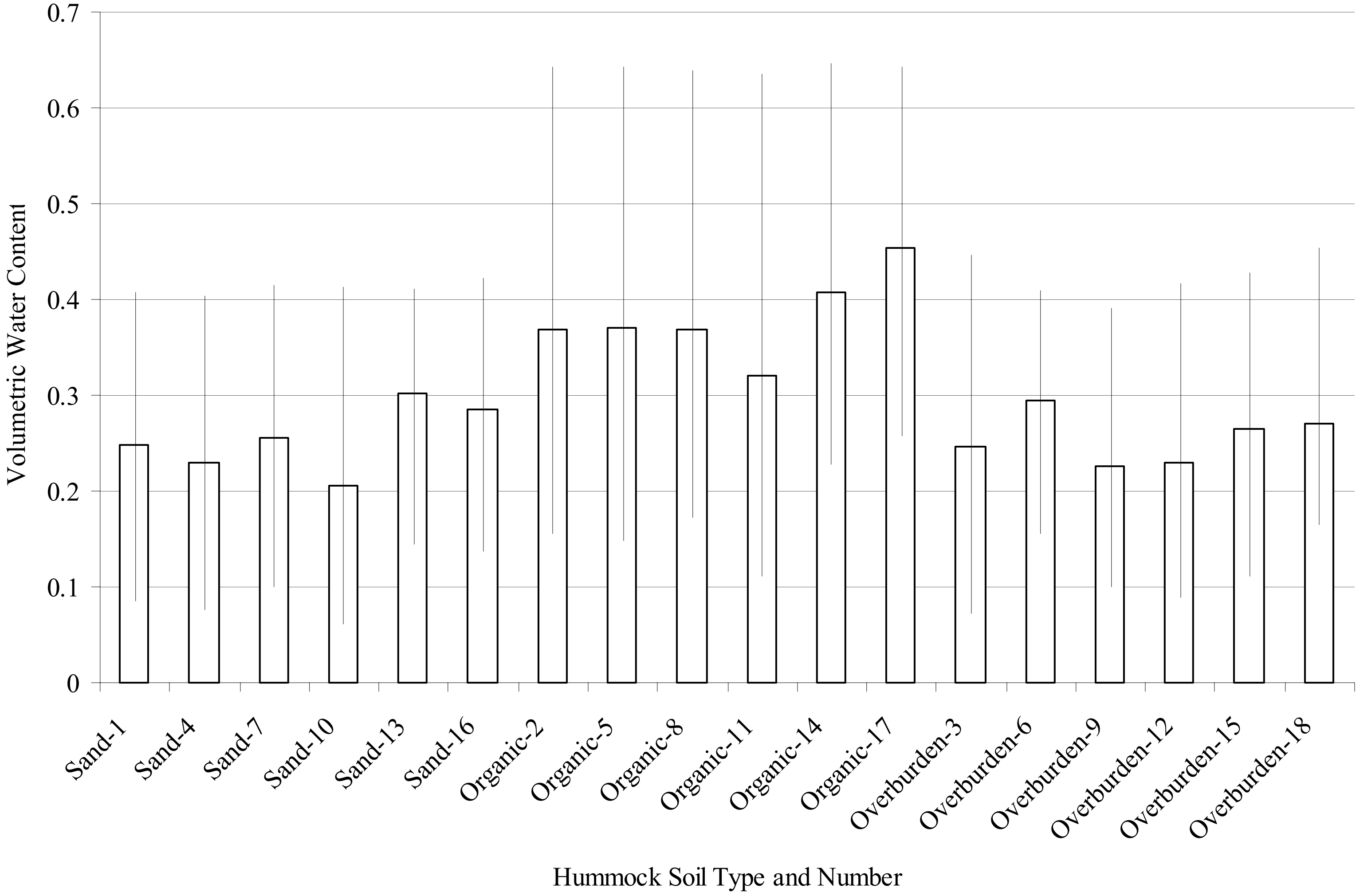


Figure 5.22. Values for Average Volumetric Water Content Plotted with Minimum and Maximum Values for Each Hummock in the Agrifos Wetland on October 13, 1999.

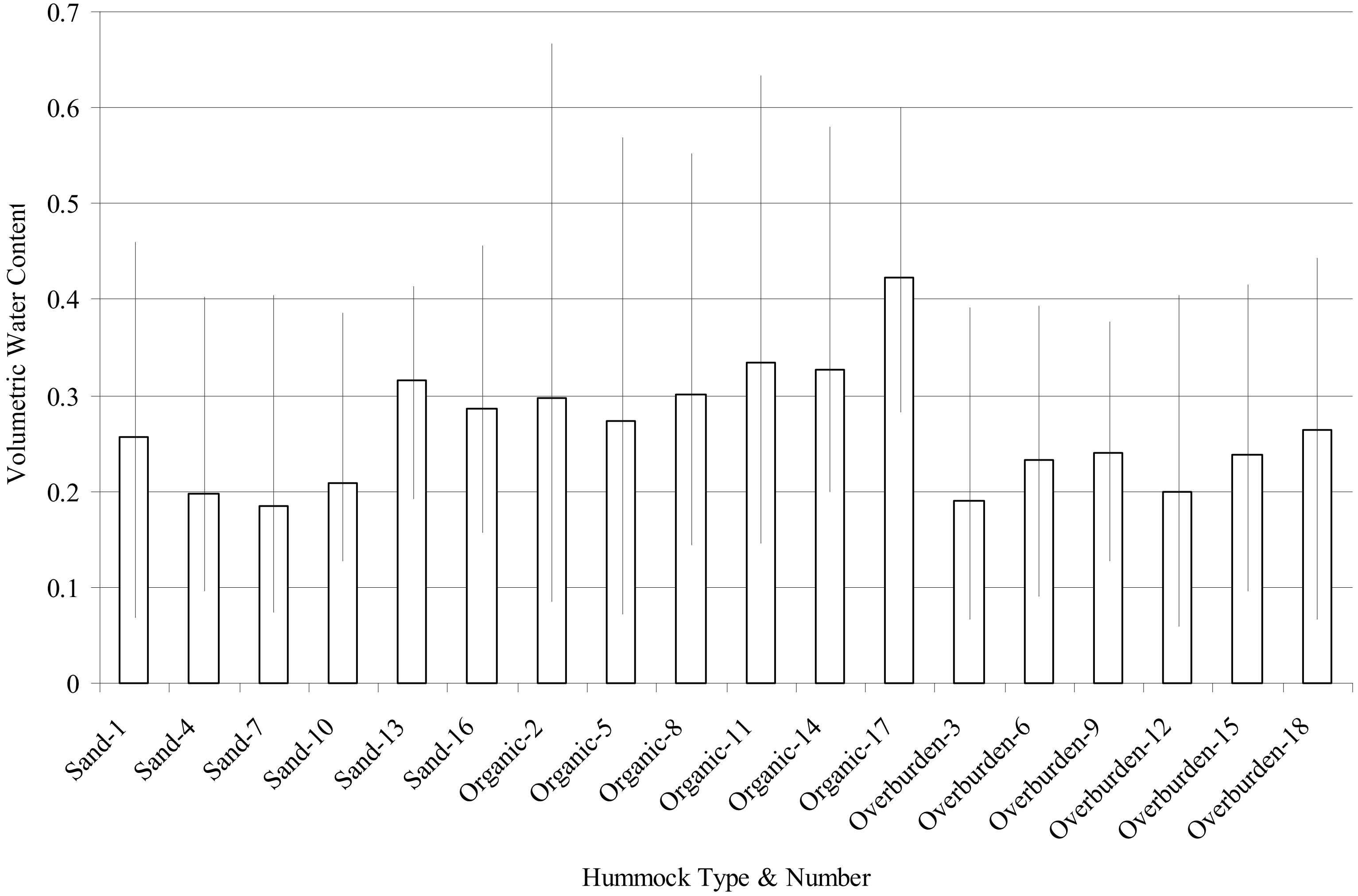


Figure 5.23. Values for Average Volumetric Water Content Plotted with Minimum and Maximum Values for Each Hummock in the Agrifos Wetland in Summer 2000.

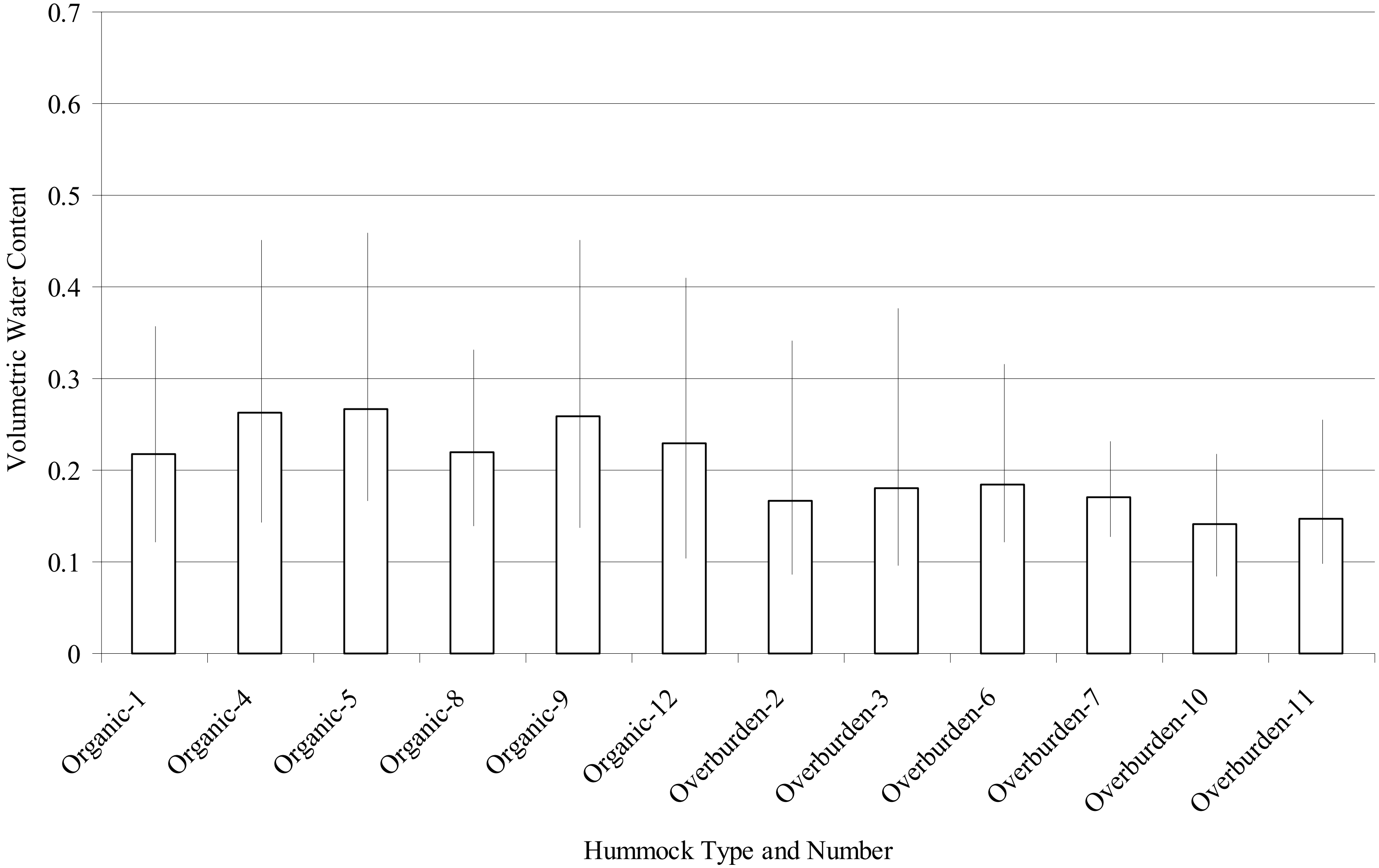


Figure 5.24. Values for Average Volumetric Water Content Plotted with Minimum and Maximum Values for Each Hummock in the Cargill Wetland on September 13, 1999.

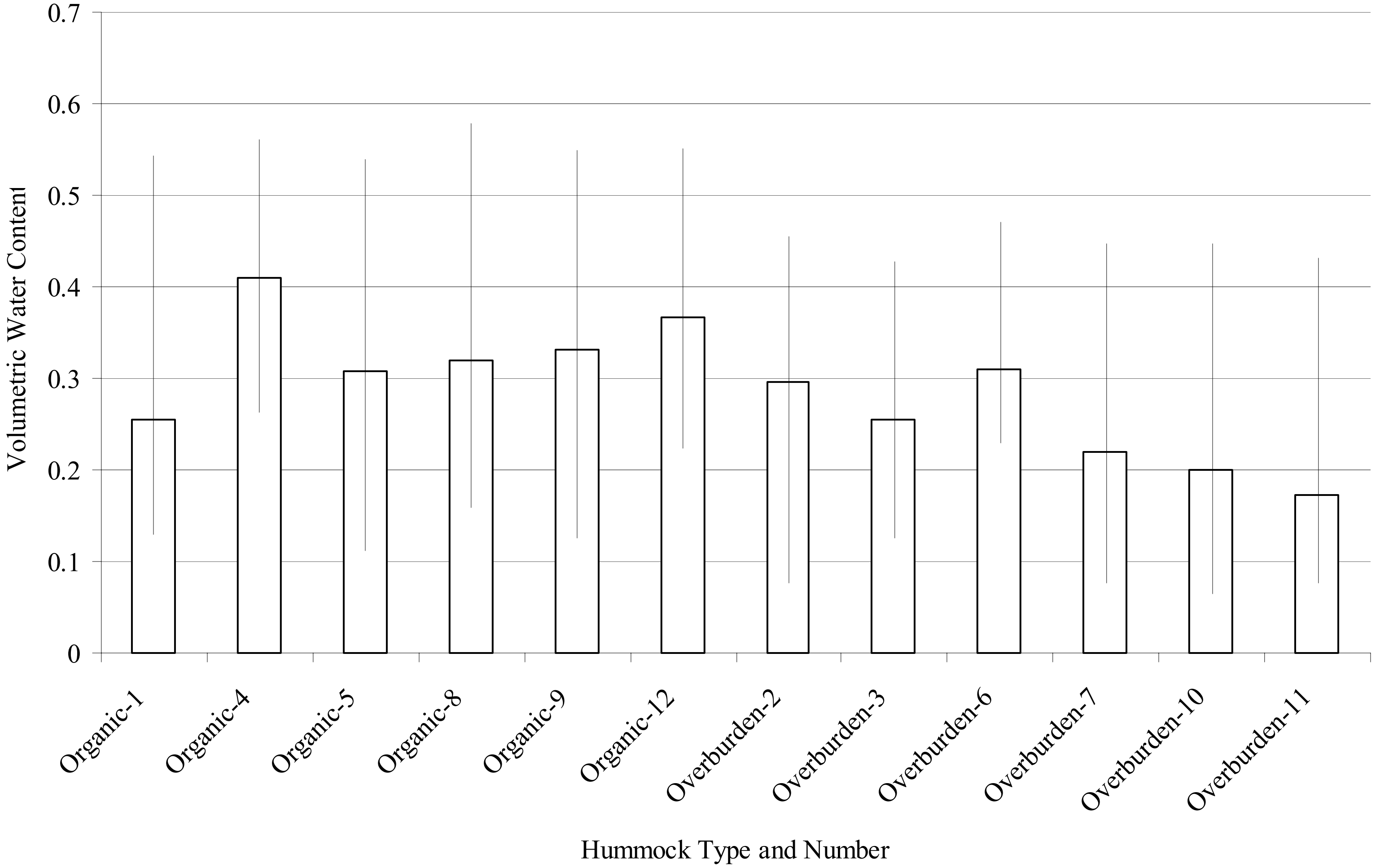


Figure 5.25. Values for Average Volumetric Water Content Plotted with Minimum and Maximum Values for Each Hummock in the Cargill Wetland on November 1, 1999.

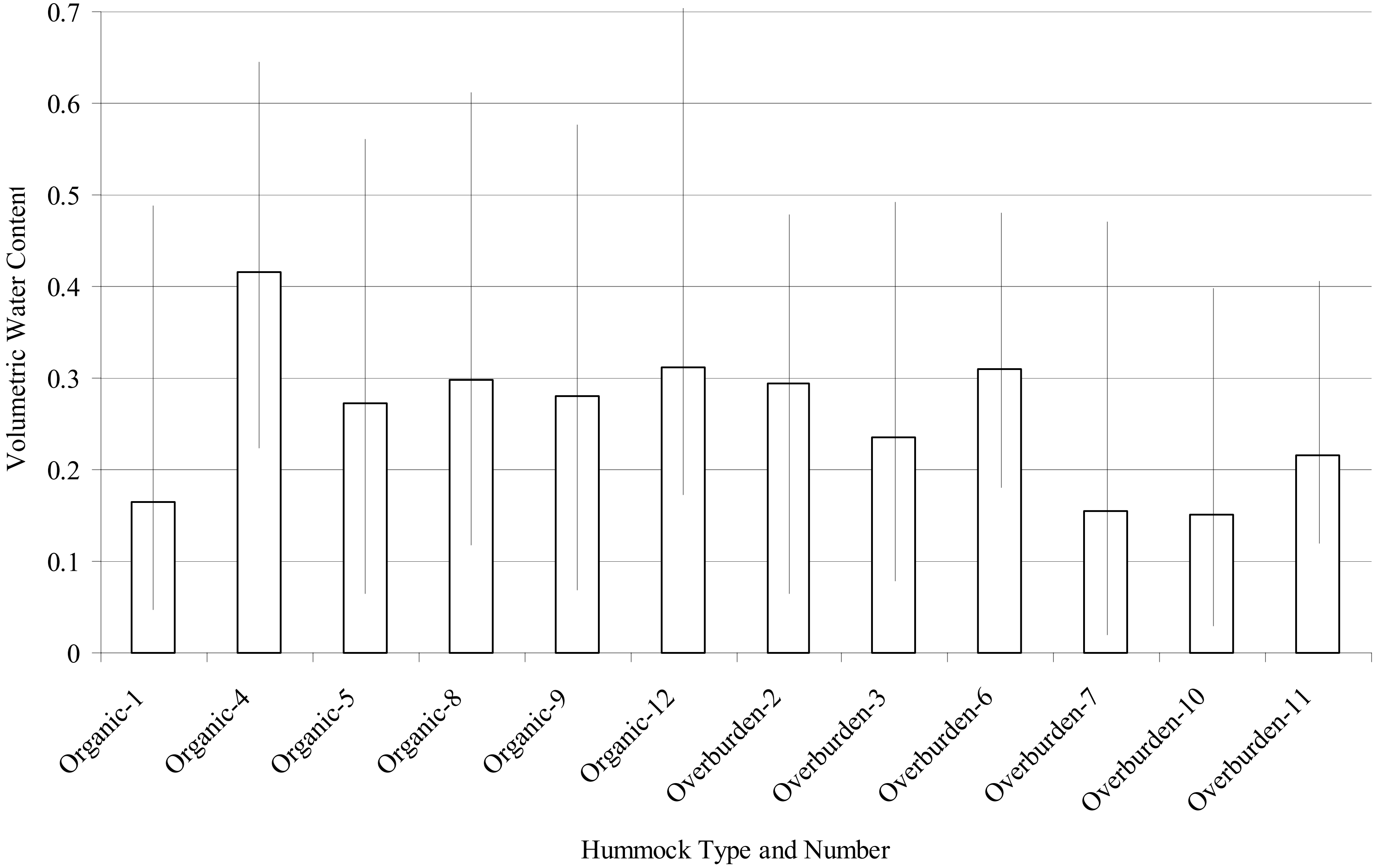


Figure 5.26. Values for Average Volumetric Water Content Plotted with Minimum and Maximum Values for Each Hummock in the Cargill Wetland on June 2, 2000.

constructed wetlands. Comparing species diversity on the hummocks to that found elsewhere in a wetland provides information on the ability of hummocks to increase vegetation diversity. Table 5.2 shows data for hummock and off-hummock species diversity indices for the Agrifos, Cargill and Iluka wetlands. In each sampling period, the number of species was greater on the hummocks than in the surrounding wetland areas. At least 8 more species were found on the hummocks during every sampling period except for the 9/13/99 sampling of the Cargill wetland where only 5 more species were found.

Shannon diversities were greater on the hummocks in all sampling periods. In every case except the first Cargill sampling, the Shannon diversity is considerably higher on than off the hummocks. Data for Shannon evenness show a different trend. The evenness is higher on the hummocks in the Agrifos wetland in each sampling period, but is lower on the hummocks in the other two wetlands indicating a dominance by a few species.

Percent cover was lower on the hummocks in the Agrifos wetland in each sampling period. The same trend was found in the Iluka wetland for the first two sampling periods. The third period percent cover on the hummocks was higher than off the hummocks. Percent cover in the Cargill wetland was higher on than off the hummocks in all sampling periods.

Community similarities between habitats on and off the hummocks are shown in Table 5.3. Values can range between 0 and 1.0, with a value of 1.0 meaning that all species are found in both communities. Values are shown for each hummock type versus the off hummock community as well as for the hummock community as a whole versus off hummock habitat. Values appear to get lower throughout the growing season possibly following increasing water level. None of the Sorensen coefficients show a high amount of similarity between the hummock and off hummock communities, as all values fall between 0.25 and 0.7. The ranges indicate some similarity in the communities. Some species are found both on and off the hummocks, but the majority are found in only one of the two community types. Low community similarities also can indicate a large difference in the species richness in the community types.

Tree Growth

The ability of hummocks two provide better growing conditions for tree saplings than found in other wetland locations provides another reason why hummocks may be valuable when incorporated into constructed wetlands. Table 5.4 contains data for trees planted on and off hummocks in the Agrifos and Iluka wetlands. *F. caroliniana* growing in the Agrifos wetland appear to be taller on the hummocks than off the hummocks in all cases except for the one tree growing in organic soil. The trees planted off the hummocks appear to be larger in basal diameter than those growing on the hummocks. Cypress trees planted in the Iluka wetland show a clear trend in growth. Those trees planted on the hummocks have a considerably larger DBH than the trees growing off the hummocks (3.36 to 1.78 cm).

Table 5.2 Hummock and Off-Hummock Species Diversity Comparison for Agrifos, Cargill, and Iluka Wetlands.

Wetland Location	Date Sampled	Location	Number of Species (s)	Shannon Diversity (H')	Shannon Evenness (J')	% Cover
Agrifos	5/19/99	on hummock	20	1.08	0.83	18
		off hummock	11	0.85	0.82	21
Agrifos	8/5/99	on hummock	29	1.32	0.91	49
		off hummock	18	1.09	0.87	53
Agrifos	10/13/99	on hummock	29	1.27	0.87	36
		off hummock	16	1.04	0.86	58
Agrifos	Sum2000	on hummock	41	1.38	0.86	51
		off hummock	28	1.34	0.92	60
Cargill	9/13/99	on hummock	15	0.94	0.80	36
		off hummock	10	0.92	0.92	18
Cargill	11/1/99	on hummock	20	0.98	0.75	51
		off hummock	7	0.73	0.86	17
Cargill	Sum2000	on hummock	52	1.53	0.89	86
		off hummock	12	0.96	0.89	57
Iluka	5/4/99	on hummock	16	1.08	0.89	38
		off hummock	8	0.87	0.97	52
Iluka	8/31/99	on hummock	21	1.19	0.90	45
		off hummock	8	0.88	0.97	60
Iluka	10/20/99	on hummock	21	1.19	0.90	36
		off hummock	11	0.98	0.94	28

Table 5.3. Community Similarity Between Hummock and Off-Hummock Species.

Wetland Location	Date Sampled	Community Type	Number of Species (s)	Species Similar to Off-Hummock	Sorensen Coefficient
Agrifos	5/19/99	sand	12	8	0.70
		organic	8	4	0.42
		overburden	17	5	0.36
		all hummocks	20	8	0.52
		off hummock	11	-	
Agrifos	8/5/99	sand	16	8	0.47
		organic	16	8	0.47
		overburden	19	8	0.43
		on hummock	29	12	0.51
		off hummock	18	-	
Agrifos	10/13/99	sand	19	10	0.57
		organic	18	7	0.41
		overburden	17	6	0.36
		on hummock	29	11	0.49
		off hummock	16	-	
Agrifos	Sum2000	sand	23	14	0.55
		organic	15	9	0.42
		overburden	30	14	0.48
		on hummock	41	17	0.49
		off hummock	28	-	
Cargill	9/13/99	organic	13	6	0.52
		overburden	10	7	0.70
		on hummock	15	8	0.64
		off hummock	10	-	
Cargill	11/1/99	organic	19	6	0.46
		overburden	13	6	0.60
		on hummock	20	7	0.52
		off hummock	7	-	
Cargill	Sum2000	organic	46	9	0.31
		overburden	43	7	0.25
		on hummock	52	9	0.28
		off hummock	12	-	
Iluka	5/4/99	on hummock	16	8	0.67
		off hummock	8	-	
Iluka	8/31/99	on hummock	21	5	0.34
		off hummock	8	-	
Iluka	10/20/99	on hummock	21	8	0.50
		off hummock	11	-	

Table 5.4. Average Values for Tree Parameters On and Off the Hummocks in the Agrifos and Iluka Wetlands.

Agrifos Wetland Averages

Location	Species	Height (cm)	Diam. (cm)
Sand	*Fraxinus caroliniana*	58.00	0.74
Organic	*Fraxinus caroliniana*	45.40	0.71
Overburden	*Fraxinus caroliniana*	51.28	0.65
Off-hummock	*Fraxinus caroliniana*	46.80	0.91

*data taken 10/13/99

Iluka Wetland Averages

Location	Species	Circum. (cm)	Diam. (cm)
On-hummock	*Taxodium distichum*	26.80	3.36
Off-hummock	*Taxodium distichum*	14.18	1.78

*data taken 5/19/99

DISCUSSION

GENERAL

Analysis of the results yields only partial answers to the questions of which soil type and hummock size are best and the value of hummocks in a wetland. The first thing one must realize is that this study was designed to provide an overall picture of the dynamics of hummocks, not provide specific information on why any one characteristic behaves in a certain way. Those are questions to be answered by continued study. The second thing one must realize when looking at these results is that they are for only one growing season (only two months in the Cargill case). A long-term study would be needed to get a clearer picture about what is really happening in the wetlands.

Conditions within a newly established ecosystem can vary greatly over a few years. Weather varies slightly from year to year, some years being drier than others. A dry year such as 1999 can have a dramatic effect on a wetland, especially a new wetland. The Agrifos wetland, which was not manually flooded, depended solely on rainfall for its water. Below average rainfall kept the wetland relatively dry. The dry conditions were not conducive to establishment of wetland plants in the infant wetland. The Cargill wetland did not experience the same dry conditions, as water was pumped into the wetland. In an older site like the Iluka Resources wetland, periods of drought might not have as big of an effect on the overall organization of the wetland. Ecosystems self-organize over time until they adjust to the conditions characteristic of the region (Odum and others 1997). The newly constructed wetlands are still beginning that process.

Though the wetlands are young and further study would be invaluable, that is not to say nothing can be learned from this study. On the contrary, there is much valuable information to be gleaned from the results of this study. Much can be said about both the colonization of hummocks by vegetation and the ability of different soils to hold their shape during early growth of the wetland. The ability of soils to hold moisture and provide habitat for a wide variety of plants can also be seen. Data on overall tree growth are limited because of the slow growth of trees, but survivorship during the early growth stage can be tracked.

AGRIFOS

Three types of soil were used to construct hummocks in the Agrifos wetland. As shown in Figure 5.6, the organic material used deteriorated the most during the first growing season. Hummocks constructed from sand tailings held their shape the best. This result is somewhat surprising due to the fact that sand tends to be more susceptible to erosion than the other two soils (Thomas and others 1985) and the fact that sand hummocks had the least percent cover of vegetation (Table 5.1). With little vegetation growing, there was no root structure to hold the soil together. The organic hummocks had a much higher percent cover of vegetation and thus likely much more root structure to bind soils. Overburden hummocks fell in the middle in terms of changes in cross-sectional area and percent cover.

There are several possible explanations for organic soils depleting more than the others did, the most likely being decomposition. The organic material was made from composted yard waste including grass and wood chips. Organic matter decomposes much more quickly in the presence of oxygen than in anaerobic conditions (Reddy and Patrick 1983). With little water in the wetland, oxygen was readily available to the exposed organic hummocks. The damp, warm, oxygen rich conditions allowed aerobic bacteria to break down the organic matter, decreasing the cross-sectional area. Erosion of all hummocks from climatic conditions such as wind and rain may have been limited because of the extremely dry conditions occurring during this growing season. Falling raindrops have enormous kinetic energy, which, when contacting soils, can cause movement of particles leading to erosion (Sharma and others 1993). Without much rainfall, there was little potential for weathering from precipitation. Wind erosion may also have been limited due to lower than normal wind speeds, the relative close proximity of the hummocks to the surface of the ground, and the growth of wind breaking vegetation like *Typha spp.* and *Sesbania spp*. Particle size of the soils may have been too large for movement by low speed wind. The possibility exists that the erosion seen in the Agrifos wetland is typical for the soil types chosen for the hummocks. Continued study would show how these soils react during the development of the wetland.

Based only on change in cross-sectional area, sand tailings hummocks appear to be a good choice. However, having a pile of sand with nothing growing on it is not the point of a hummock. Hummocks are supposed to provide conditions for vegetation growth not found in other parts of a wetland. Availability of nutrients and soil moisture contributes to determining vegetation growth.

Sand and overburden are both highly mineral soils. Mineral soils generally have high nutrient availability, meaning plants can easily utilize any nutrients present in the soil (Mitsch and Gosselink 1993). Sand tailings are likely to be very low in nutrients due to their structure consisting almost entirely of sand grains. Overburden likely contains some phosphorus as its structure includes clays, sands, and organic matter. The available nutrients lead to higher vegetation growth on the overburden hummocks than on the sand hummocks even with the lack of water. Ground water and surface water contributing to the wetland would contain some level of phosphate due to the abundance of phosphate in central Florida. The water level in the wetland was very low however, and likely provided little nutrient to the hummocks. Organic soils can have low nutrient availability because many nutrients are tied up in organic form. Plants require inorganic forms for uptake and use in photosynthesis. Availability depends on the degree of decomposition in the organic soil. More decomposition means more available nutrients. The rapid decomposition of organic hummocks makes more nutrients available to plants, seen as the high percent cover in Table 5.1.

Plants must also have available soil water for nutrient uptake and biological processes. Organic soils have greater porosity and thus greater ability to hold water than do mineral soils (Mitsch and Gosselink 1993). The results discussed from Figures 5.19-5.22 clearly show that the organic hummocks have much higher average volumetric water content meaning more available pore water. Sand has fewer pore spaces than organic and overburden soils and contains the least amount of soil water. Overburden, with its composition of sand, clay, and organic material, holds water better than sand, making more available for plant uptake.

Organic hummocks show greater available pore water and in this case likely have greater nutrient availability of nutrient (indicated by higher percent cover). Figures 5.11-5.14 show that organic soils also have a wider range of micro-sites for plant growth. The organic hummocks show lower species diversity and evenness. A few fast growing species colonizing these hummocks likely are better able to uptake nutrients and out compete other slower growing species. Overburden hummocks show greater ability to hold soil water at higher elevation than do sand hummocks creating more available micro-sites for plant growth. Overburden and sand hummocks show higher diversity than organic hummocks. The same fast growing plants that can uptake readily available nutrients are likely out competed in the lower nutrient situation by plants better able to access nutrients.

Tree growth and survivorship is also related to soil moisture and nutrient availability. The results of the tree study show that the growth of understory vegetation may also have a large impact. Figure 5.9 shows that trees growing on organic hummocks do not survive nearly as well as those on the sand and overburden hummocks. The growth of understory vegetation on organic hummocks may have choked the trees by using all available nutrient, water, and blocked most of the sunlight from the small tree seedlings. The trees growing on the other hummocks showed an increase in basal diameter and small increases in height. With lower nutrients and pore water, the likely difference in survivorship and growth can be linked to the lack of competing understory vegetation.

CARGILL

Overburden and muck were used to construct the hummocks in the Cargill wetland. Figure 5.7 shows the muck hummocks fared slightly better than the overburden hummocks in terms of soil erosion. The change was only seen between two sampling periods, thus it is hard to see any trends developing. Both hummock types had relatively high percent covers of vegetation (Table 5.1) whose root structure helps hold soil in place. In contrast to the Agrifos wetland, the Cargill wetland was flooded by water from other mining sites. Flooding the wetland had the added effect of surface water erosion on the hummocks. Surface water movement caused by wind has the potential to carry away soil particles causing undercutting along the sides of the hummocks. The wetland was not flooded immediately, but gradually. Thus, the effect of surface water erosion was not seen over the entire sampling period.

Flooding the wetland had the added effect of increasing the soil pore water in the hummocks. Figures 5.24 and 5.25 show that the organic hummocks have higher volumetric water content than the overburden hummocks as expected based on the properties of organic and mineral soils. An increase in number of species, Shannon diversity, and percent cover accompanied the increase in soil pore water. The water pumped into the wetland likely had background levels of phosphorus, which were utilized by the growing vegetation. The muck hummocks, which were exposed to oxygen, would have added nutrients to the soil upon decomposition. The overburden soils, because of their origin, also contain background amounts of phosphorous, which plants could uptake as pore water increased. The muck hummocks likely had greater diversity and percent cover due to more available nutrients and higher soil moisture. Figures 5.16 and 5.17 show the two hummock types to have similar ranges of soil moisture providing a similar distribution of micro-sites for vegetation growth. Organic hummocks have higher values of soil moisture at similar elevations than do overburden hummocks. This would be expected based on the characteristics of organic and mineral soils.

Based on initial data, these two hummock soil types provide similar benefits in terms of stability and colonizing vegetation. Tree data may provide the defining characteristic when chosen between the two soil types. Due to the late construction of the site during this study, only initial tree data were available and no comparison can be made.

WETLAND COMPARISON

Comparing the hummocks in the Agrifos and Cargill wetlands becomes difficult due to the difference in time of construction and the conditions found in each wetland. Because the Cargill wetland was not completed until late in the growing season, only two sampling periods of data were taken. These can be compared to the first two sampling periods in the Agrifos wetland, but they occurred at opposite ends of the growing season. The samplings taken at the end of the growing season can be compared, but the wetlands are slightly different ages. In the early growth of the wetlands, the small age difference could influence data. The difference in flood stage of the wetlands also makes comparison difficult. Water level greatly influences soil moisture and nutrient availability, which in turn affects the vegetation growing on the hummocks. None-the-less, the comparison will be made between the two new wetland hummocks and the third elder Iluka wetland hummocks.

The stability of the hummocks in the three wetlands begs the first comparison. The hummocks in the Iluka wetland show a slight growth as opposed to the decay seen in the infant hummocks in the other two wetlands. The soils in the older hummocks have already undergone the period of settling and compaction, which takes place in newly disturbed soils. The newly constructed hummocks in the Cargill and Agrifos wetlands are still experiencing the settling, which accounts for some decay. The mature hummocks in the Iluka wetland also have more vegetative root structure to provide soil stability than do newly colonized infant hummocks. The data suggest that sometime between the construction of wetland hummocks and seven years of age hummocks reach structural equilibrium. Structural equilibrium refers to both soils having finished settling and erosion and deposition being relatively equal. Buildup of organic matter may occur causing the apparent growth in the Iluka hummocks. It should be noted that completely accurate height measurement was made difficult by low lying tree limbs interfering with laser level rod positioning. Drastic changes in the results due to the error are unlikely, as extra time was taken to position the rod carefully for measurement. Comparing the hummocks in the other two wetlands over the first two sampling periods shows that the organic hummocks in the Agrifos wetland have more decay than the organic hummocks in the Cargill wetland. Both have high percent cover of vegetation to bind soils. The big difference is the composition of the soils. The Agrifos soils, being completely organic in nature, likely decomposed faster than the sandy muck used in the Cargill wetland. The overburden hummocks showed similar erosion, although differences were seen between major and minor transects. Weathering patterns along the transects show differences due to the direction of the prevailing wind and the direction of rainfall hitting the hummocks. No comparison with the sand hummocks in the Agrifos wetland can be made as none were constructed in the other wetlands.

Soil moisture values reflect not only the soil type, but also the level of surface water in the wetland. Values for the hummocks in the Agrifos wetland increase as surface water increases as do those in the other two wetlands. Comparing the soil pore water for the different hummock types becomes tricky because the surface water level is different in each wetland. The only accurate way to determine each soil's ability to hold water would be by taking soil cores and running tests in laboratory conditions. The data available from this study suggest that in flooded conditions (Figure 5.22, Figure 5.25, and Figure A38), values are similar for the overburden hummocks in all three wetlands. The values suggest that the composition of the overburden soils give them similar properties. The organic hummocks in the Agrifos and Cargill wetlands show slightly different averages with the Agrifos hummocks made of yard compost being higher. Based on the origin of each soil type, this variation would be expected. Again, no comparison can be made with sand tailings as only the Agrifos wetland had sand hummocks. It is interesting to note the increase in r^2 values for graphs of volumetric water content versus elevation in each wetland. The trend suggests that, as hummocks age and equilibrium is reached, the soil becomes uniform in its ability to hold pore water.

Vegetation growth on the hummocks shows that the mature Iluka wetland's overburden hummocks have the highest diversity (s) and highest Shannon diversity (Table 5.1). The evenness (J') is among the highest as well indicating even distribution among species. The age of the hummocks may be the reason more species and higher diversity were recorded. More stable conditions reached during equilibrium may promote the growth of more species. Climatic conditions, soil composition, nutrient availability may all influence the diversity as well. While the Agrifos overburden hummocks have similar high values for diversity, the Cargill overburden hummocks show much lower diversities. This may be attributed to the late construction of the Cargill site. Different species colonizing the hummocks during the latter part of the growing season may be the cause of the discrepancy.

Another possible reason for the difference comes to light when looking at the percent cover. The overburden hummocks in the Cargill wetland have much higher percent cover than do the Agrifos overburden hummocks. Combining the fact that vegetation is abundant with the low diversities shows that a few select species are dominating. This fact may also be attributed to the late construction of the hummocks. The organic hummocks in both the Agrifos and Cargill wetlands show higher percent cover when compared to the overburden hummocks. As stated previously, they may have higher nutrient availability and have higher soil moisture than the overburden hummocks, which is the likely cause of more vegetation cover. The values for diversity are similar for the organic hummocks in both wetlands. Similar soil conditions and nutrient availability likely exist for hummocks in both wetlands.

Tree survivorship and growth from the wetlands can not be compared because of the lack of early stage data. Only initial data were available from the Cargill site, and no early numbers were available from Iluka site.

VALUE OF HUMMOCKS IN WETLANDS

The advantage of hummocks can be seen from the data shown in Table 5.2. Diversity indices are higher on the hummocks than off in all cases. The variation in micro-site hydrology found on the hummocks permits a wide variety of plants with different ranges of moisture requirements to establish themselves. The relatively uniform moisture found in the flat areas off the hummocks only allows growth of plants tolerant to high soil moisture and/or flooded conditions. These results substantiate those found by Sloan (1998) and Bukata (1999) in previous microtopography studies. Sloan found that species diversity increased with increased hummock frequency (rugosity) and expanded elevation ranges in lake and stream systems. Bukata found that constructed hummocks significantly contribute to the overall species richness and diversity of a constructed wetland. Species richness and diversity was higher on hummocks than areas between hummocks.

Evenness numbers are higher off the hummocks in situations where there is a low number of species. The Agrifos wetland has a high number of species living off the hummocks and lower evenness than on the hummocks. The other two wetlands have higher evenness off the hummocks and have fewer species growing off the hummocks. The numbers are not dramatically different and might not indicate anything significant. The soil moisture off the hummocks in the Iluka wetland and the water level in the Cargill wetland were higher in relation to the hummocks than in the Agrifos. That fact might explain why fewer species were growing off the hummocks and why they are slightly more evenly distributed. Fewer plants were tolerant of the higher moisture conditions in the Iluka and Cargill wetlands. Those that were tolerant had an even distribution. In the Agrifos wetland, conditions were tolerated by more species, but some species flourished where others did not.

The flooded conditions also likely explain the lower percent cover found off the hummocks in the Cargill wetland than in the other two wetlands. The trend can be seen in the Iluka wetland as well. Later in the growing season, when standing water began to accumulate, the percent cover off the hummocks in the Iluka wetland began to decrease. High soil moisture conditions similar to those found early in the growing season in the Iluka wetland are conducive to a high volume of vegetation growth. The trend can be seen in the Agrifos wetland. Early in the growing season, when the wetland was dry, there is little vegetation cover. As the wetland began to fill with water and the soil became moister, the percent cover went up. The Agrifos wetland never experienced flooded conditions as seen in the Cargill and Iluka wetlands, so the downward trend was never seen. The moist conditions allow rapid uptake of nutrients for those plants tolerant of the high moisture conditions, which leads to higher growth. Lower percent cover was seen on the hummocks than off the hummocks in all situations when flooded conditions did not exist. This lends further credence to the idea that the high moisture conditions lead to more plant growth. The lower moisture conditions found at the top of the hummocks during non-flood stage do allow growth different species than in the high moisture conditions, but do not allow as much growth due to lower nutrient uptake.

The community similarity (Table 5.3) shows that the plants growing on the hummocks are different than those growing off the hummocks. The difference in water regime between the two communities confines most plants to one of the two community types. Some plants tolerant of a wide range of moisture conditions are found on the hummocks and off the hummocks as indicated by the Sorensen coefficient.

Increased tree growth is the other supposed advantage of hummocks. Bukata (1999) noted that hummocks appear to provide sites, which allow for increased survivorship and growth of wetland tree stock. Table 5.4 shows that cypress trees planted on the hummocks in the Iluka wetland have grown more than those planted off the hummocks. This is likely because when a tree is stressed, as it would be in flooded conditions, more energy goes to overcoming the stressed condition than goes to growth. On the hummock, where soil conditions are drier, the tree can put more energy towards growth than maintenance. Unfortunately, little can be said about the trees in the Agrifos wetland. Initial data on the numbers and sizes of trees planted off the hummocks were unattainable because of the planting conditions. Data for survivorship, as seen for on hummock conditions, can not be calculated. Little can be said about growth at this time either. The relatively slow growth of trees makes one growing season of data hard to decipher. The trees on the hummocks look like they grew taller than the trees off the hummocks, and those off the hummocks look to be shorter with wider trunks. Water regime might account for the difference, but without initial planting data, that can not be stated as fact.

CONCLUSIONS

While no definitive conclusions about either the value of hummocks or the best material from which to construct them can be drawn from this project, a few recommendations can be made based on the features the hummocks are lacking. The composted organic material used in the Agrifos wetland showed 2% more change in cross sectional area than the overburden hummocks and 4% more than the sand hummocks. The composted organic material did not provide for tree survivorship as only 17% of the pop ash and 33% of the sweet bay survived the first growing season. Sand tailings appear to be a reasonable choice because it has high diversity, 100% ash and 83% bay tree survivorship, and only 2% change in cross sectional area. Two functional flaws exist with sand tailings: it holds little pore water and has only 23% understory cover. Overburden had no fatal flaws and performed well in both the Cargill and Agrifos wetlands. The overburden hummocks had 100% tree survivorship in the Agrifos wetland, over 30% understory vegetation cover, high species diversity, and only 2% (Cargill) and 4% (Agrifos) change in cross sectional area during the first growing season. The organic hummocks in the Cargill wetland also performed to a high standard and may prove to be the most desirable by long term study. Muck does have one drawback when compared to overburden in that it must be hauled into the site for construction. Overburden is already on site and thus costs less than muck. Those cost differences must be weighed against the performance of the hummock types. Continued data collection over multiple growing seasons would provide more definite information on the performance of these materials, especially tree survivorship and growth and long term stability of the hummocks. The data collected during this study show a definite advantage in using hummocks in order to increase species diversity, especially in situations where the wetlands will be flooded for the majority of the growing season. Further study will show if the superior tree growth seen in the Iluka wetland applies to more than cypress trees. Survivorship will also be better understood after the trees in the Cargill and Agrifos wetlands are monitored over multiple growing seasons. Based on this study and those of Sloan (1998) and Bukata (1999), hummocks do appear to be beneficial to the overall structure and health of a wetland and should be included in new construction.

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APPENDIX 5-A

ELEVATION ALONG MAJOR AND MINOR TRANSECTS

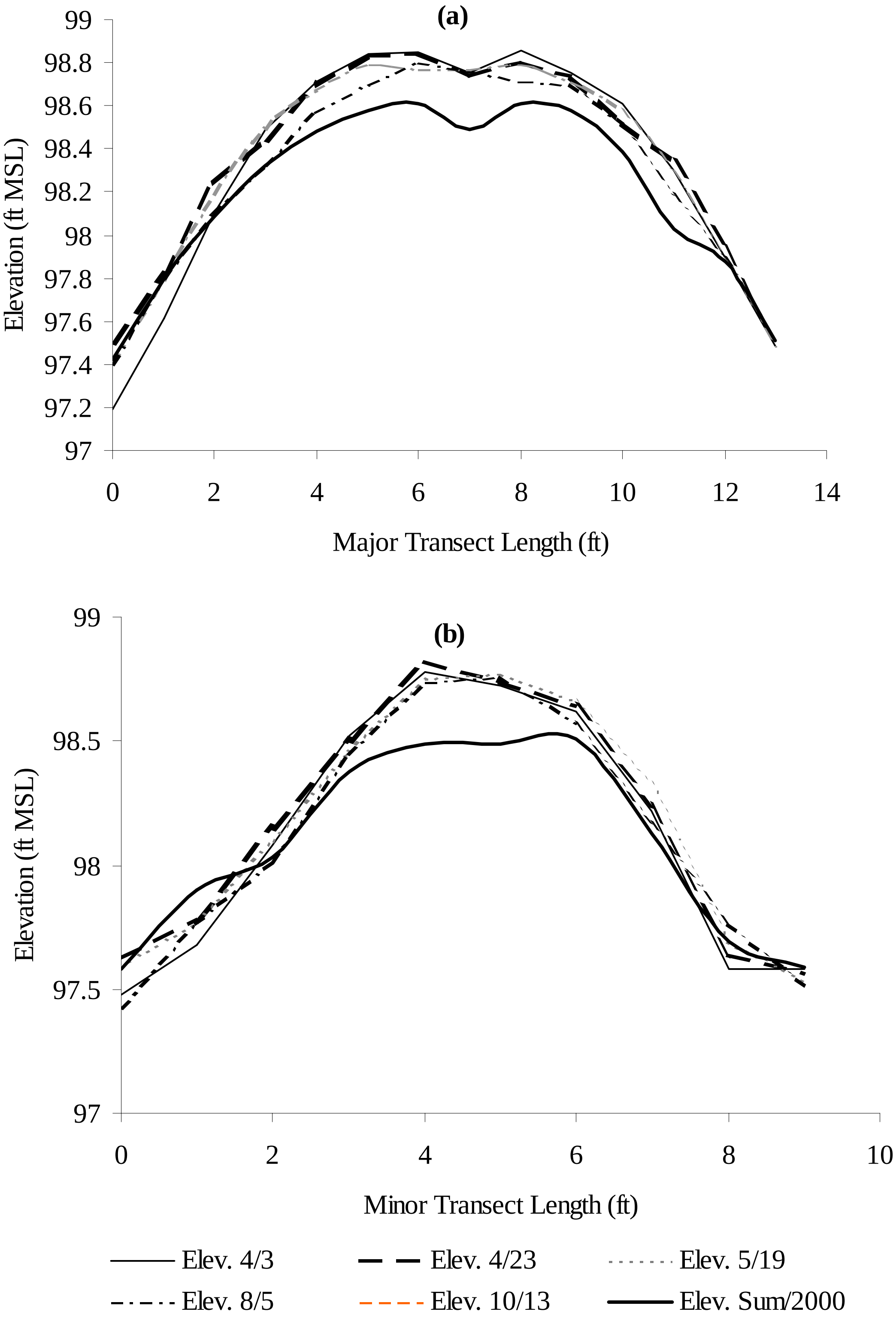


Figure 5A-1. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 1.

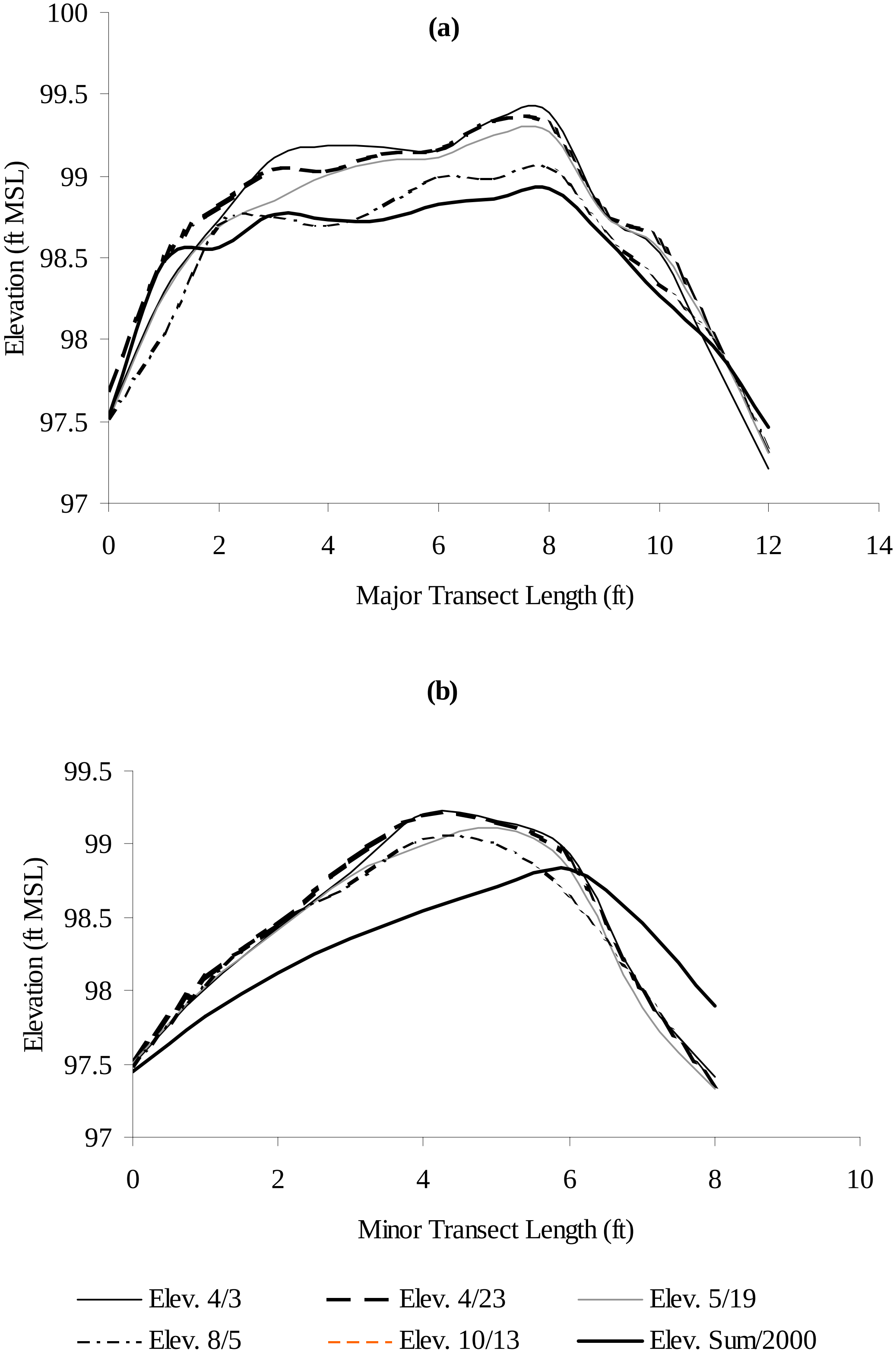


Figure 5A-2. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 2.

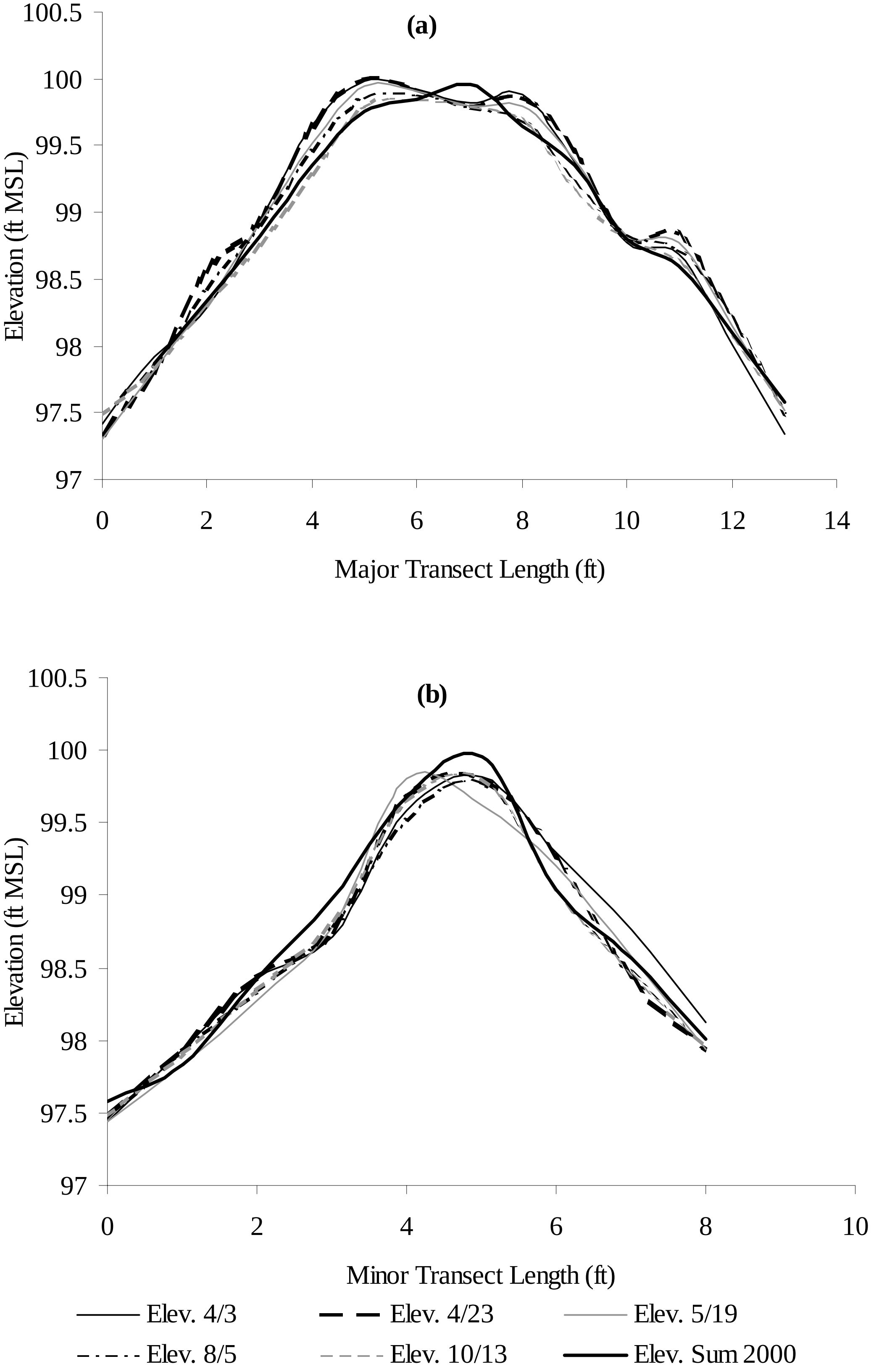


Figure 5A-3. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 3.

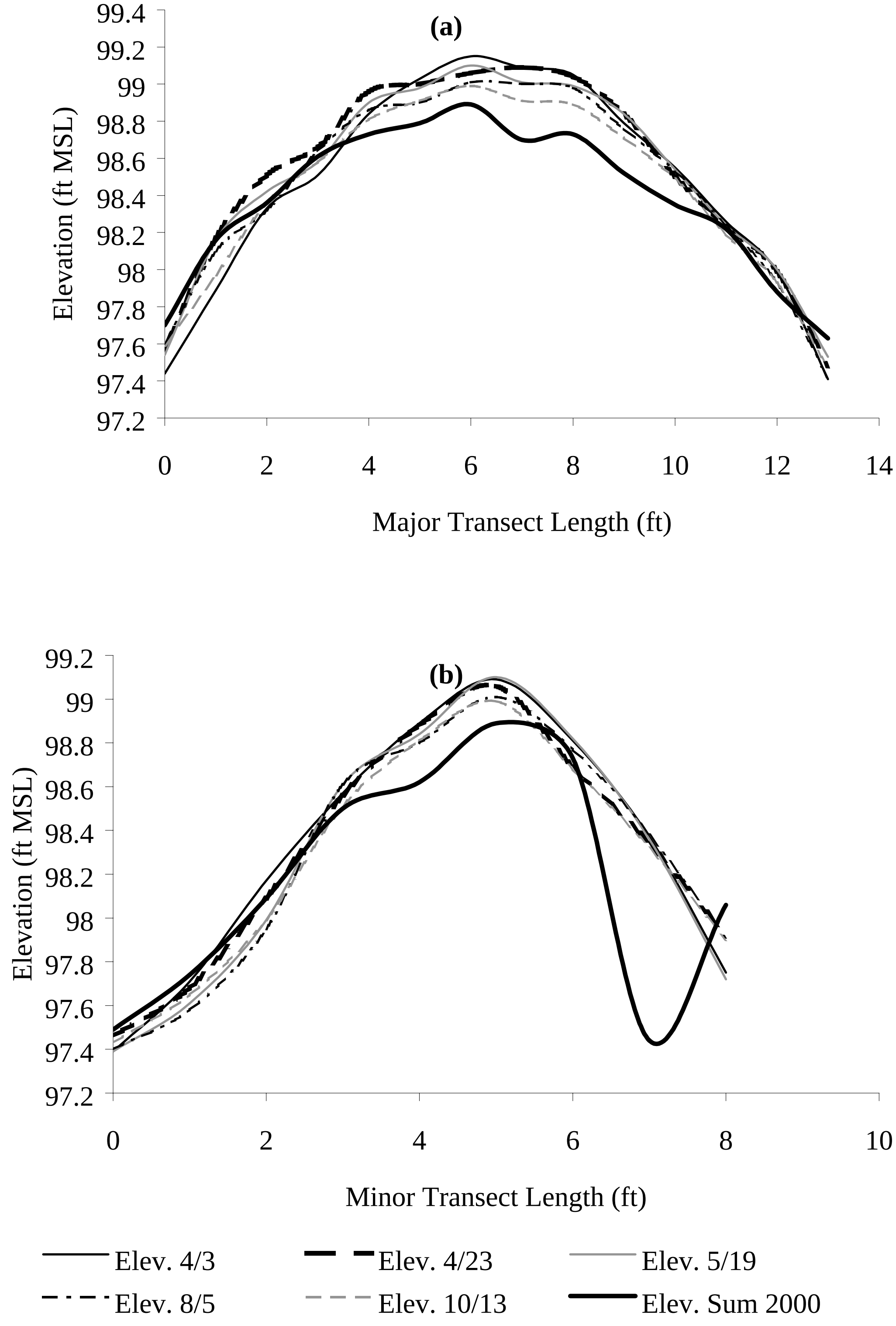


Figure 5A-4. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 4.

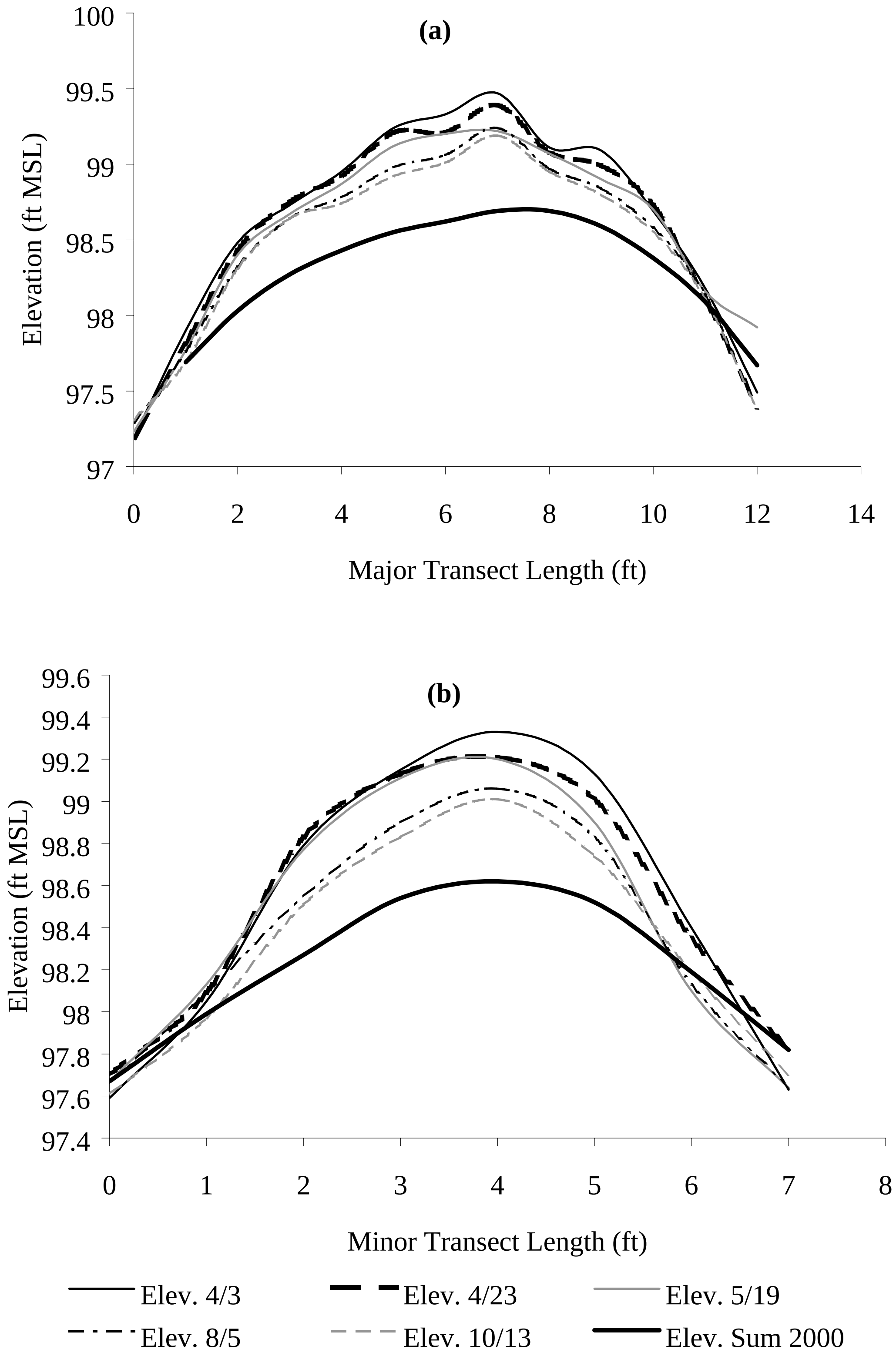


Figure 5A-5. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 5.

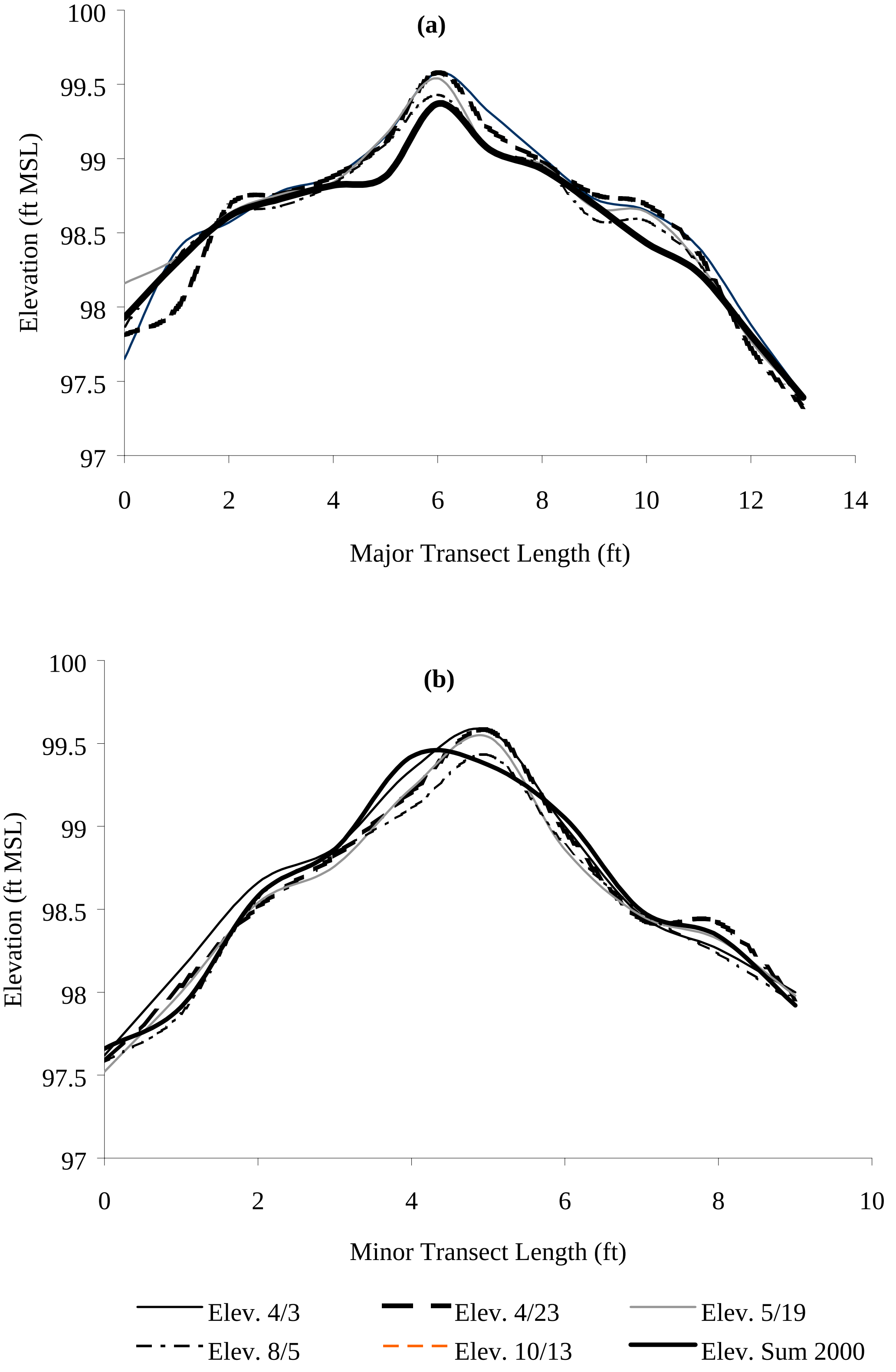


Figure 5A-6. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 6.

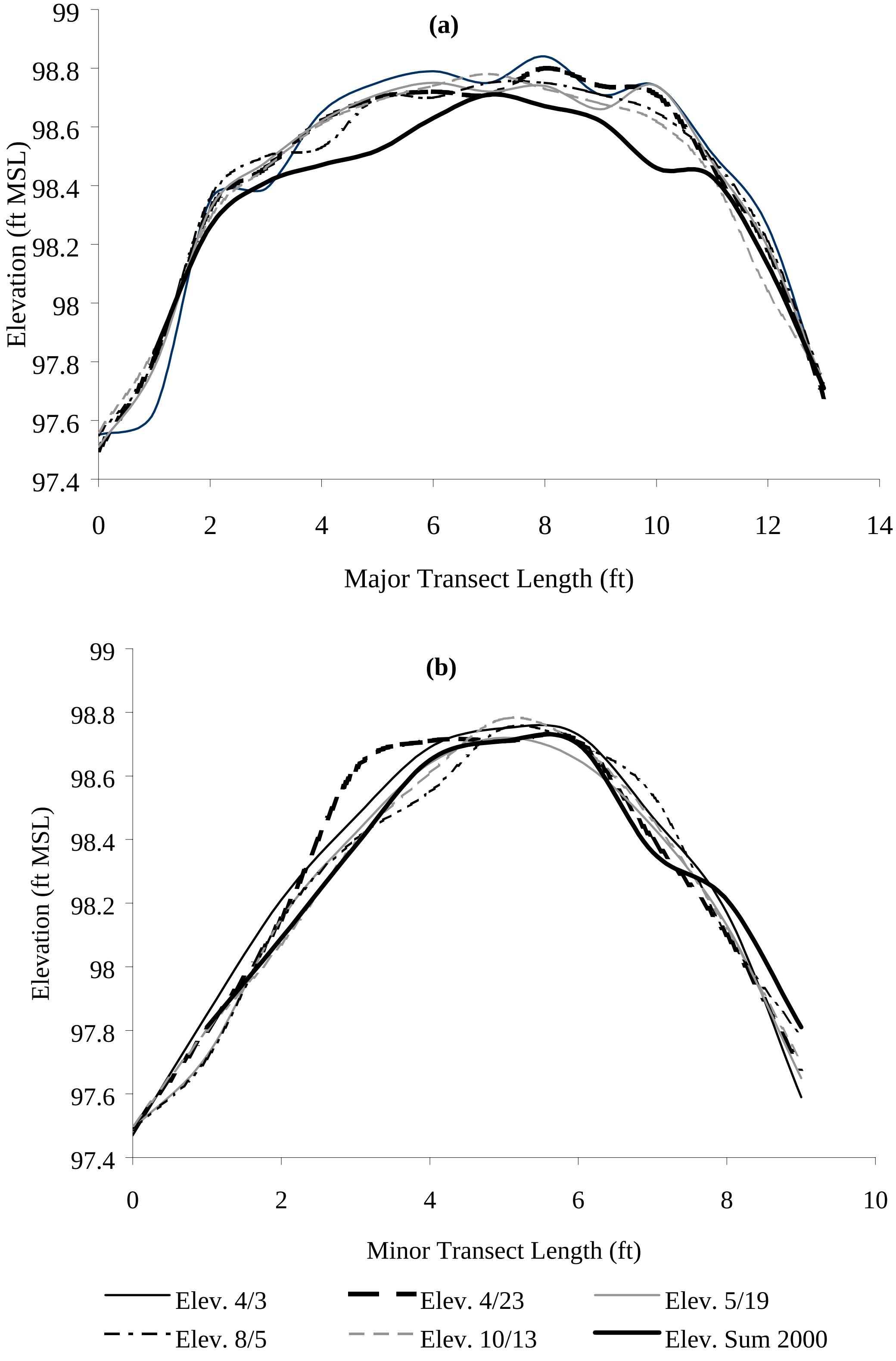


Figure 5A-7. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 7.

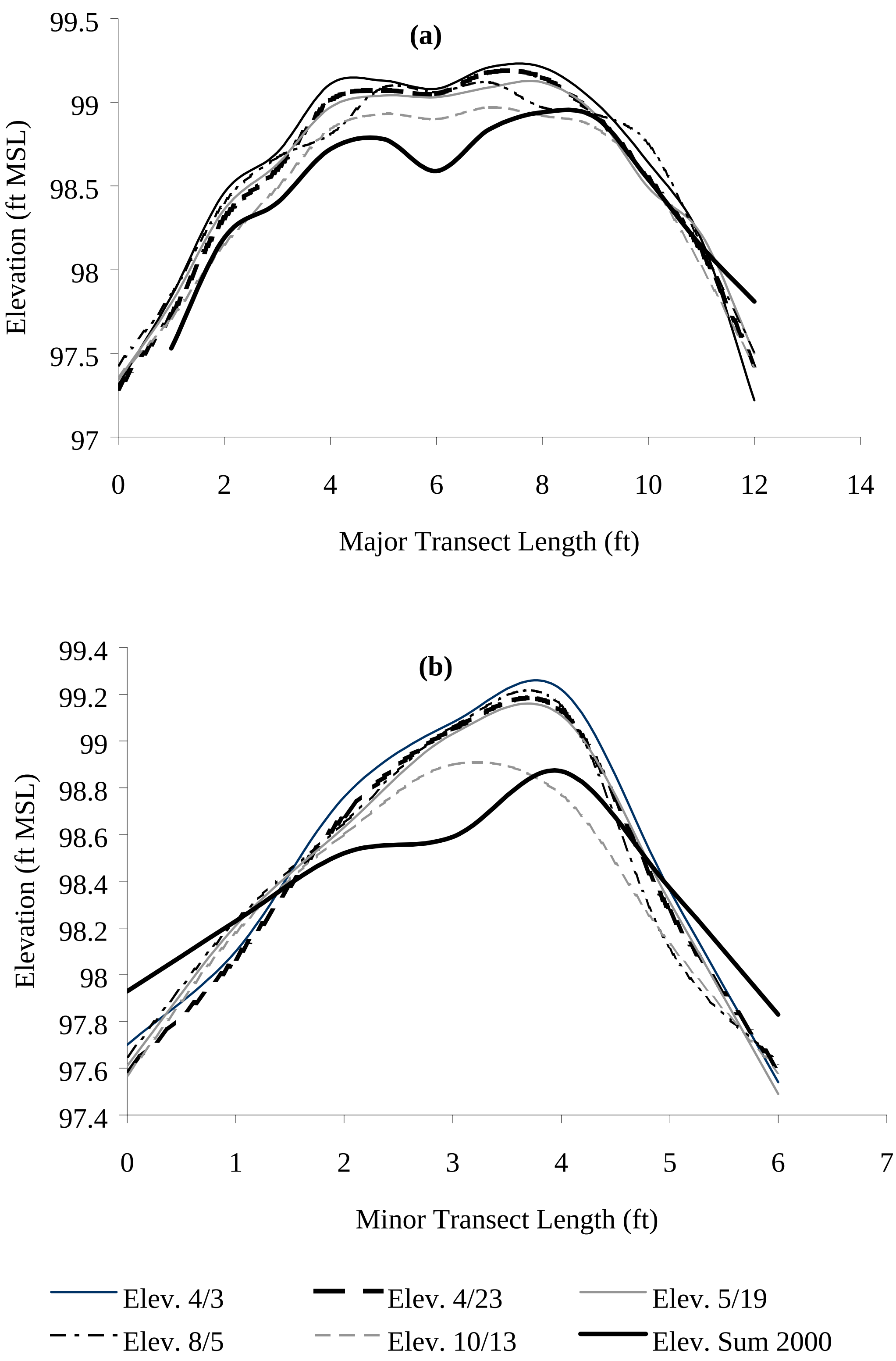


Figure 5A-8. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 8.

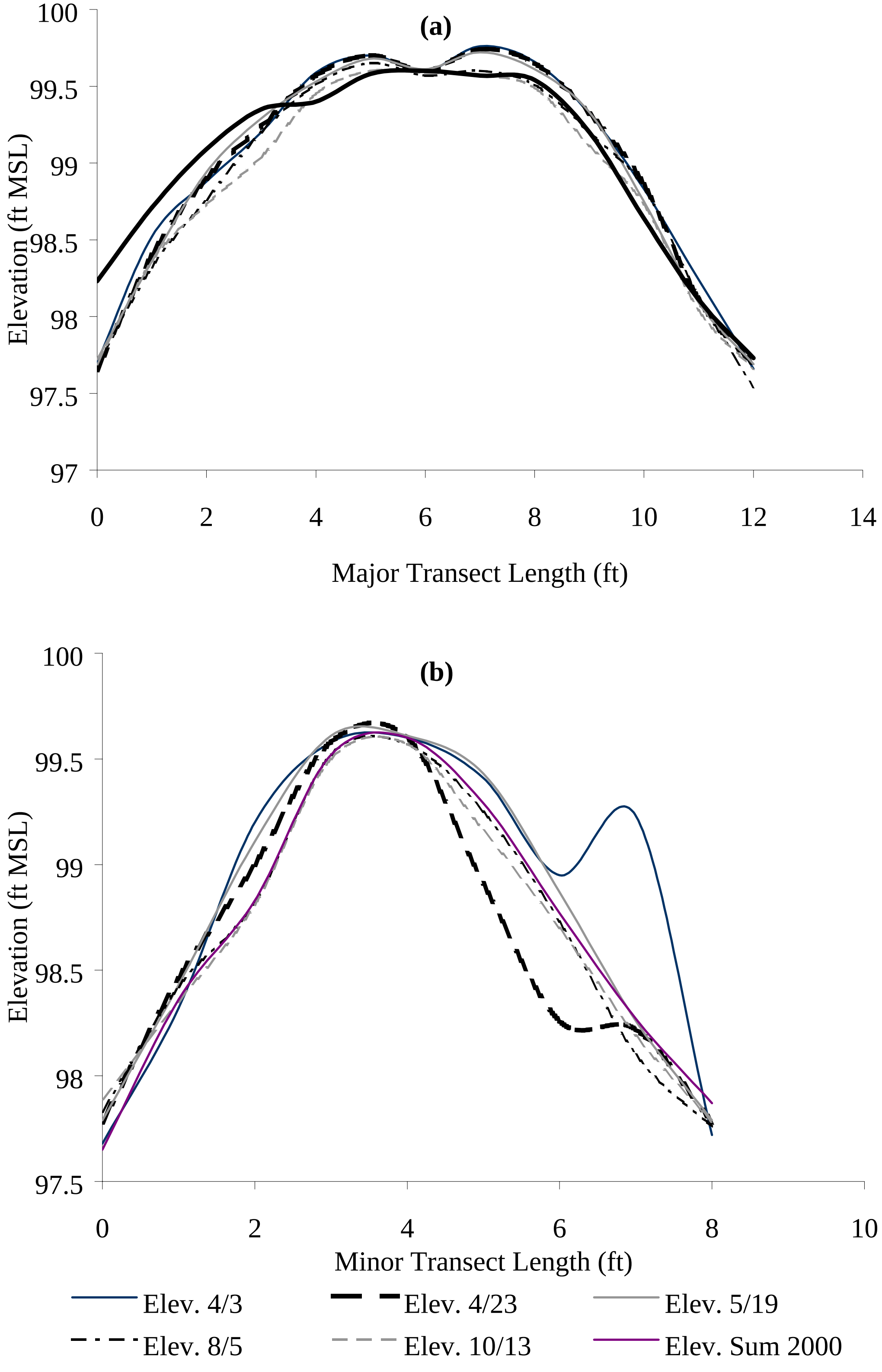


Figure 5A-9. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 9.

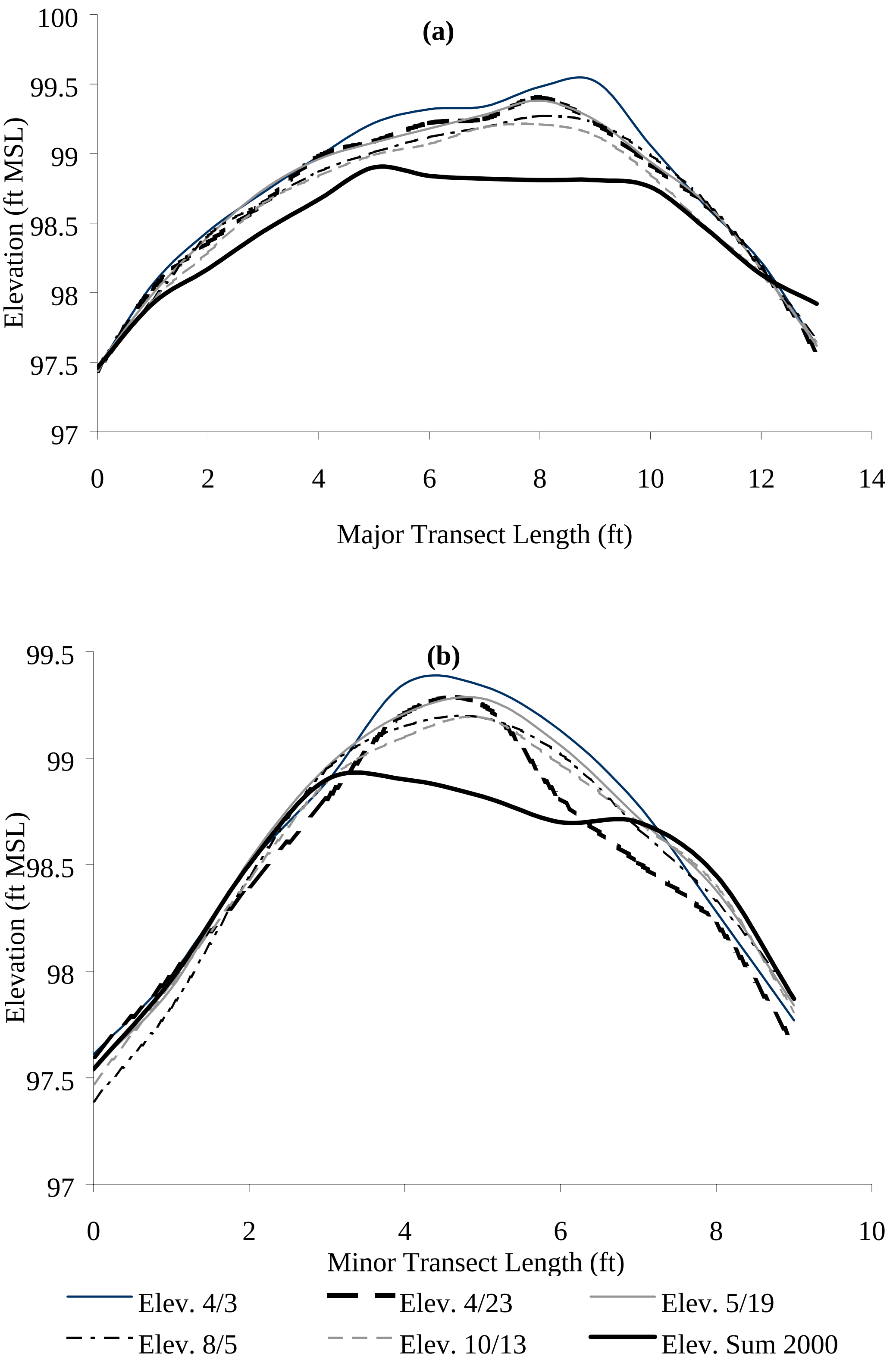


Figure 5A-10. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 10.

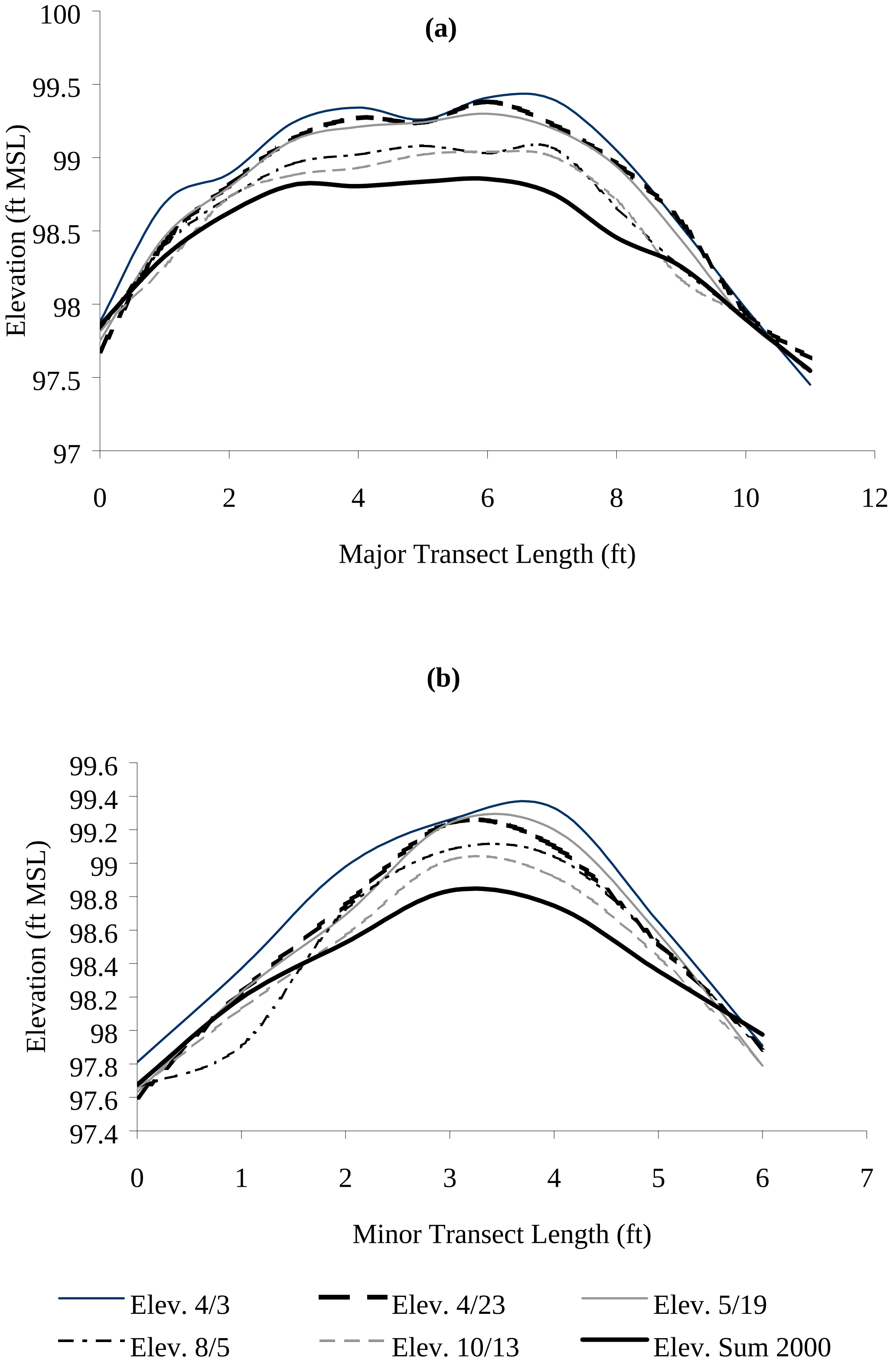


Figure 5A-11. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 11.

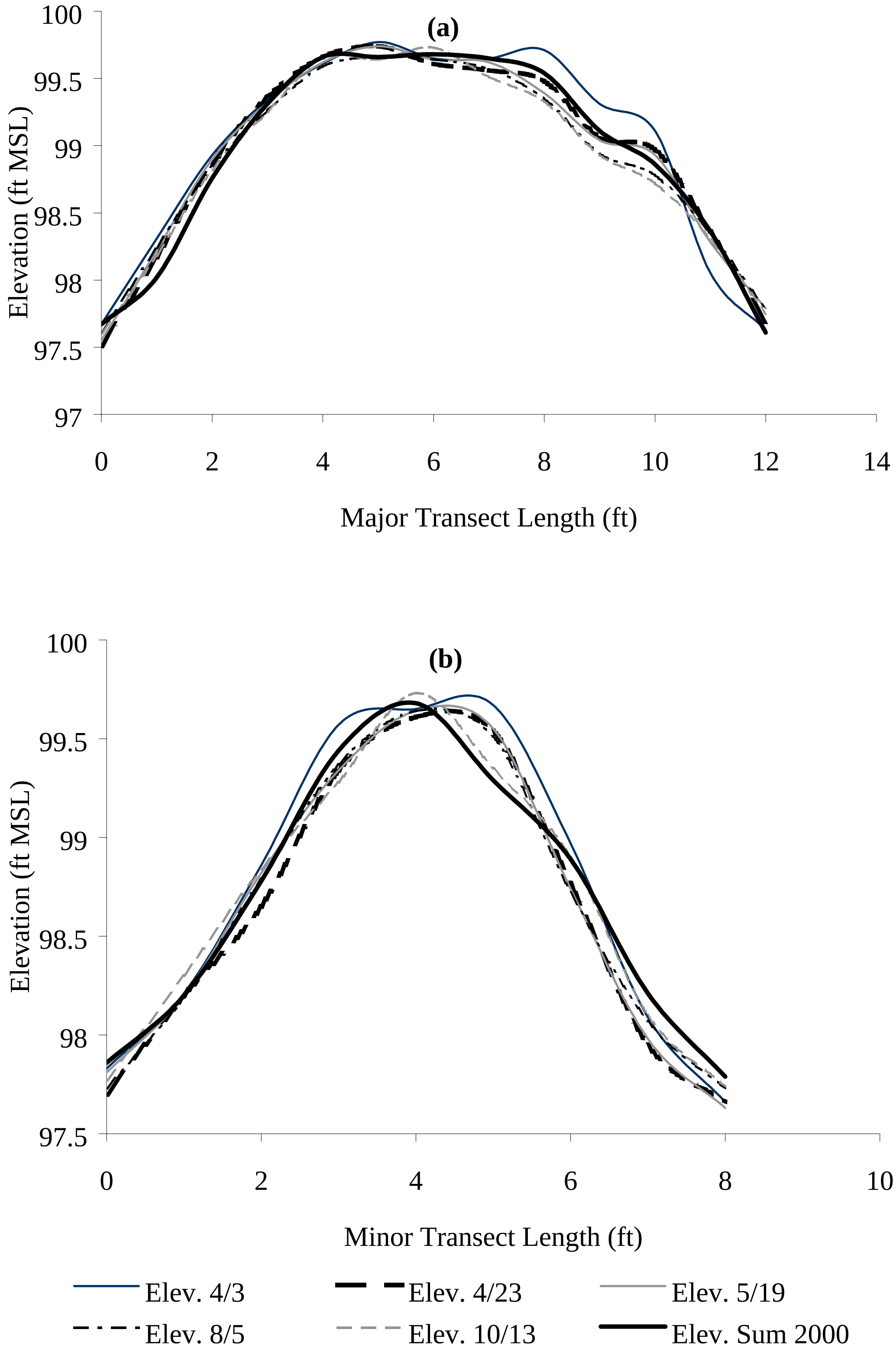


Figure 5A-12. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 12.

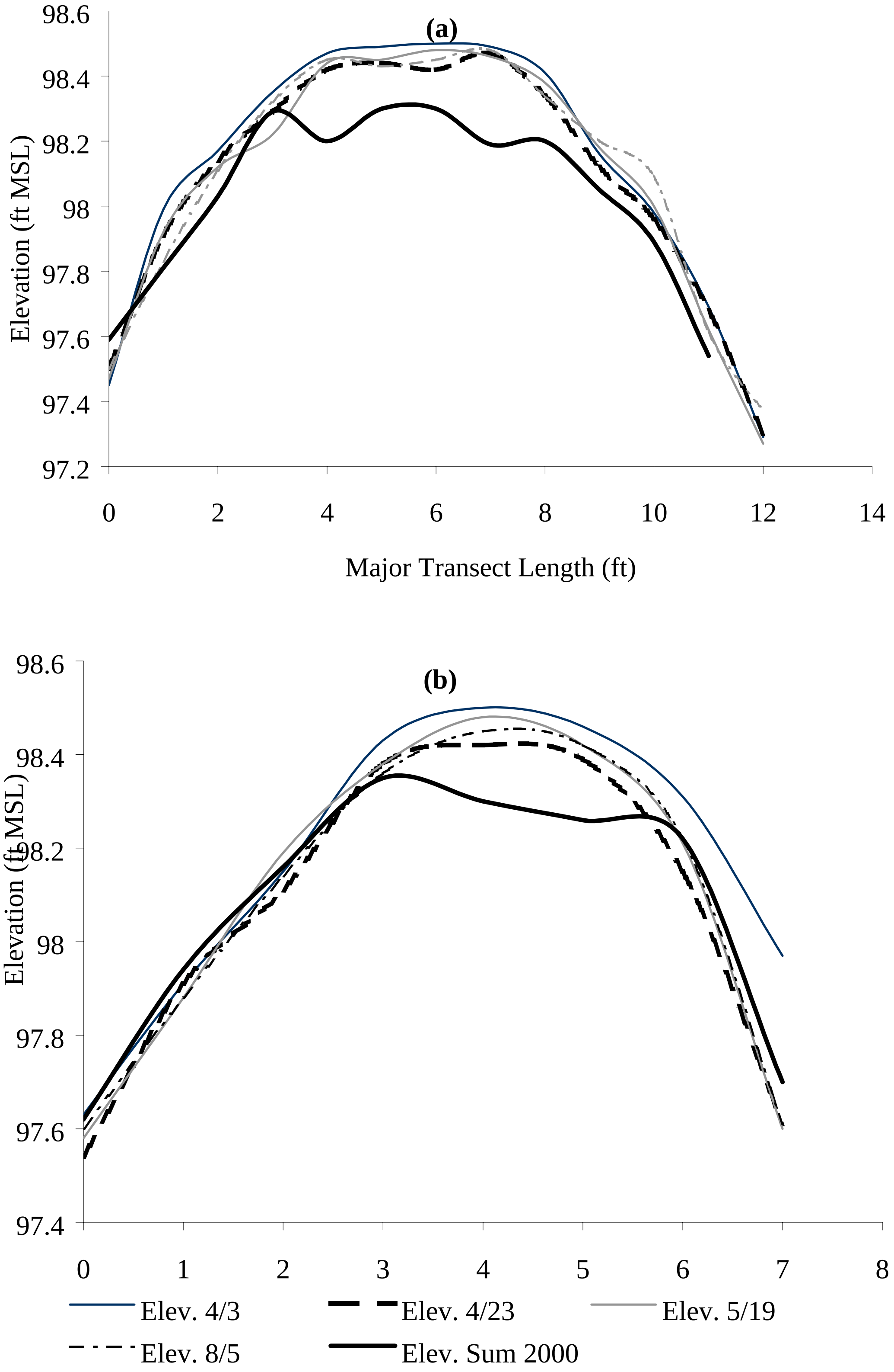


Figure 5A-13. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 13.

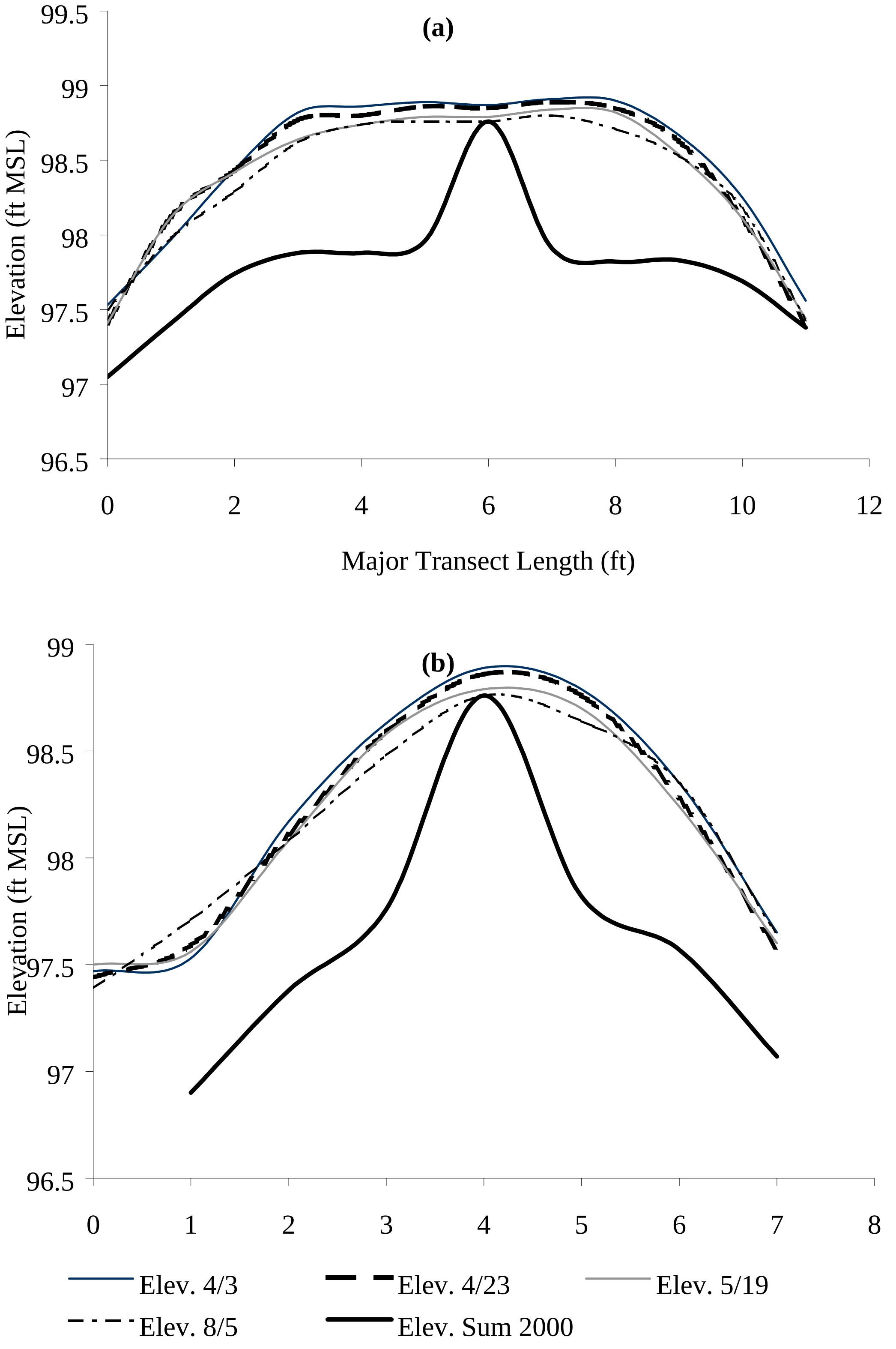


Figure 5A-14. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 14.

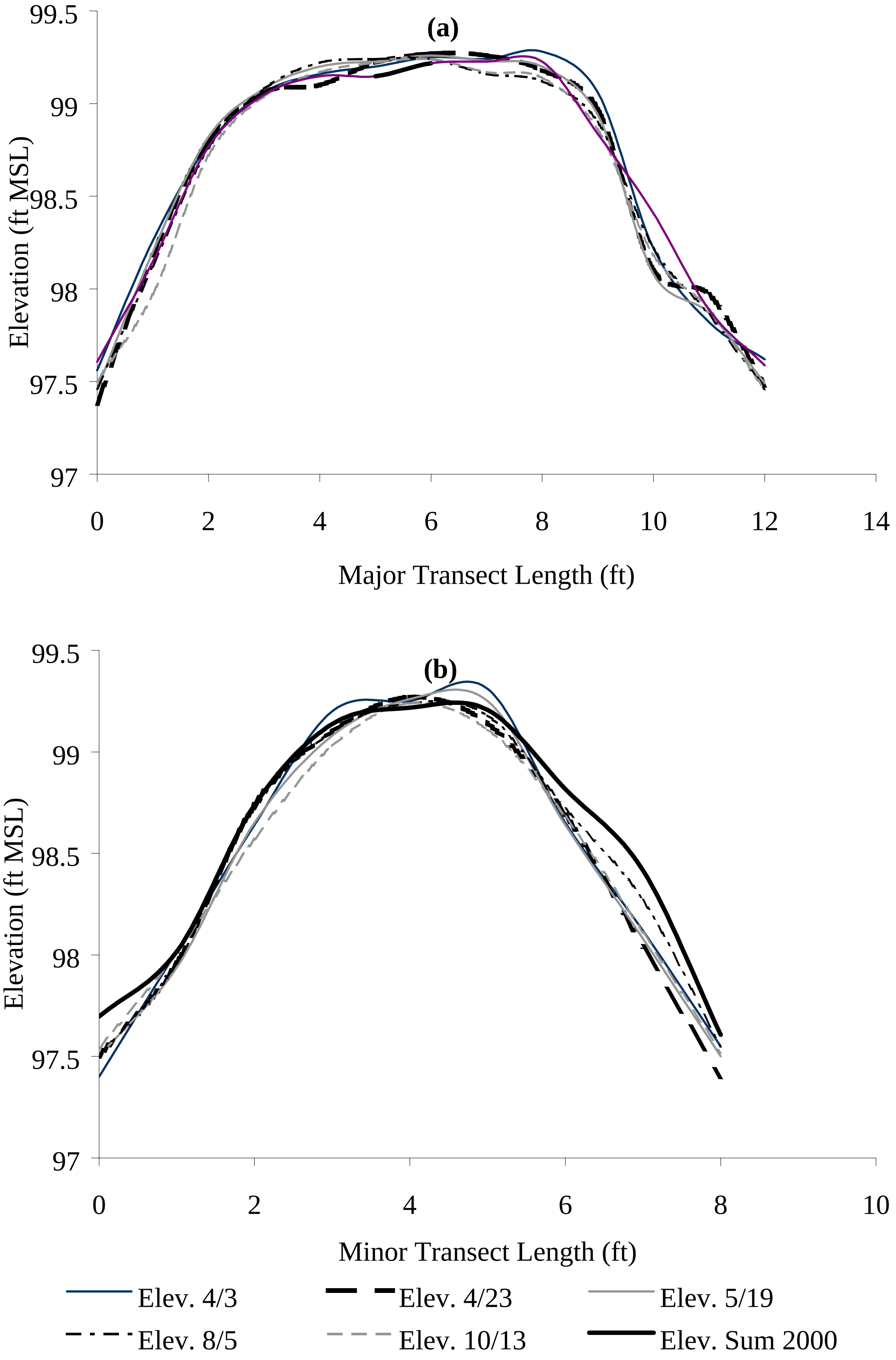


Figure 5A-15. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 15.

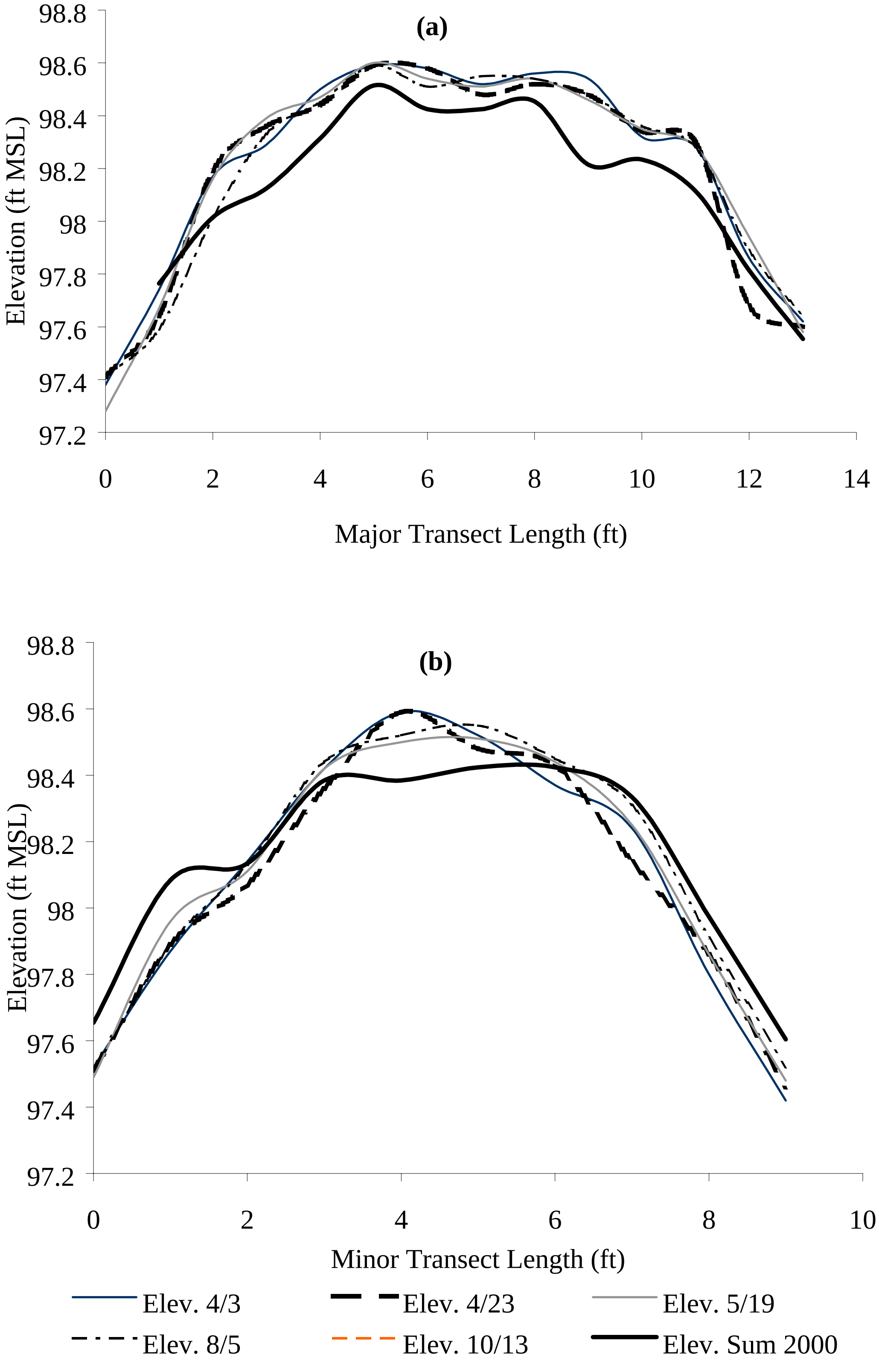


Figure 5A-16. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 16.

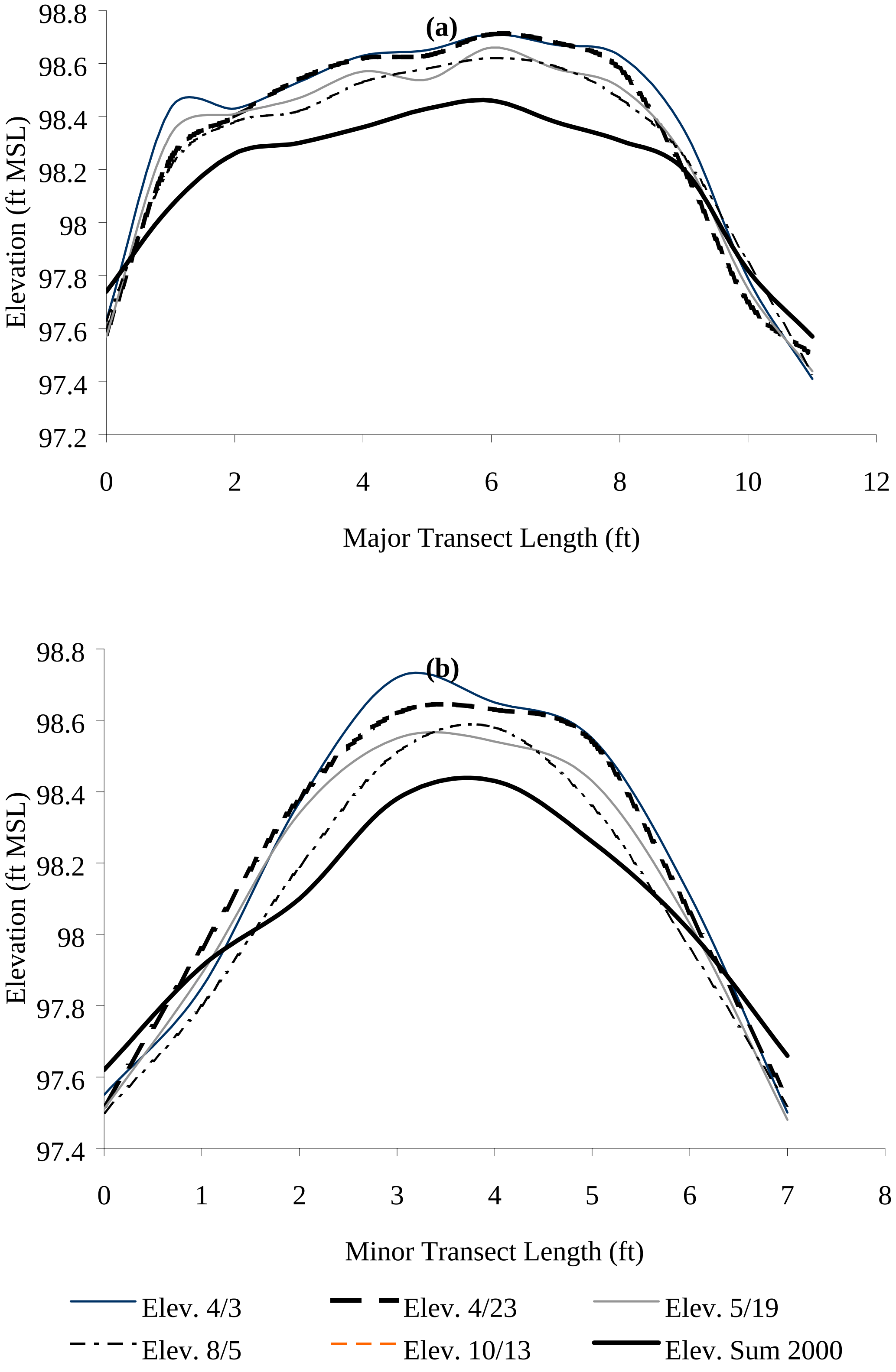


Figure 5A-17. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 17.

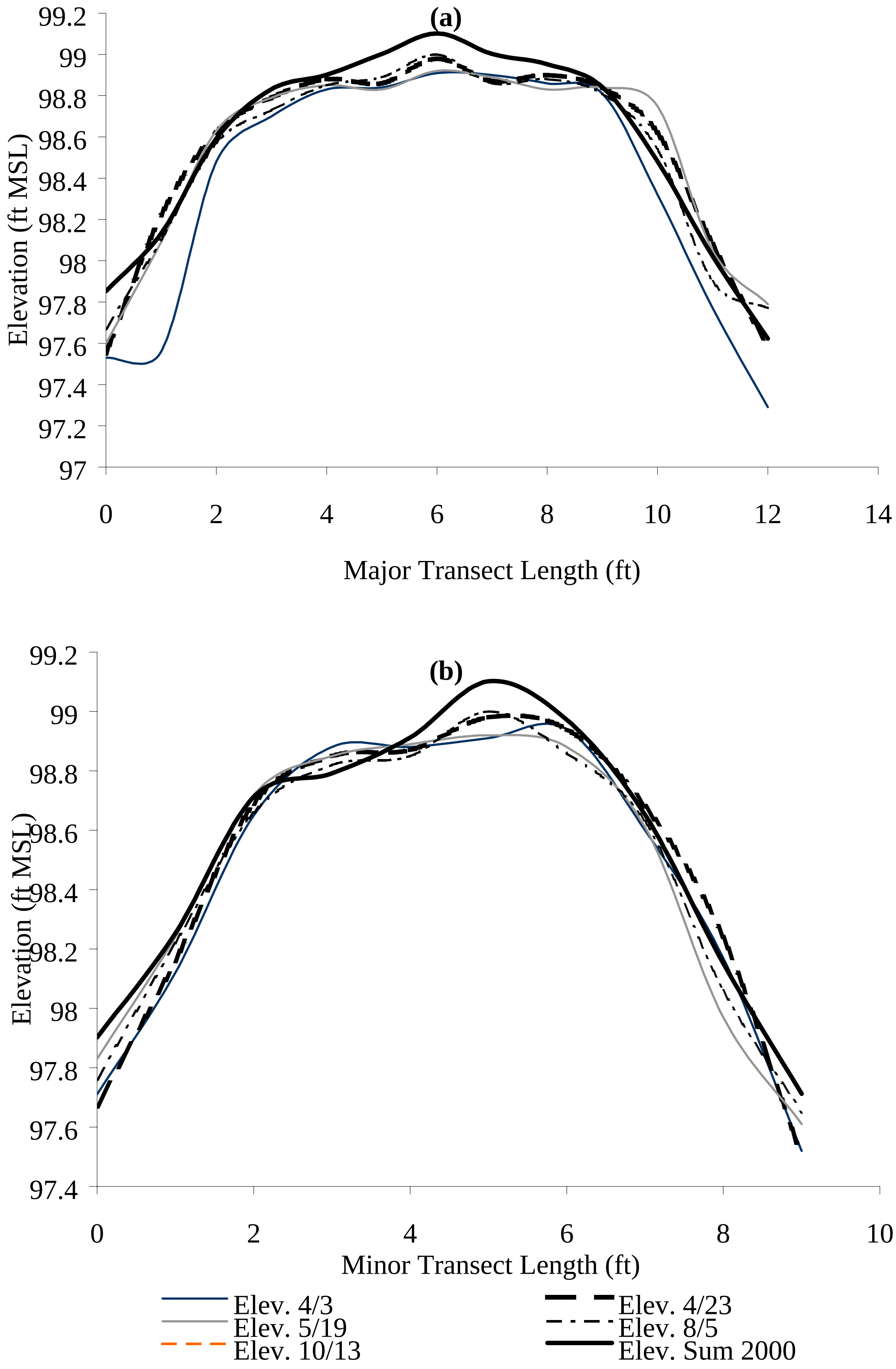


Figure 5A-18. Elevation Along Major Transect (a) and Minor Transect (b) on Agrifos Hummock 18.

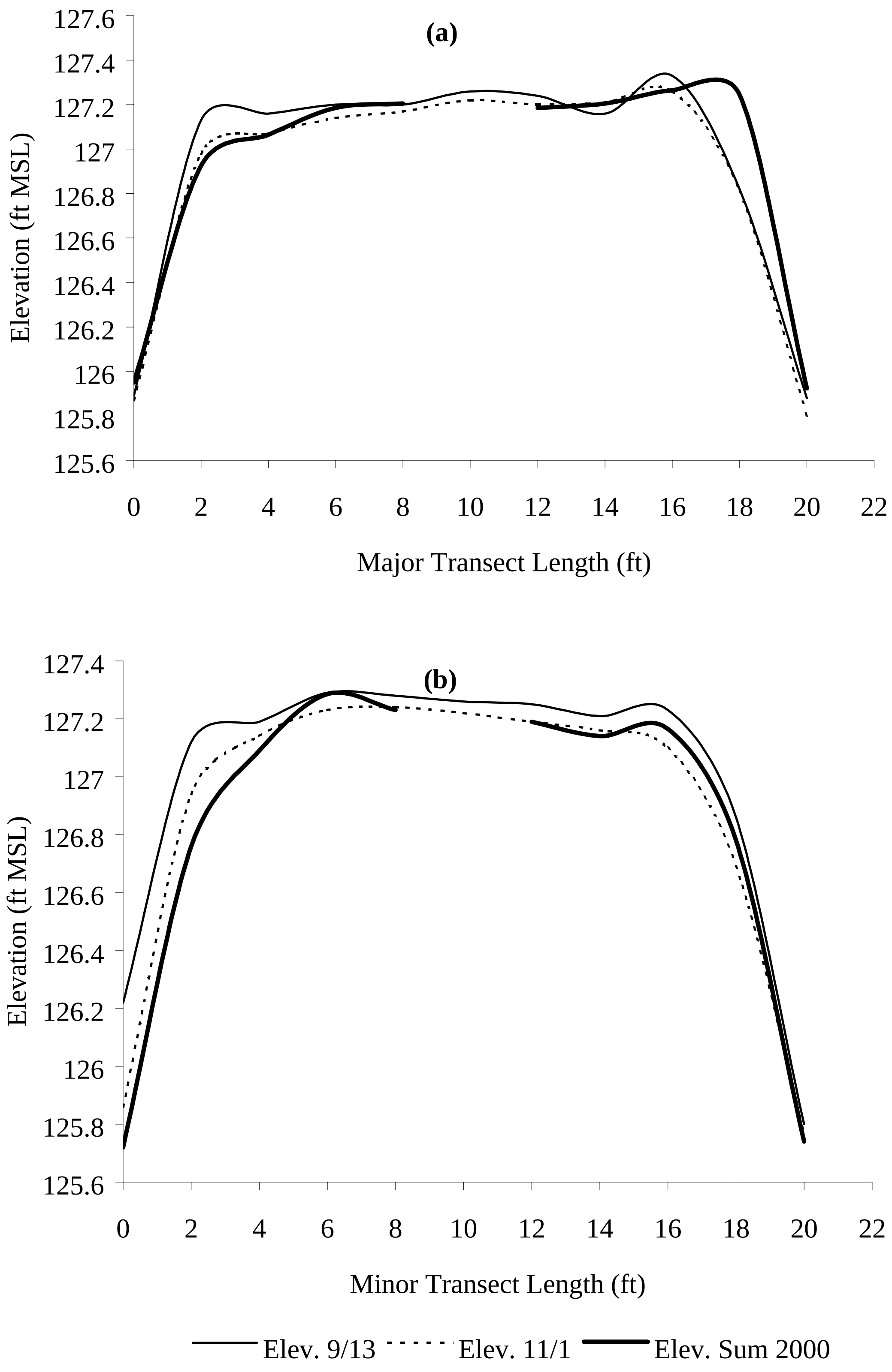


Figure 5A-19. Elevation Along Major Transect (a) and Minor Transect (b) on Cargill Hummock 1.

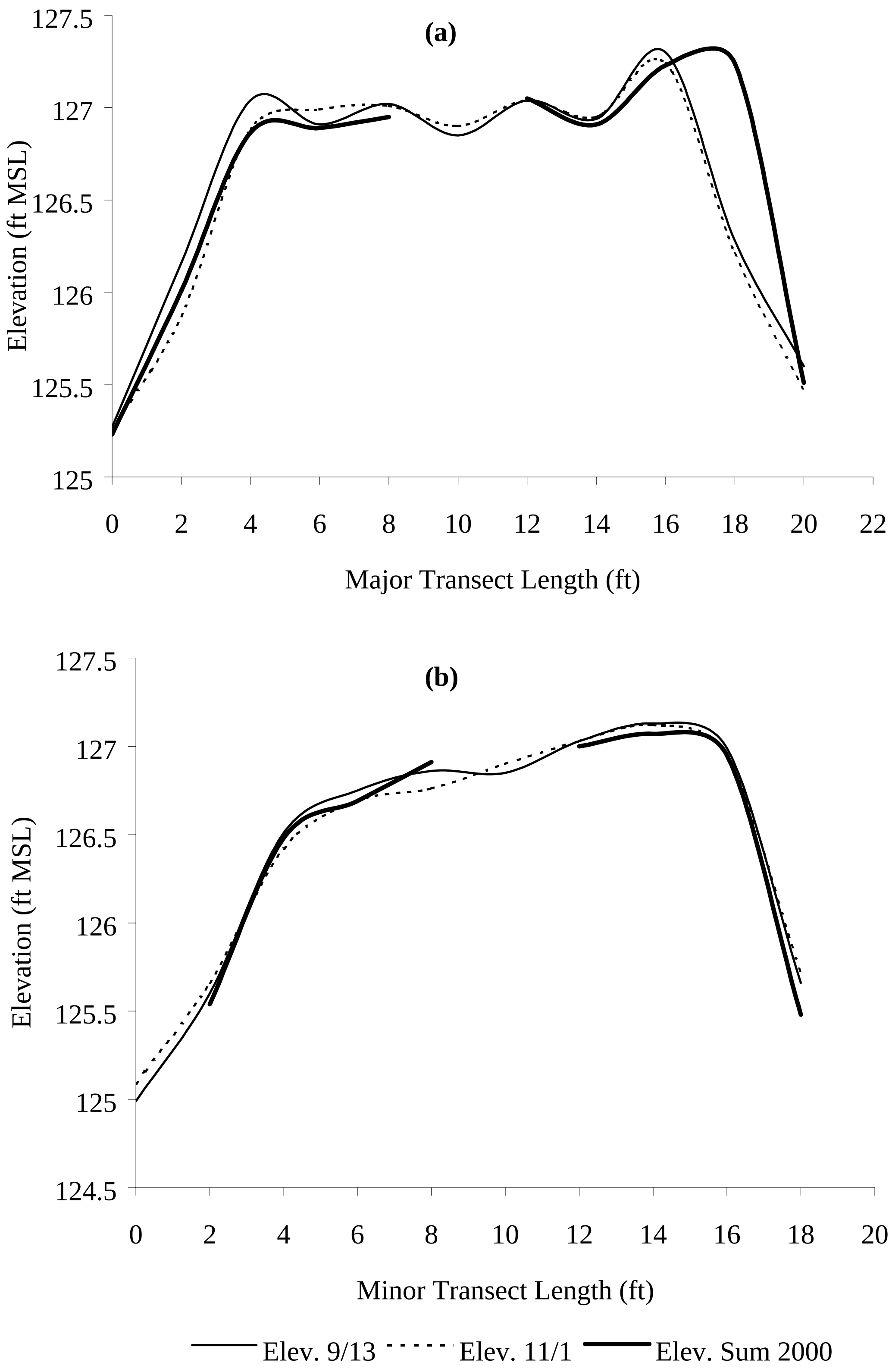


Figure 5A-20. Elevation Along Major Transect (a) and Minor Transect (b) on Cargill Hummock 2.

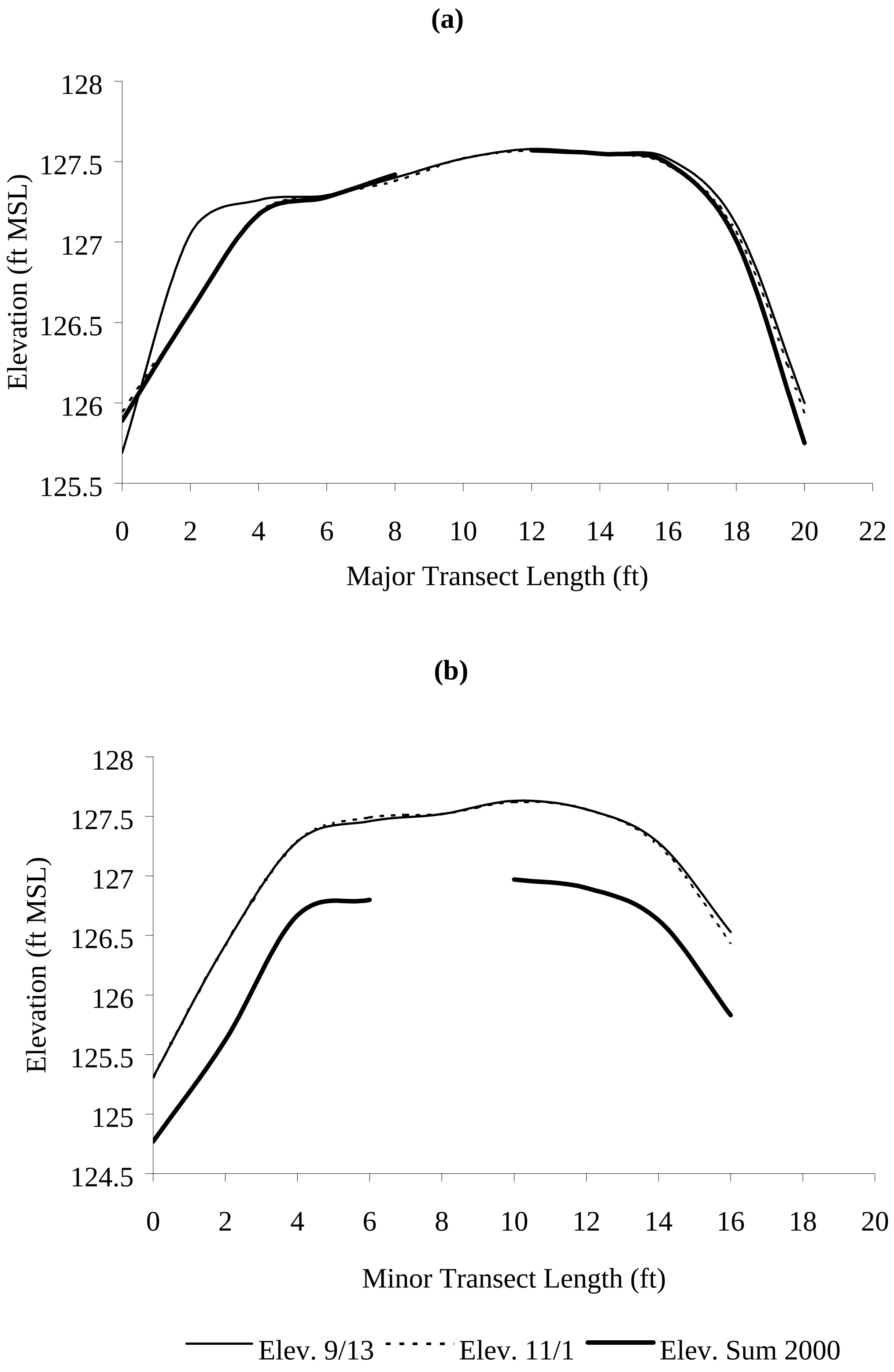


Figure 5A-21. Elevation Along Major Transect (a) and Minor Transect (b) on Cargill Hummock 3.

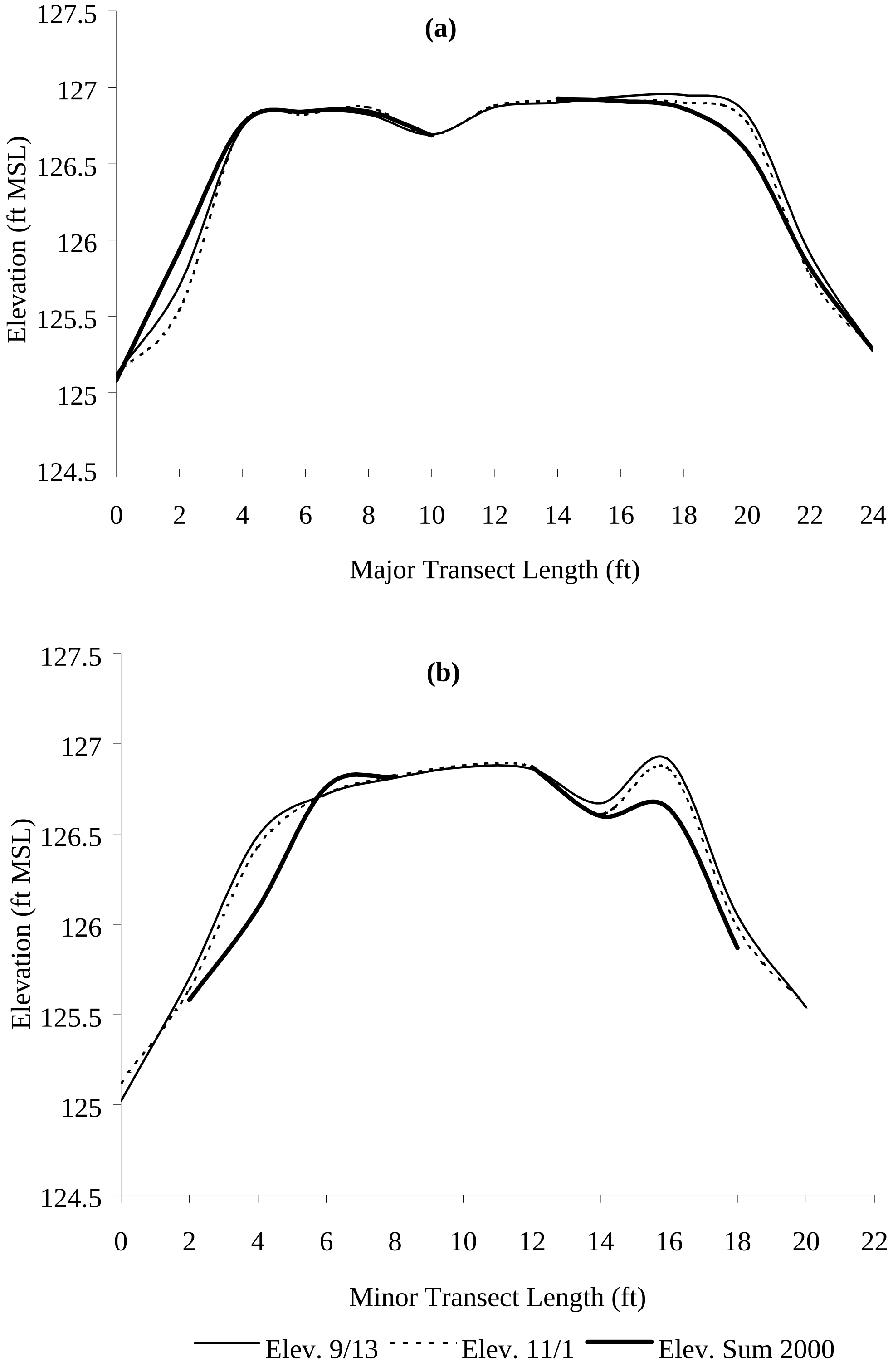


Figure 5A-22. Elevation Along Major Transect (a) and Minor Transect (b) on Cargill Hummock 4.

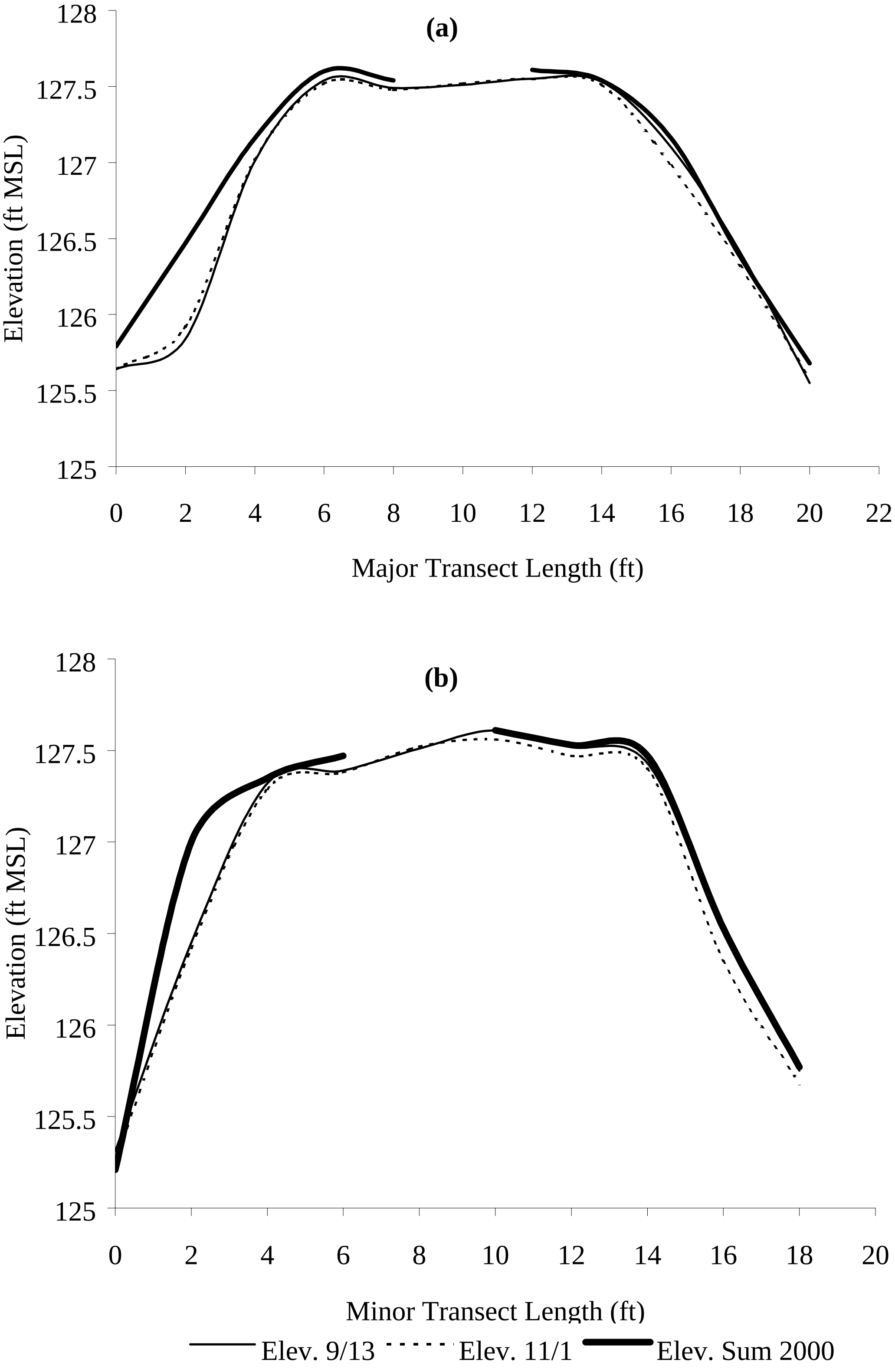


Figure 5A-23. Elevation Along Major Transect (a) and Minor Transect (b) on Cargill Hummock 5.

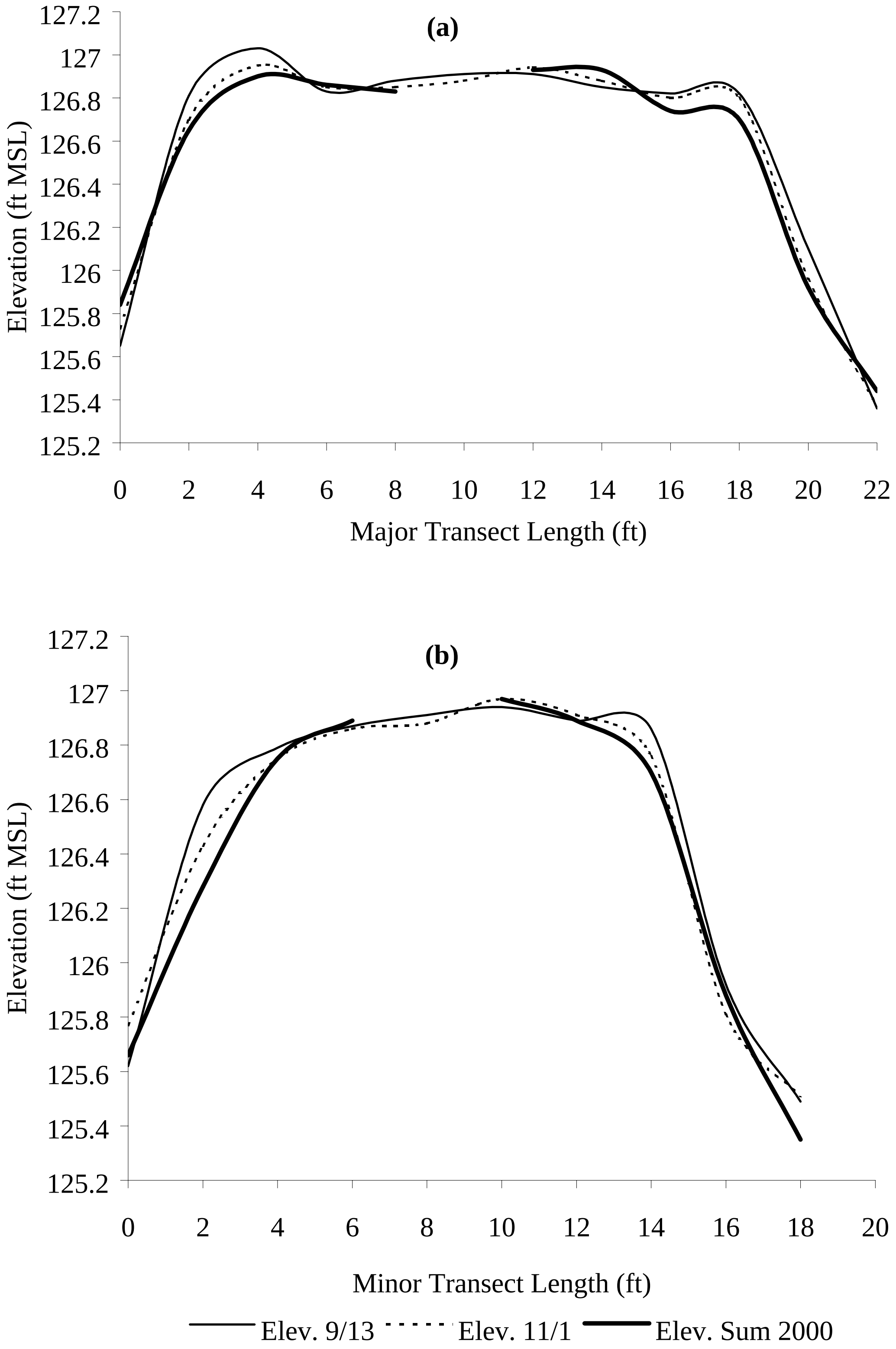


Figure 5A-24. Elevation Along Major Transect (a) and Minor Transect (b) on Cargill Hummock 6.

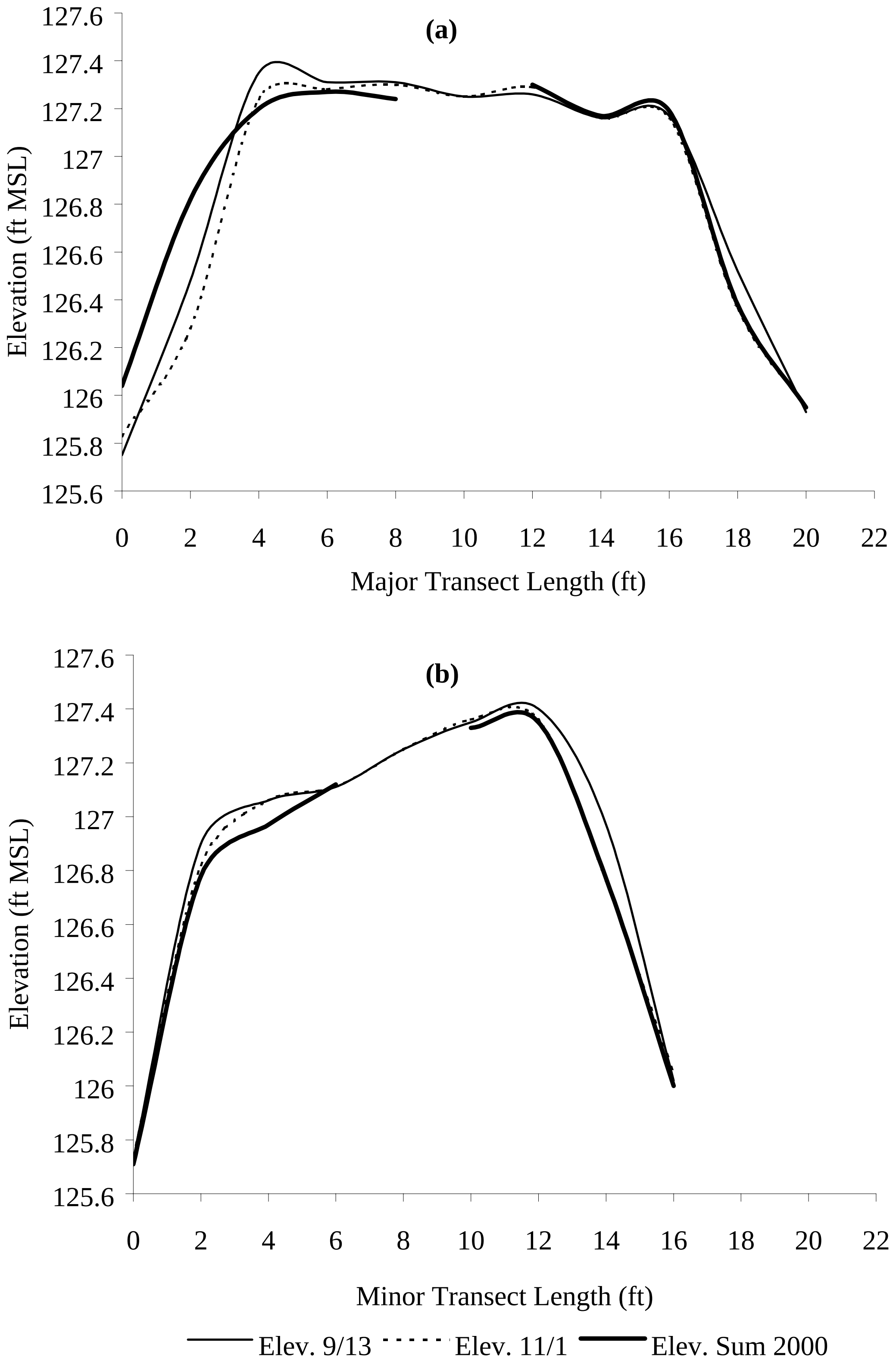


Figure 5A-25. Elevation Along Major Transect (a) and Minor Transect (b) on Cargill Hummock 7.

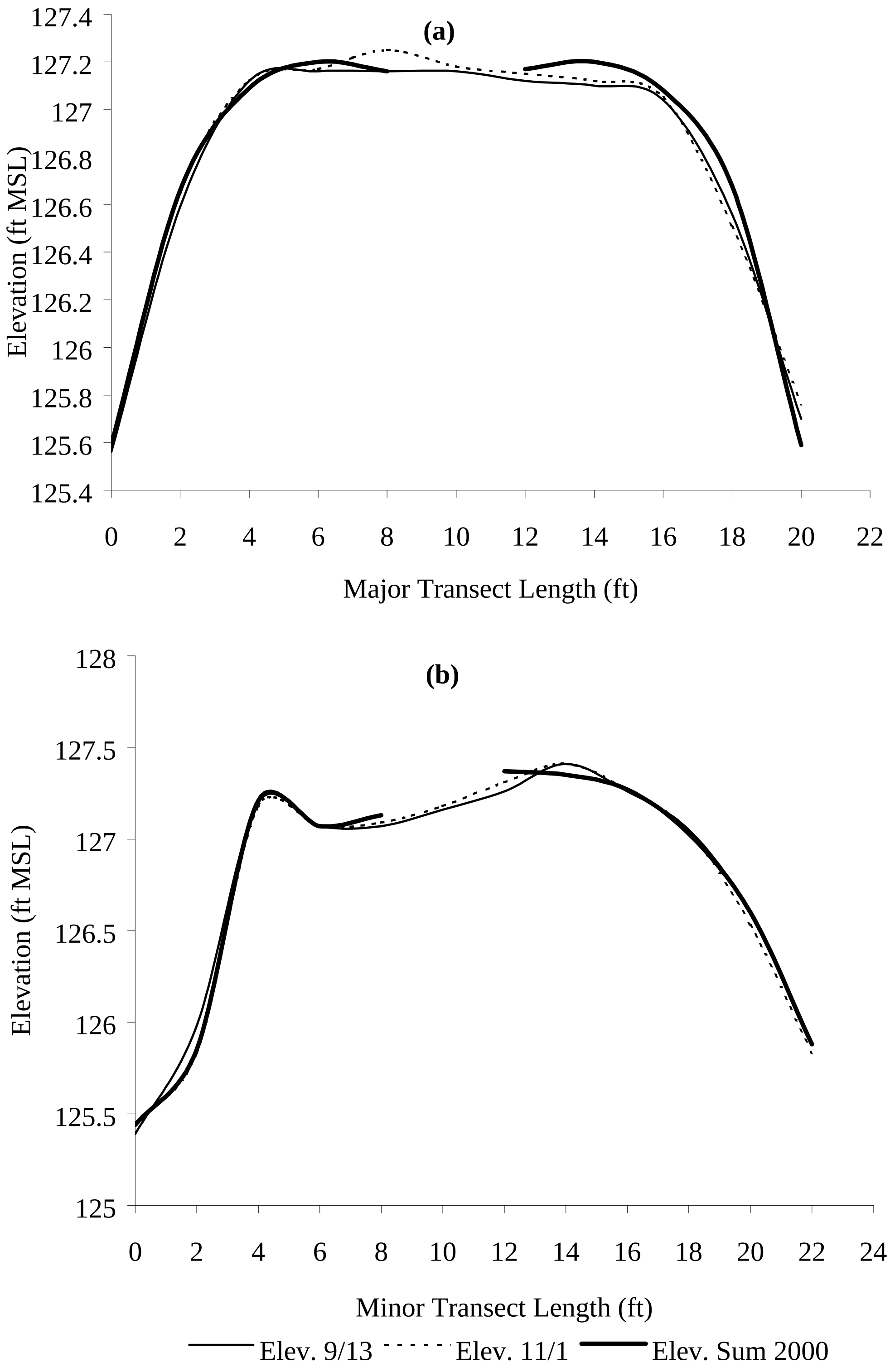


Figure 5A-26. Elevation Along Major Transect (a) and Minor Transect (b) on Cargill Hummock 8.

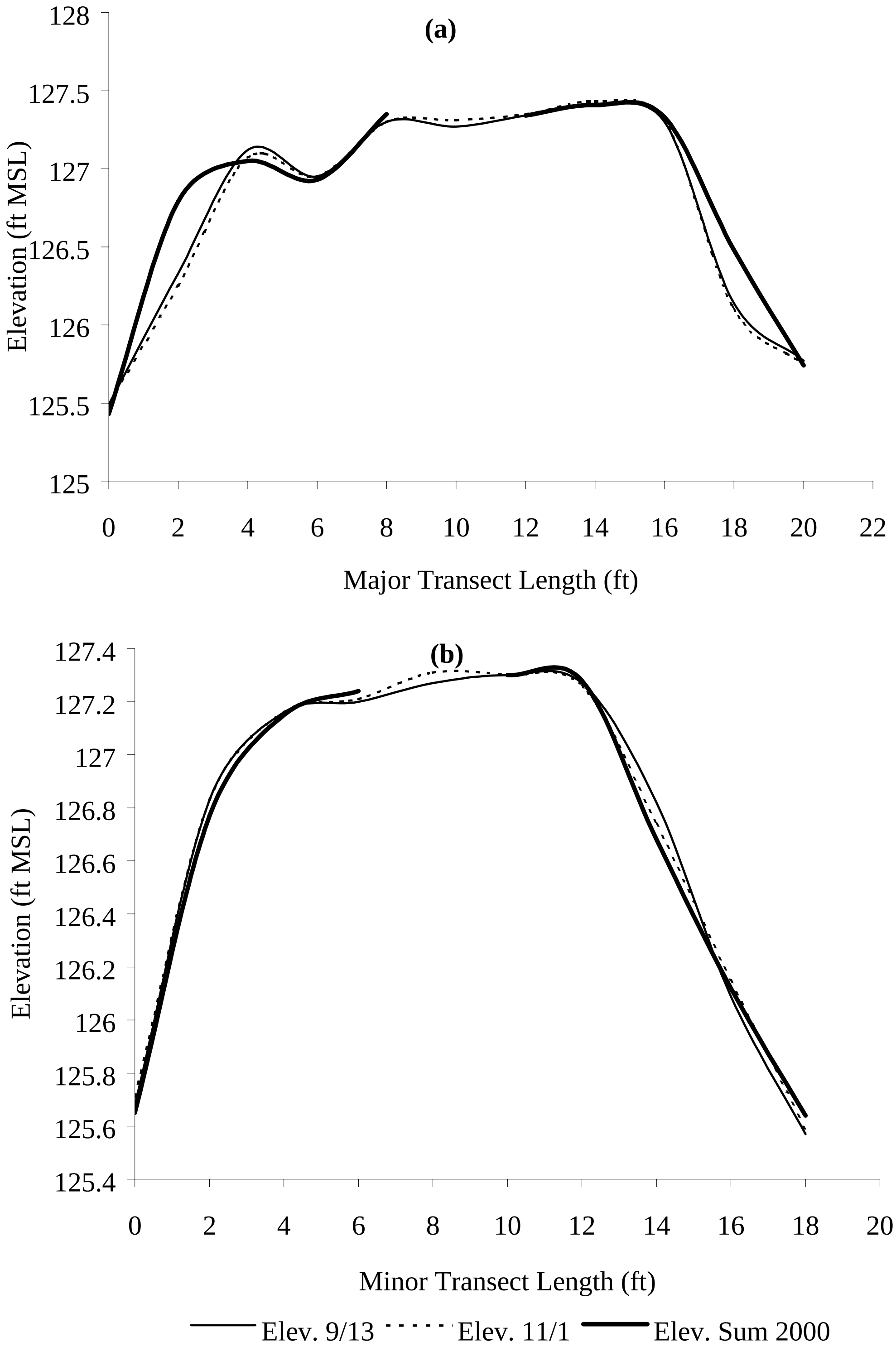


Figure 5A-27. Elevation Along Major Transect (a) and Minor Transect (b) on Cargill Hummock 9.

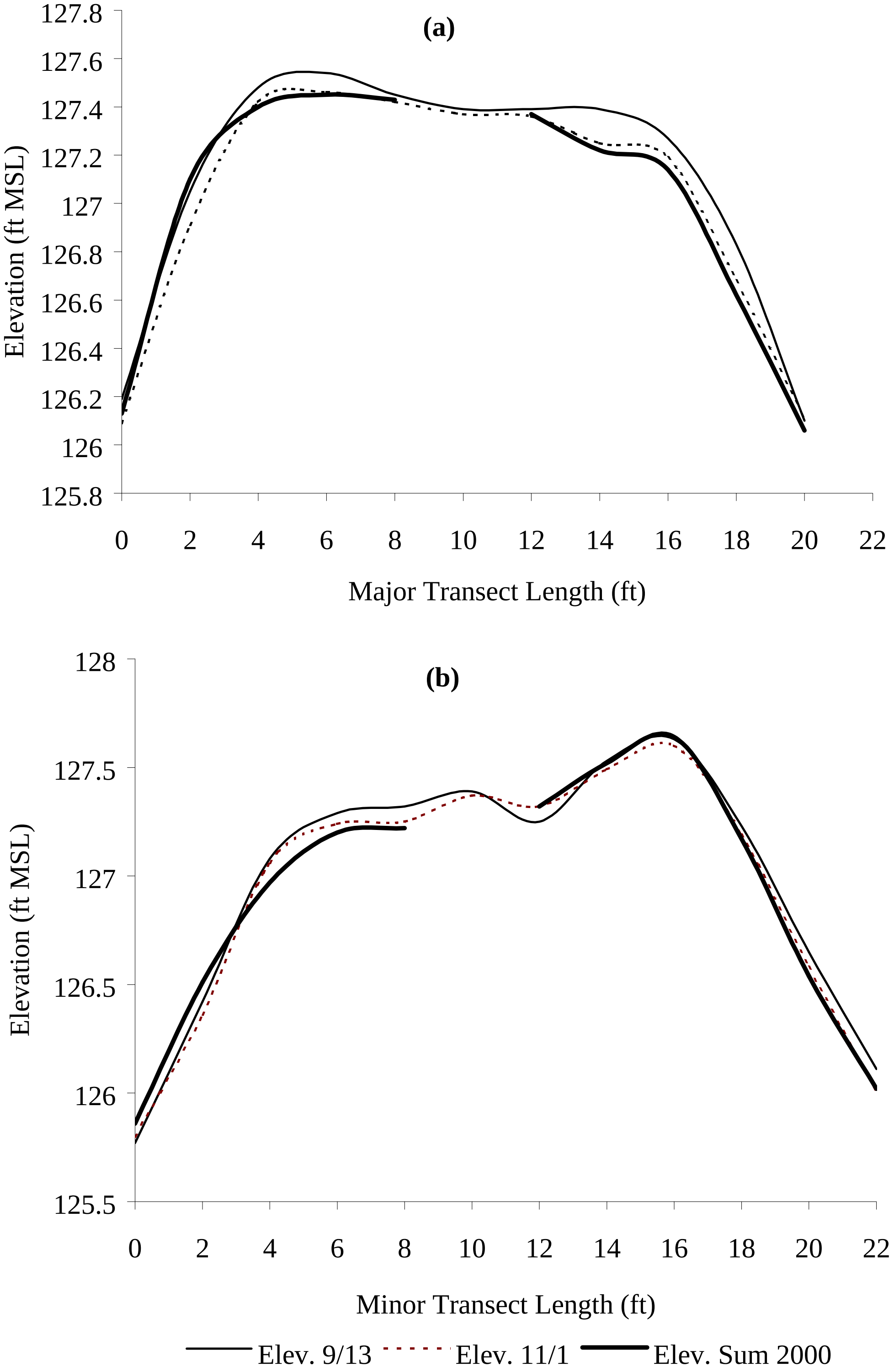


Figure 5A-28. Elevation Along Major Transect (a) and Minor Transect (b) on Cargill Hummock 10.

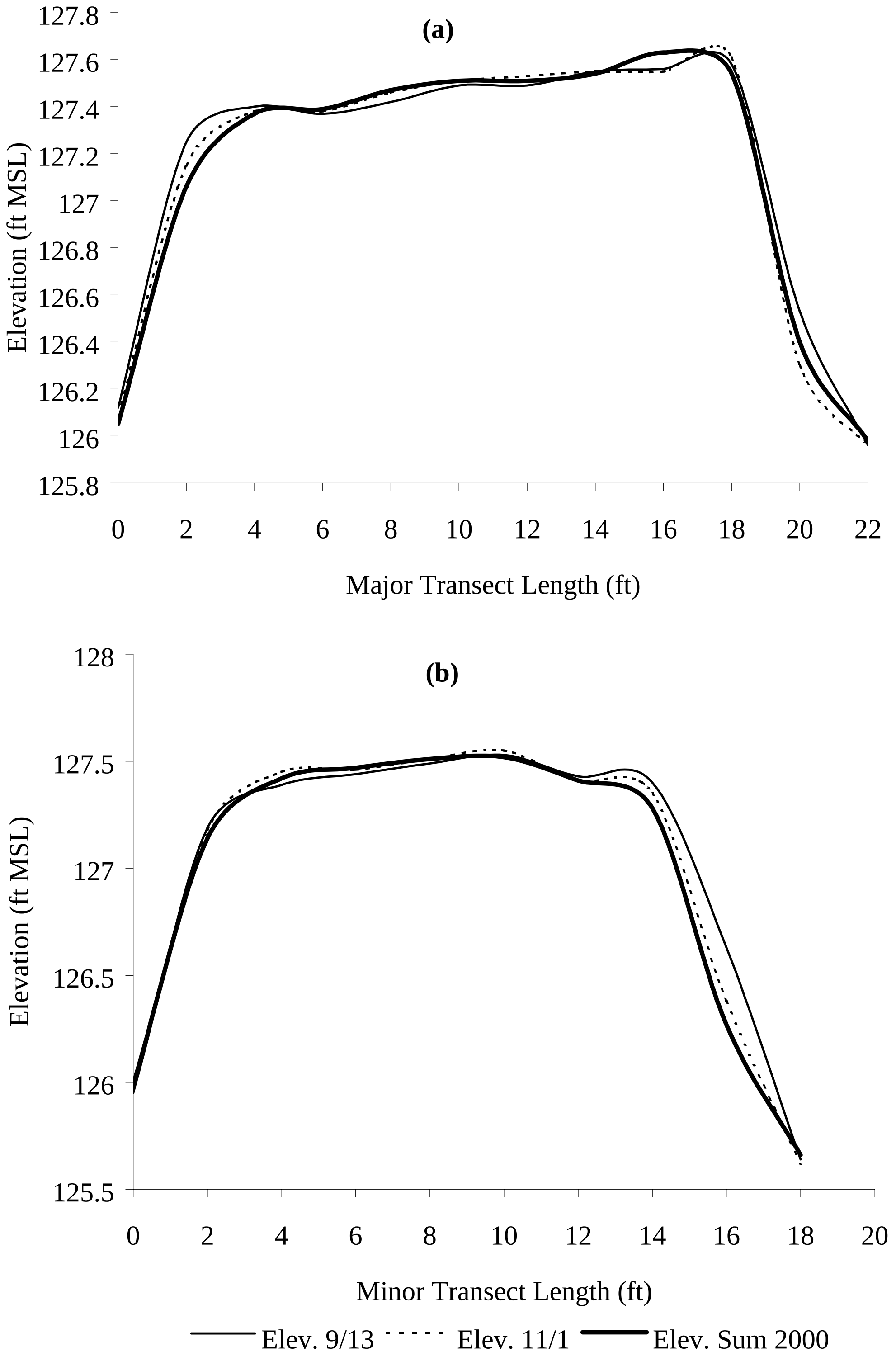


Figure 5A-29. Elevation Along Major Transect (a) and Minor Transect (b) on Cargill Hummock 11.

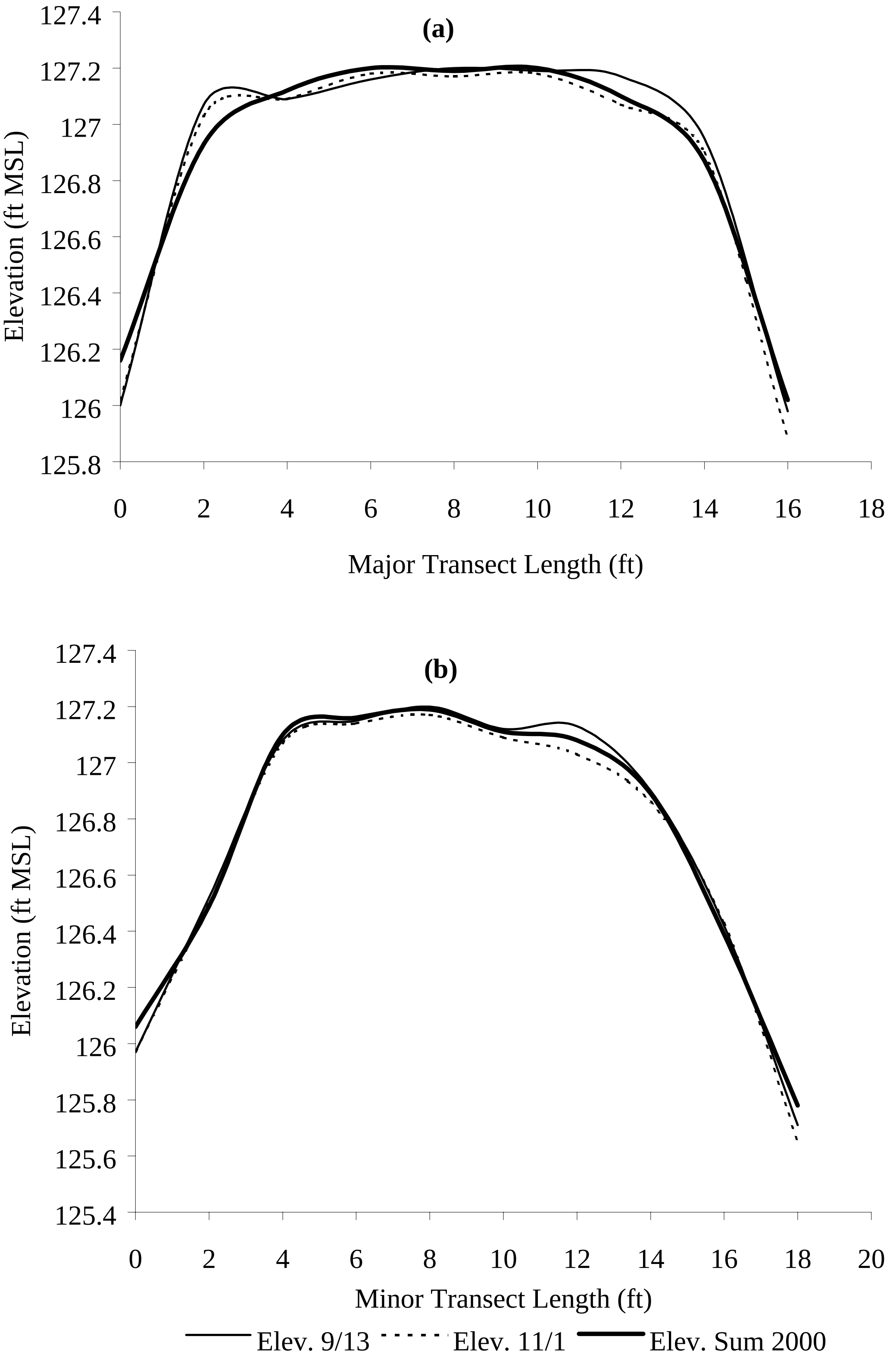


Figure 5A-30. Elevation Along Major Transect (a) and Minor Transect (b) on Cargill Hummock 12.

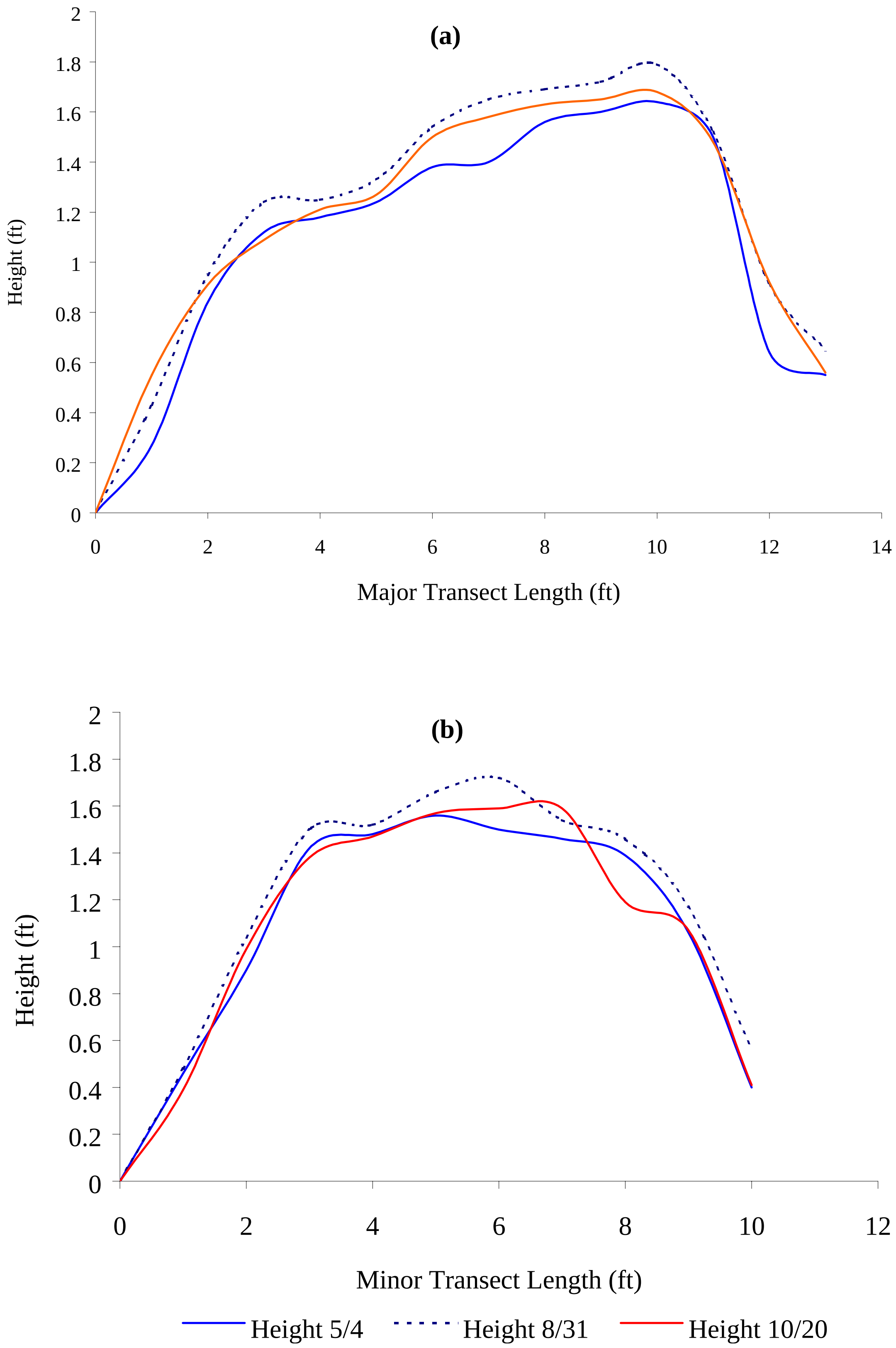


Figure 5A-31. Elevation Along Major Transect (a) and Minor Transect (b) on Iluka Resource Hummock 1.

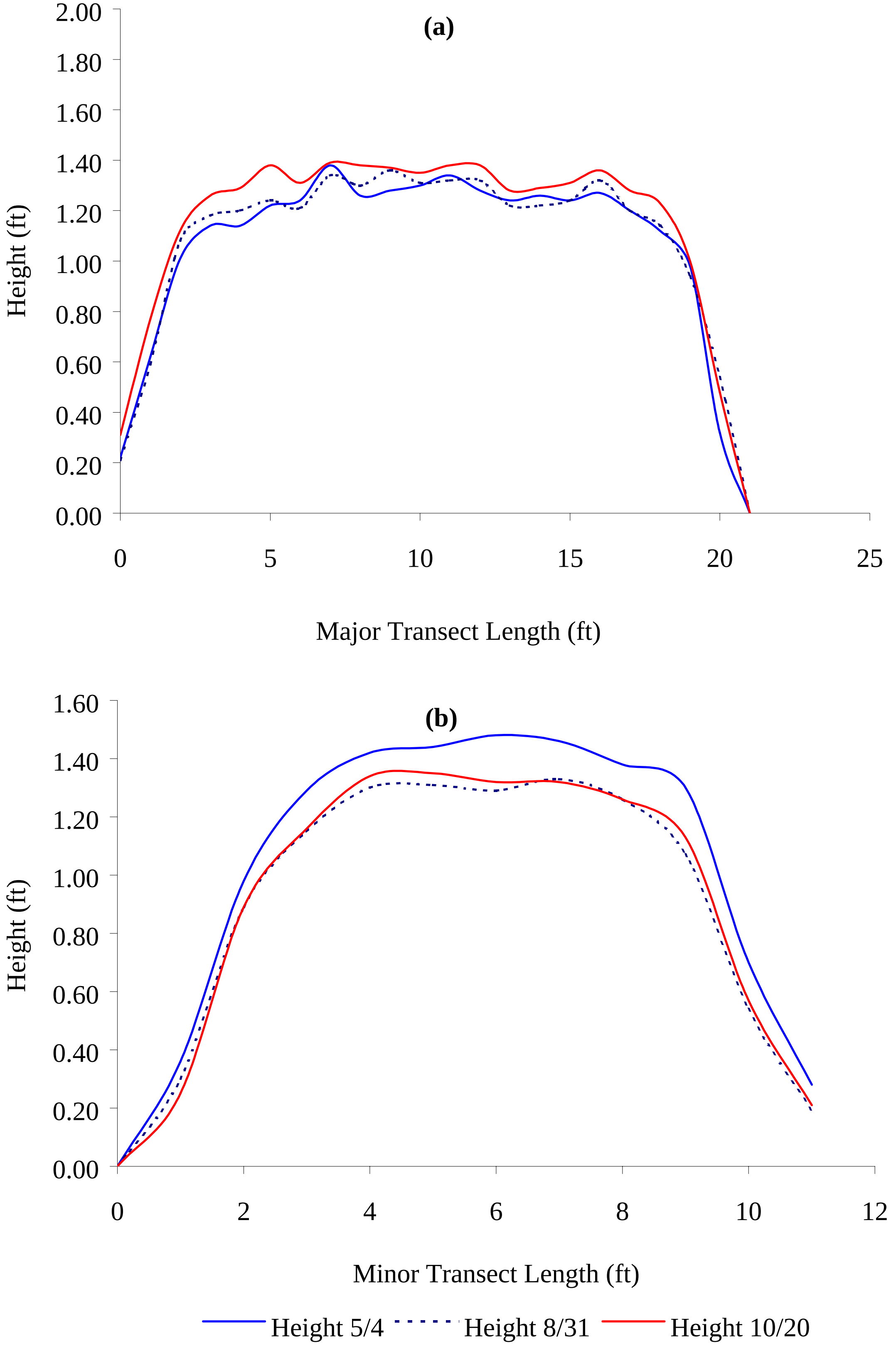


Figure 5A-32. Elevation Along Major Transect (a) and Minor Transect (b) on Iluka Resource Hummock 2.

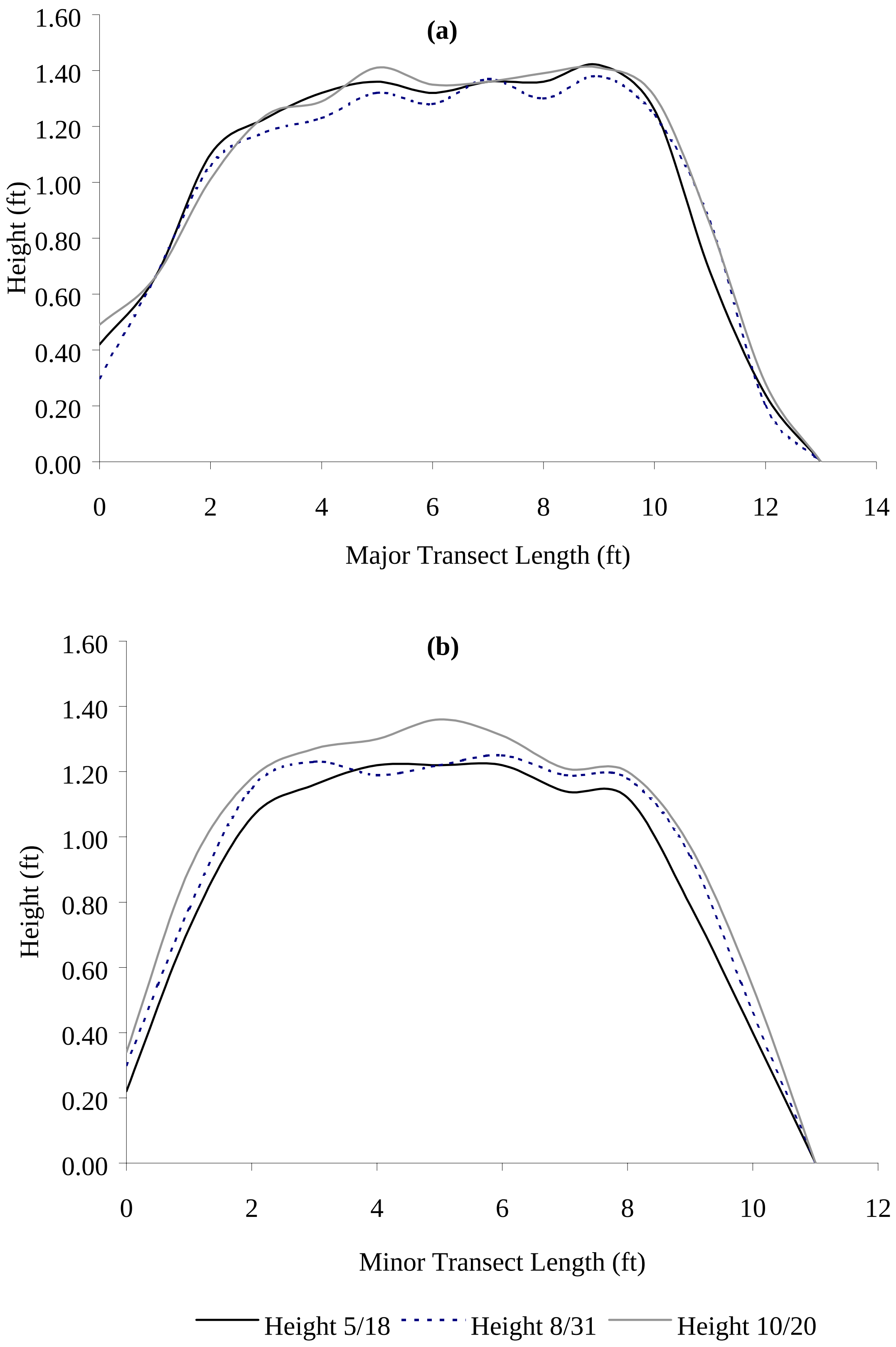


Figure 5A-33. Elevation Along Major Transect (a) and Minor Transect (b) on Iluka Resource Hummock 3.

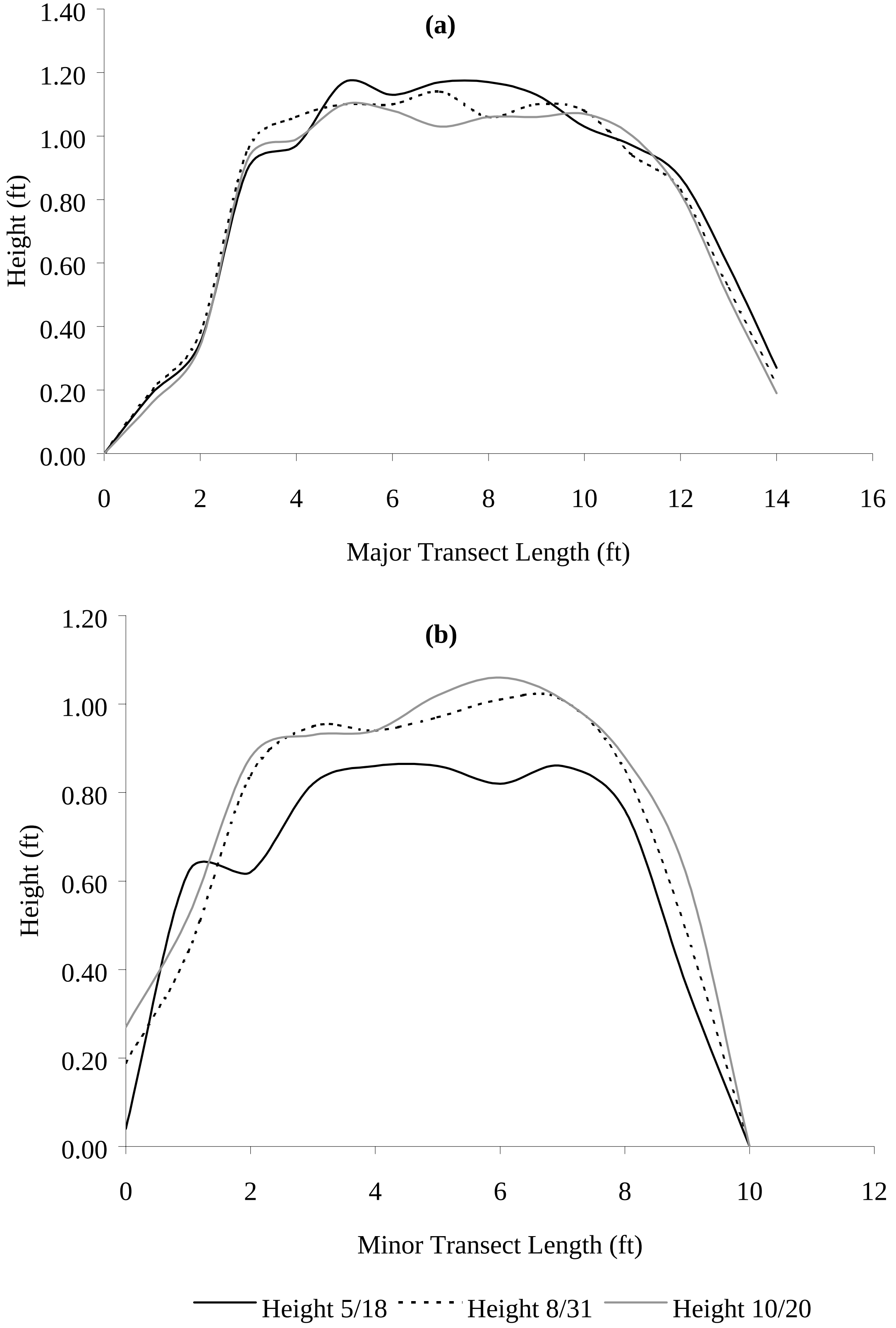


Figure 5A-34. Elevation Along Major Transect (a) and Minor Transect (b) on Iluka Resource Hummock 4.

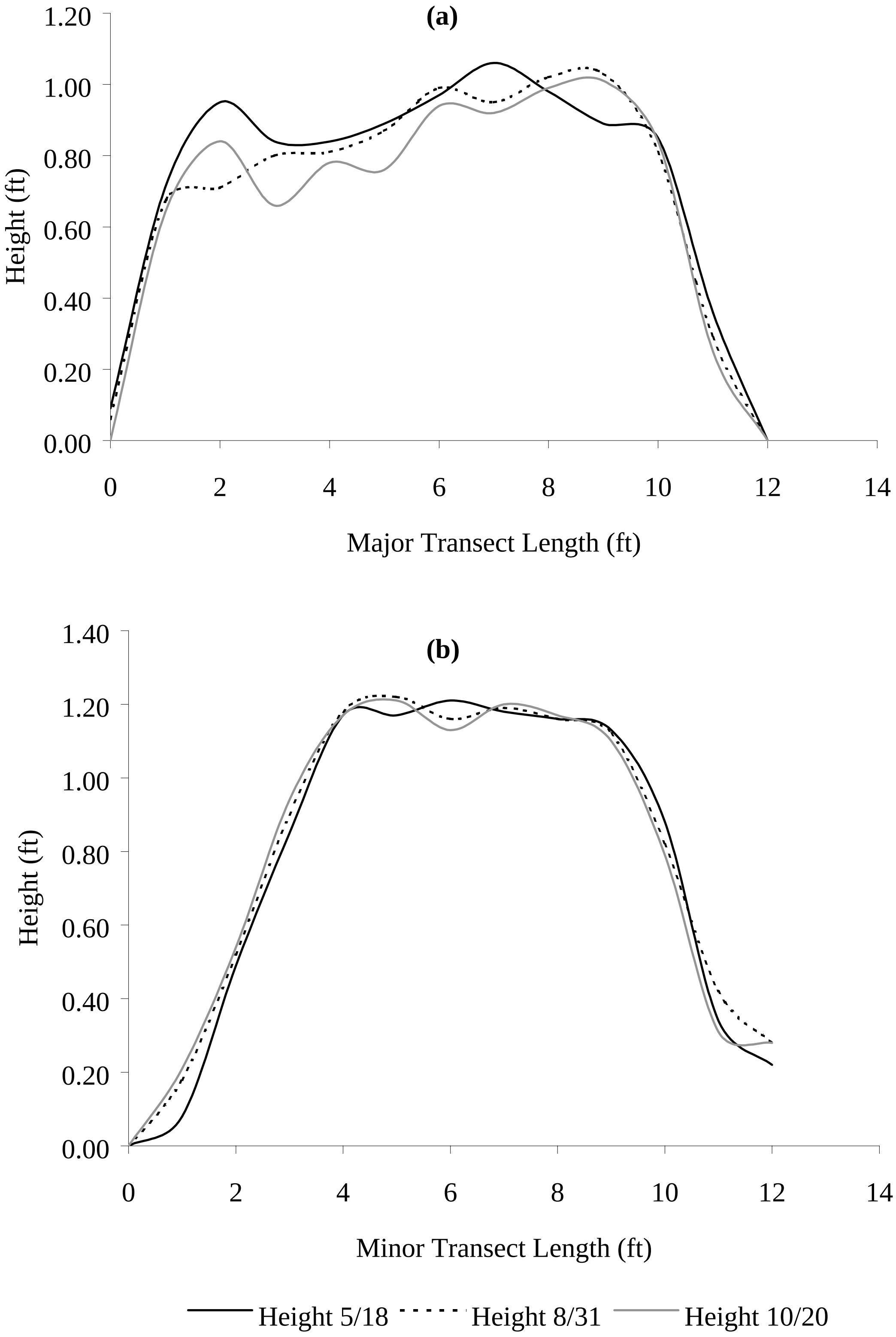


Figure 5A-35. Height Along Major Transect (a) and Minor Transect (b) on Iluka Resources Hummock 5.

APPENDIX 5-B

VOLUMETRIC WATER CONTENT AT ILUKA RESOURCES WETLAND

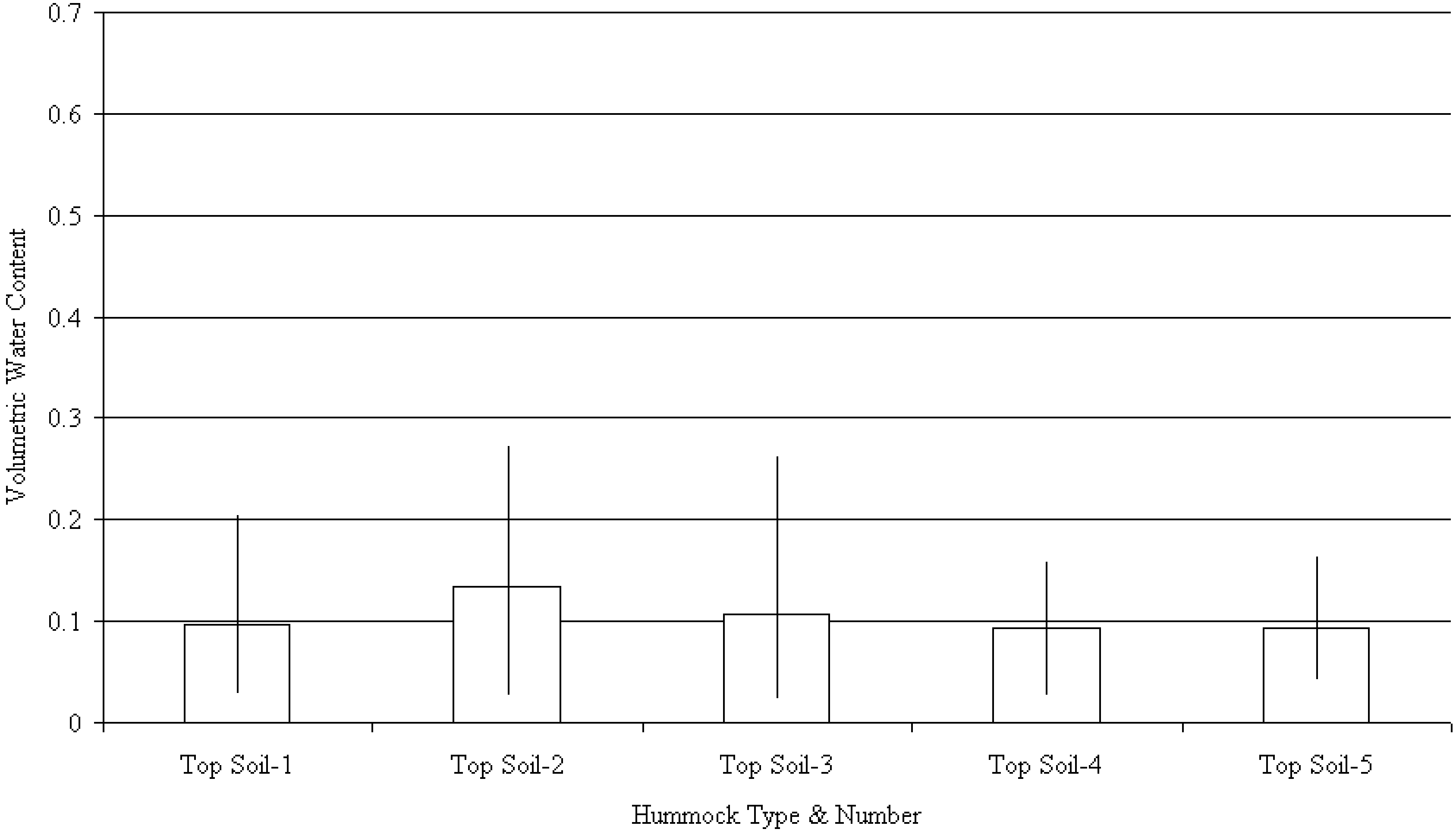


Figure 5B-1. Values for Average Volumetric Water Content Plotted with Minimum and Maximum Values for Each Hummock in the Iluka Resources Wetland on May 4, 1999.

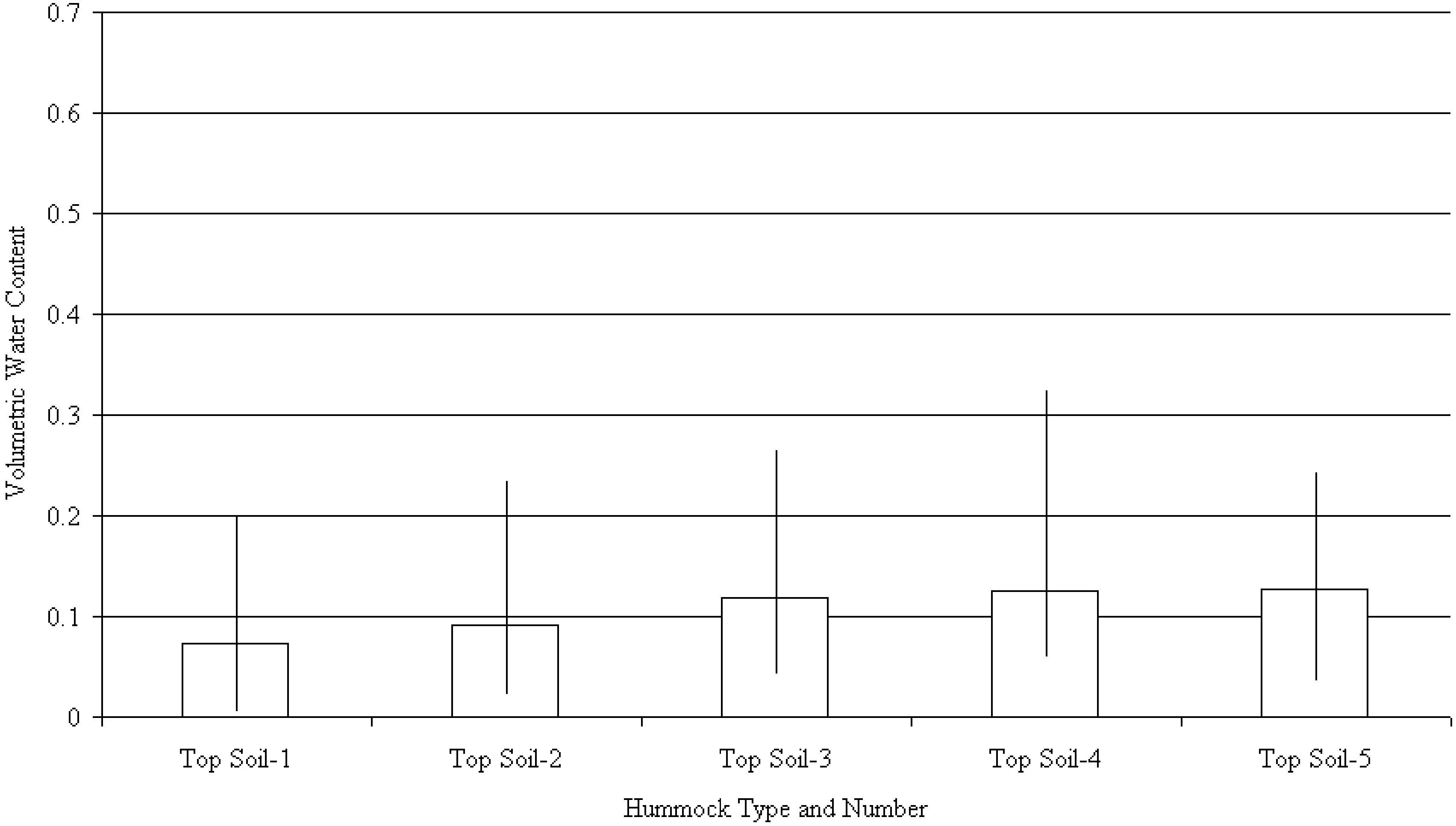


Figure 5B-2. Values for Average Volumetric Water Content Plotted with Minimum and Maximum Values for Each Hummock in the Iluka Resources Wetland on August 31, 1999.

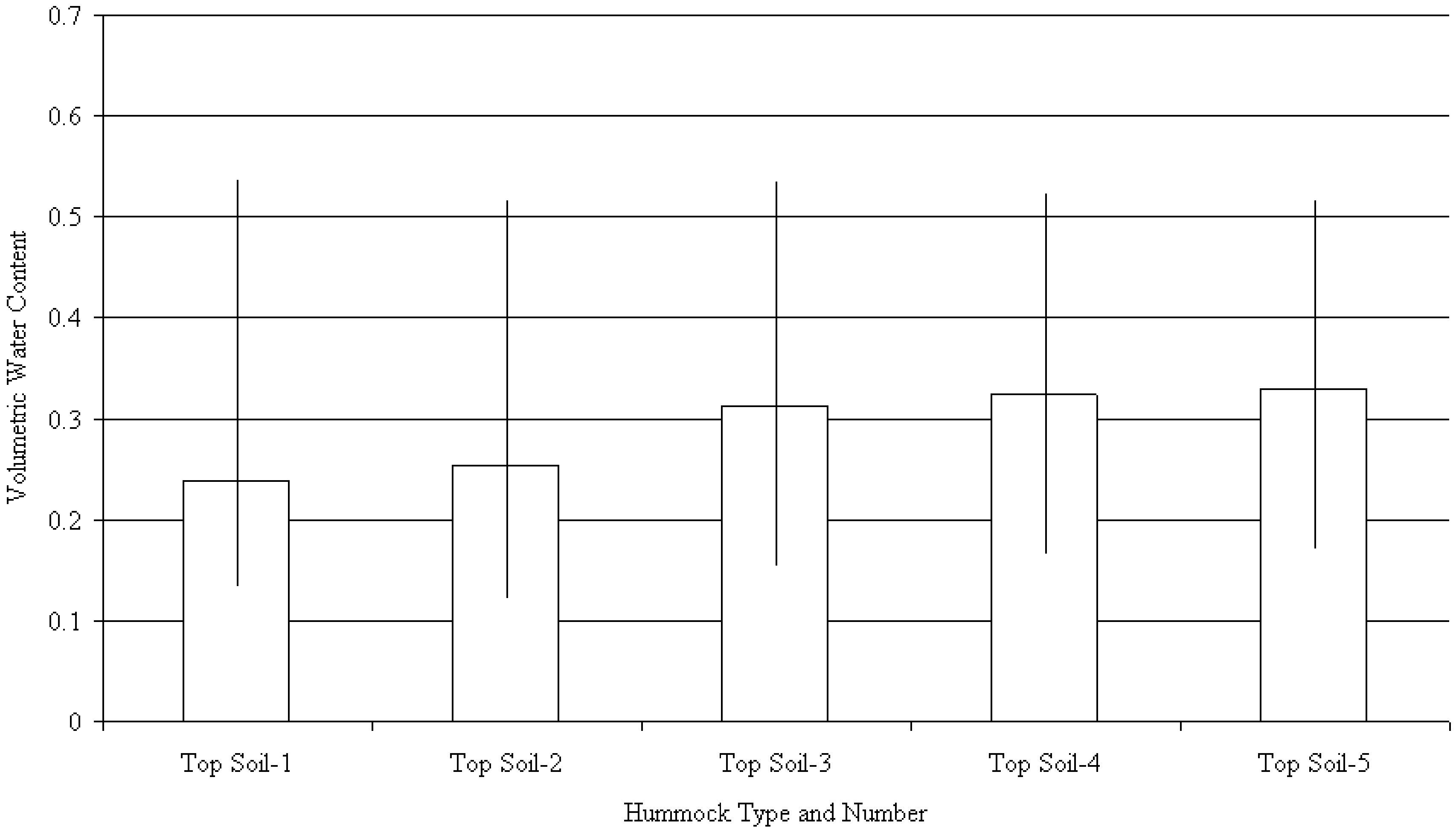


Figure 5B-3. Values for Average Volumetric Water Content Plotted with Minimum and Maximum Values for Each Hummock in the Iluka Resources Wetland on October 20, 1999.

CHAPTER 6

THE ROLE OF VINES IN THE SUCCESSIONAL DEVELOPMENT OF CONSTRUCTED RECLAIMED FORESTED WETLANDS IN THE CENTRAL FLORIDA PHOSPHATE DISTRICT

Kelly Chinners Reiss

INTRODUCTION

STATEMENT OF PROBLEM

The ecological role of vines has long been debated. Their interplay within ecological systems at times is suggested to be beneficial and at times to be detrimental to competing vegetation and overall system development. Vines occur in most forested ecosystems from the temperate zone to the tropics, and their presence in all types of forested systems suggests that they may play some beneficial roles. Even forested wetland ecosystems have vines, which tend to be rooted on hummocks or at the upland ecotones of the wetland since most vines do not tolerate inundation and soil saturation. Vines build organic matter and process nutrients that may benefit late successional tree growth and development. Hence, without vines forested wetland systems may take longer to reach a successional climax.

Vines often appear to be more prevalent in early successional systems, and are more visible in areas dominated by aggressive introduced vine species. Yet, there is little scientific documentation of the prevalence and effects of vines (either native or introduced) in early successional ecosystems, especially forested wetland ecosystems. Nor is the persistence or successional trends in vine species as ecosystems develop well documented.

Newly constructed landscapes, such as those that result from reclamation of phosphate mined lands in central Florida, offer the potential to study the role and interactions of vines within the developing ecological community. Along with native vines, there are several non-native species that have been recorded in reclaimed landscapes. By studying reclaimed landscapes of various ages, it may be possible to answer the following questions:

Are vines detrimental to the development of newly constructed landscapes? Do vines interfere with or enhance ecological succession and community development? As ecosystems develop, do vines persist? Do vines exhibit successional trends, where different species are dominant during different stages of forested wetland succession? Are there specific environmental conditions that favor vine dominance?

In this research, the occurrence, persistence, and successional trends of vine species in newly constructed landscapes were studied on forested wetlands reclaimed over the past two decades. By studying different aged sites (a chronosequence design), the changes in species abundance of vines at different successional stages may be evaluated. By studying where and under what biotic and abiotic conditions vines seem to dominate, a better understanding of the ecological characteristics that favor vines can be developed. Finally, by studying vines in newly constructed forested wetlands, including their persistence and successional tendencies, it may be possible to gain understanding of their role in ecosystem processes, determine if they are a problem in newly constructed landscapes, and suggest management strategies if they are.

REVIEW OF THE LITERATURE

Vines and Lianas

Little research is available on vines in reclaimed landscapes in Florida. Most of the research on vines has focused on lianas (woody vines) in tropical systems. Additionally, research on the long-term succession characteristics of reclaimed forested wetlands and the role vines play in these systems is lacking.

Beneficial and Detrimental Roles of Vines

Throughout the southeastern United States, vines comprise an important biomass component of many disturbed and undisturbed, dry, mesic, and wetland forests (Collins and Wein 1993). Gough and Grace (1997) noted the important role that vine species seem to play in the development of the Louisiana wetland communities they studied, and Bush and others (1995) identified the influences vines have on tropical forested communities, both beneficial through rapid carbon and nutrient cycling and detrimental causing death on an individual tree basis. Vines play many roles within forests, and their importance to the environmental system has yet to be documented. In fact, little research has examined the effects of vine species on whole communities, except as part of larger removal experiments (Gough and Grace 1997). Little research exists on the presence or role of vines in Florida.

Some of the most complete work on the successional role of vines was done on the Krakatau Islands of Indonesia where Bush and others (1995) noted the contributions vines make to carbon and nutrient cycles and forest soil formation. Additionally, Putz (1995; 1990; 1984) and Putz and Chai (1987) investigated the role of vines and community structure in tropical rainforests. Putz (1984) identified various ways woody vines of tropical rainforests influence tree growth and mortality rates. These included:

1) Competition for light,
2) Weighing down tree crowns and increasing mechanical strain,
3) Increasing the number and size of tree falls, and
4) Increasing the stability of individual trees by binding trees together.

The dominance of vines in forest gaps (whether natural or created by humans) may appear harmful to individual trees, but it is unclear if the forest as a whole is negatively affected by the death of individual trees and the presence of vines. Bush and others (1995) documented the detrimental effects vines have on an individual tree, but did not establish what role vines play within the forested community as a whole. Putz (1995; 1984) and Putz and Chai (1987) found that trees hosting woody vines have higher mortality rates than vine-free trees, and that in disturbed areas, woody vines decrease regeneration growth rates of trees and mechanically damage host trees. Additionally, Hegarty (1991) noted that host trees might exhibit reduced leaf area and changes in fecundity due to the presence of vines. Also, downward translocation in trees may be inhibited by the presence of twining vines on tree trunks.

Vines may have a number of effects on nearby plants, including competitive suppression by means of shading, below ground interactions through roots (Dillenburg and others 1993a; Putz 1988; Whigham 1984), physical interference of growth, and increased fecundity of supporting plants (Gough and Grace 1997; Hegarty 1991; Stevens 1987). An important factor affecting growth rates of all plant species is shading, and the numerous overlapping layers of vine leaves within a forest can lead to increased shading to the lower vegetative layers (Larcher 1980).

Compared to trees, vines are believed to be extremely competitive since they occupy considerable space compared to their biomass quantity. Additionally, vines appropriate larger quantities of resources to leaves and smaller amounts to stems, and they have longer internodes and less structural stability (Collins and Wein 1993; Putz 1988). These characteristic growth habits of vines are well adapted to resource exploration in the varied forested systems they inhabit (Castellanos and others 1992). In effect, vines feedback benefits to themselves by increasing their leaf area through allocating available resources to leaf production. This enables more sunlight to reach them allowing for increased photosynthesis and growth. Thus, as a competitive advantage, vines can increase their chances of success by using all suitable microenvironments (Baars and Kelly 1996).

The type of light environment significantly affects vine physiology and leaf structure (Kozlowski and others 1991). In general, vines are considered light demanding (such as vines in the genus *Clematis*), as a high light environment is essential at least throughout vine establishment (Boring and others 1981; Putz 1984). This explains why forest margins characterized by high disturbance and high light levels are commonly dominated by vines (Putz 1988). In fact, site disturbance often leads to an abundance of vine growth (Webb 1958; Putz 1988; Putz 1984).

Hommel (1987) suggested that vines might have prevented forest re-colonization on some abandoned fields on Krakatau, thus leaving the system in a scrub state of arrested succession. Bush and others (1995) disagree, suggesting that vines do not appear to have limited forest regeneration on Krakatau. In fact, they concluded that the detrimental effects of vines are certainly more obvious and prevalent on an individual tree basis than for entire communities. While Bush and others (1995) did not specifically support the theory that vines play some significant and beneficial role in succession of forested systems, they did not find any evidence against this theory. In fact, Friedland and Smith (1982) found that herbaceous vegetation rooted within experimental quadrats with vines actually grew taller and had greater mean overall dry biomass weights suggesting an increased growth rate of herbaceous vegetation when growing in competition with vines.

In a removal and fertilization experiment on the effects of competitive suppression by vines, Gough and Grace (1997) found that fertilized plots, containing both vines and other vegetation, displayed no overall change in species richness or non-vine vegetative biomass accrual. Additionally, they found that non-vine vegetation biomass increased in sites where vines were removed, but that no significant change occurred in species richness. However, this contradicts Friedland and Smith's (1982) findings for herbaceous vegetation.

Whigham (1984) also performed a removal experiment using the hardwood tree *Liquidambar styraciflua* (sweetgum). He found increased tree growth associated with release from below ground vine competition. However, when the above-ground vine biomass was removed from the trunks and crowns of trees without uprooting the vines, *Liquidambar styraciflua* showed no improvement in growth.

Successional Trends of Vines

Some researchers have theorized a shift from herbaceous to woody vines in forested ecosystems over time, and others have suggested that the climbing mode of vines can be used as an estimation of forest maturity (Bush and others 1995; Putz and Chai 1987). In highly disturbed tropical forests and in early successional forests tendrillar species are abundant. As forests mature, the abundance of twining species and root climbers increases proportionately. Carter and others (1987) found that tendrillar vine species are better adapted to climb the structures typical of closed canopy deciduous forests, and are physiologically better adapted to low-light conditions than other vines that have a variety of other climbing mechanisms. Considering the physiological adaptations of early- versus later-successional plants, Carter and others (1987) suggest that physiological performance on disturbed sites might be reduced for the tendrillar vine species as opposed to the non-tendrillar vine species.

Vines are frequently associated with heterogeneous light habitats such as gaps, forest margins, or canopy irregularities (Collins and Wein 1993), yet vines and trees often have a close association because of the vine's reliance on host canopies (Dillenburg and others 1993b). This suggests that a difference exists in the vine species present in high light environments versus those growing in association with trees in closed canopied forests.

In a study of temperate New Jersey Pine Barren swamps, Ehrenfeld (1983) found that a large number of the species invading disturbed areas were vine species. This suggests that vine species are active pioneer species following many forms of disturbance. Baars and Kelly (1996) found that vines could be particularly aggressive on sites when they become naturalized. Vine species also increase in relative abundance on disturbed sites (Ehrenfeld 1983).

Edaphic Conditions Favoring Vine Growth

Bush and others (1995), Castellanos and others (1992), and Putz and Mooney (1989) agree that the rapid turnover time and the comparatively small quantity of stem tissue of vines make them a fundamental component in the carbon and nutrient cycling and forest soil generation. Bush and others (1995, p 365) found that in areas where vines occupy dense areas, "their leaf litter is likely to be important in the accumulation of soil organic matter."

Collins and Wein (1993) also found that soil moisture availability limits vine growth and distribution in mesic slope bottomland hardwood and seep forests in the southeastern United States. Vine density was highest in areas of intermediate soil moisture, and no vine species occurred in areas with exceptionally high soil moisture. Also, a clumping of vines and potential understory competitors was observed in areas with intermediate soil moisture conditions, suggesting that "the microenvironment, more than interspecific interactions, influences vine distribution" (Collins and Wein 1993).

Common Vines Occurring in Florida

One herbaceous vine found in forested wetlands in Florida is *Mikania scandens* (L.) Willd. (hemp vine), which often forms a dense blanket covering other plants due to its aggressive, climbing growth habit (Moon and others 1993). *Mikania scandens* is a twining vine (Carlquist 1992; Gentry 1992) that typically grows as a trailing vine along the ground, rooting at most nodes, and occasionally reaching the canopy (Gough and Grace 1997). Typically found along stream banks and in drainage ditches, *Mikania scandens* appears to be flood-resistant. Moon and others (1993) suggested that flooding might actually enhance *Mikania scandens* growth. However, there is no evidence that *Mikania scan*dens maintains underground structures over winter (Gough and Grace 1997), so profusions may be seasonal.

A second native non-weedy herbaceous vine found on reclaimed forested wetlands is *Clematis crispa* L. (leather-flower), which climbs by leaf tendrils that place curling touch sensitive petioles around supports (Gentry 1992; Teramura and others 1992; Carter and others 1987). Juvenile *Clematis* leaves curve downward, grabbing and twining around objects of suitable diameter that they contact (Darwin 1875). By increasing its number of leaves*,* *Clematis* increases the prospective number of attachment tips that it can use to climb into the canopy. However, *Clematis* is generally not a high-climbing vine mainly due to winter diebacks of the stems (Baars and Kelly 1996).

Apios americana Medicus (groundnut) in the Leguminosae Family (bean or pea) is an herbaceous twining vine also found on the reclaimed forested wetlands of central Florida (Godfrey and Wooten 1981). *Apios americana* primarily inhabits wet thickets, and it has nearly smooth, tuberous enlargements on the roots that are edible. Some authors place this vine in the genus *Glycin*e (Taylor 1992).

There are also numerous woody vine species found in natural forested wetlands. In one study on understory vines in mature southern hardwood hammocks, eleven vine species were reported. Three vine species *Vitis rotundifolia* Michx. (muscadine grape), *Smilax bona-nox* L. (bullbrier), and *Rhus radicans* (now recognized as *Toxicodendron radicans* (L). Kuntze, or poison ivy) were the most common and are natural components of most mature southeastern mesic slope bottomland hardwood and seep forests (Collins and Wein 1993). Jones and others (1994) found that *Vitis* spp. had lower survival (both absolute and relative to other species) in flooded versus in non-flooded sites, an indication that this vine group is relatively intolerant of flooding especially in the seedling stage (Jones and others 1994).

Vitis spp. and *Smilax* spp. use tendrils to grow into the supporting tree canopies and eventually to shade trees from sunlight (Gentry 1992; Teramura and others 1992; Carter and others 1987), and in Hernando County, Florida, *Smilax* spp. was noted to grow in moist areas (Beckwith 1968). On the other hand, *Toxicodendron radicans*, an adventitious-root climber (Teramura and others 1992; Carter and others 1987), generally does not overtop tree canopies. It is often profuse on more stable surfaces like tree trunks and large branches in the understory and on the forest floor (Carter and others 1987). Likewise, *Parthenocissus quinquefolia* L. (Virginia creeper), an adhesive root climber using tendrils with adhesive disks (Teramura and others 1992; Carter and others 1987), seldom dominates tree canopies despite its extensive ability for vertical growth (Beckwith 1968). In Fernando County, Florida, Beckwith (1968) found that *Parthenocissus quinquefolia* along with *Doxantha unguis-cati* (L). Miers. (catclawvine, some literature places this vine in the genus *Macfadyena*) and *Paederia foetida* L. (fevervine or skunkvine) commonly form thick mats over fallen trees and sometimes form solid mats over extensive portions of the forest floor.

Three vine species present at Turtle Mound in New Smyrna Beach, Volusia County, Florida, were *Mikania cordifolia* (L. f.) Wild. (climbing hempweed), *Passiflora incarnata* L. (purple passionflower), and *Smilax auriculata* Walt. (wild-bamboo or catbrier) (Norman and Hawley 1995). The vine cover was luxuriant and covered large portions of shrubby vegetation and canopy species, including the canopy tree *Celtis laevigata* Willd. (sugarberry). The high climbers included *Cissus trifoliate* L. (possum grape), *Parthenocissus quinquefolia*, and *Cynanchum scoparium* Nutt. (leafless Cynanchum or leafless swallowwort).

At Turtle Mound, Norman and Hawley (1995) found that winter freezes have presumably caused vegetation dieback on shell mounds, which they believed resulted in a general increased frequency of vine occurrence for both temperate and tropical species. They hypothesized that the reason was that many vines have rhizomes and underground tubers that can survive underground and resprout after periods of freeze (Norman and Hawley 1995). Other disturbances at Turtle Mound including boardwalk construction and continued removal of encroaching vegetation also may have stimulated the growth of vines.

Monk (1965) sampled 60 mixed hardwood forests in north central Florida. He found many vines species occurring throughout these sites. *Vitis rotundifolia* was found at 90% of the sites, followed by *Gelsemium sempervirens*, *Parthenocissus quinquefolia*, *Smilax bona-nox*, and *Toxicodendron radicans* being found at 81%, 80%, 79%, and 75% of the sites, respectively. Additionally, he found *Campsis radicans* on 37% of the sites and *Galactia elliotti* on 2% of the sites.

Ecosystem Succession

Ecosystem succession encompasses changes in the environment over time. While no unified theory of succession has been accepted, many have been hypothesized. Vines have been theorized to play an important role in succession, and a history of successional theory is provided below to further explain the possible role vines play in succession.

Cowles (1899) was one of the first to study vegetative succession. He described changes in vegetation over time on the dunes of the Indiana portion of Lake Michigan. Later, Tansley (1935) described succession based on the concept of ecosystems and vegetation in the landscape as a mosaic controlled by environmental factors including soil moisture, nutrients, topography, perturbations, and animal activity. Then in 1936, Clements defined succession as being a set path that ecosystems follow based solely on the prevailing regional climate and the physical conditions of the environment. Soon after, Lindeman (1942) described ecological succession as ecosystem based and controlled, placing an emphasis on the role of energy flow as expressed in trophic level structure.

Keever (1950) and Bormann (1953) based early successional theory on old field succession in the North Carolina piedmont, studying passive revegetation of disturbed lands. Then Egler (1954) discussed two separate models of succession. First, vegetation is replaced in a set pattern by specific vegetation and resists outside invasion. Second, the species that arrive first establish and remain on-site.

Gleason (1962) opposed Clement's successional theory but agreed with Egler's second model of succession. Gleason (1962) said that entirely different vegetation associations might occupy climatically identical sites. Basically, he theorized that species are organized along environmental gradients and that species existing together do so because they arrive together and endure the site conditions.

E. P. Odum (1969, 1971) restated classical successional theory as an orderly, reasonably directional, foreseeable process that results in alteration of the physical environment by the community and ending in a constant or climax ecosystem. He described succession as community-controlled, where the physical environment decides the pattern and rate of change within the ecosystem. He suggested that succession is not a simple clear-cut idea, but that multiple successional pathways are possible for any given ecosystem. He described succession as involving an interacting development of processes that often offset one another and physical limitations that can set restrictions on system development. At the next larger or regional scale, the system selects and supports those species that feed back energies and materials that maximize flow (Odum 1994).

Horn (1971, 1974) proposed that early successional species create an environment where later successional species are competitively superior. In essence, pioneer species prepare the way for the more complex structure of late succession (Odum and others 1997; Odum 1994; Rushton 1983). The organization of an ecosystem changes through time. Succession is an ever-changing procedure, developing structure and processing energy (Richardson 1988).

In its broadest sense, succession deals with the initial approach or return to a climax or steady state condition of a system from some non-climax state. Margalef (1968) termed this stage maturity. He defined maturity as relating only to those situations that start with low quantities of resource materials and species where time causes increases in these quantities in reaching a steady pattern. These resource materials appear in many forms including the accumulation of high quality matter and structure by ecosystems on land in the form of soil and partly in the vegetation structure of above ground biomass (trunks, branches, leaves), below ground biomass (roots, tubers), microbes, and animals.

Generally speaking, succession involves possible choices based on positive feedbacks that work toward maximizing power and useful transformation (H. T. Odum 1994; E. P. Odum 1971). Odum (1994) offers a bioenergetics view of ecological succession and self-organization that focuses on energy inputs and energy use by the developing system. This definition of succession emphasizes "useful" power resulting from the physical structure being built. This feedback energy acts as reinforcement and intensifies efficiencies and energy flows into the structure of the system. The efficiency of the maximum power principle at each successional stage emphasizes the advancement of natural succession. Rushton (1983) hypothesized that when choices are limited, ecosystem development decreases, and stress on the ecosystem delays the timely evolution of new components when inflowing energy sources are limiting.

The theory of maximum power suggests that systems organize based on efficiency and speed of energy use (Odum and others 1997). The maximum power principle is a basis for the control of self-organization and implies that the combination of components that contribute most to the total structure of their ecosystem prevail due to internal feedbacks (Odum 1994). Additionally, efficient systems add to the larger scale systems to which they belong (Odum and others 1997). In order for a system to follow the maximum power principle, it must develop mechanisms that build structure to capture the largest amount of energy possible (Richardson 1988). In essence, the theory of maximum power supports survival of those groups of components that contribute the most to the ecosystem (Odum and Odum 1996), and system designs succeed that capitalize on resource use, productivity, and feedback (Odum 1971; Odum 1994; and Odum and Pinkerton 1955).

Odum (1994) defined succession as the use of available resources (such as sunlight, rainfall, nutrients, etc.) in the self-organizational progression by which ecosystems become established, develop structure and processes, and sometimes retrogress. Self-organization involves the cooperation among various parts of a system succeeding due to the positive returns for their actions (Odum and others 1997). Rushton (1983) hypothesized that through self-organization, natural systems are able to adjust to changing situations.

During periods of early succession, gross production is insignificant, as a sufficient nutrient/mineral cycle has yet developed. The initial storage levels within a system drive early successional trends. An increase in biomass is one of the effects of net production early in succession. There is also a net accumulation of organic matter in the early phase of ecosystem succession (Odum and others 1997).

Odum (1994) suggests the most important measures of succession may not be net production or biomass, but rather gross production and total respiratory metabolism. The species most adapted to these early successional stages are those that grow rapidly, actually over-growing other species, cover more surface area, and occur in systems with low species diversity (Odum and others 1997). These early successional species are also called pioneer species or colonizers, but may also be identified as weeds. Pioneer species have frequently low-grade, temporary, and wasteful structures that permit extraordinary growth rates, but do not use growth energies for structure development. As long as available resources are prevalent, early successional species will prevail (Odum and others 1997).

In reclaimed forested wetland systems, successional theory might define herbaceous vines as early successional species, rapidly creating organic matter and available nutrients that help prepare the ecosystem for the later successional species. Odum (1994) suggests that in ecological succession, the smallest components with rapid turnover times evolve, or that species replace each other through successional time. In other words, herbaceous vines have faster turnover times than species allocating more resources to woody, permanent structure. A shift from herbaceous vines (with predominantly leaf structure) to woody vine species (which allocate some resources to woody stem structure as well as leaf structure) occurs. This adaptation, or "evolution" is in response to the reorganization and growth of the larger, later successional tree species.

More efficient, specialized species begin to replace pioneer species in later successional stages (Odum and others 1997). Gross production, biomass, and diversity are maximized in these later successional stages, and species diversity increases, which enhances system stability. In other words, as the system matures, the resources are used more efficiently as maintained by the maximum power principle. Succession usually deals with the efficient use of resources and the development of patterns in the structure and operation of the system. In simpler terms, E. P. Odum (1969) and H. T. Odum (1994) described ecological succession as the organizational process by which an ecosystem develops structure over time.

In Richardson's (1988) production-consumption computer simulation model, the ecosystem did not develop to a steady state when early successional species were at low levels. However, when some threshold initial condition of early successional species existed, sufficient structure was built, and the ecosystem proceeded to a steady state. Late succession is described by decreasing herbaceous vegetation, increasing taller woody species, increasing organic matter accumulation, reduced light penetration due to canopy development, and possibly increasing species diversity. Systems adjustments to renewable or recurring sources drive late successional trends (Odum 1994).

Wetlands in Florida

Historically, some 8.2 million hectares, or 54% of the states surface, was covered by wetlands. By the 1980's, an estimated 4.5 million hectares remained (FDNR 1988, Shaw and Fredine 1956, Tschinkel 1984), and in 1990, Dahl reported that Florida had only 3.8 million hectares of wetlands. Annually Florida losses 162,000 hectares of wetlands, while gaining only 10,000 hectares. With an annual decrease in the total hectares of wetlands coverage in Florida, it is thought to be critical that the phosphate industry successfully reclaim mined lands as wetlands.

Constructed wetlands provide many services to the environment, including mitigating for losses of wetlands, restoring or replacing degraded wetlands, reducing the impacts of activities in or near wetlands, treating surface and wastewaters, providing habitat for wildlife and waterfowl, and supporting aquaculture (Best and others 1997). All wetland ecosystems, both constructed and native, have structural and functional values including:

1. High net primary productivity,
2. Providing wildlife habitat,
3. Providing recreational and research opportunities,
4. Retaining nutrients, sediments, and toxins
5. Protecting shorelines
6. Attenuating peak flows of surface water

7. Recharging the Floridian aquifer
8. Atmospheric gas exchange, and
9. Nutrient cycling.

These ecosystem values suggest the importance of wetlands construction and reclamation for the maintenance of environmental integrity throughout Florida (Best and others 1997). Determining the role of vines within developing forested wetland systems is important in these constructed systems. If vines are preventing forest development, then control measures should be implemented. However, if the occurrence of vines benefits successional development than control measures would delay forest development.

Other important topics pertaining to the processes involved in wetland construction include reclamation and restoration, pertinent legislation, and phosphate mining. A brief literature review of these topics is available in Appendix A.

Systems Modeling

Models are useful tools to identify patterns in system development. Systems modeling has a long history of computer simulations showing succession. Burns (1970) and Regan (1977) each created successional models at the ecosystem scale. These models showed the automatic transfer of energy from developing the short-term rapidly charging feedback loop first (such as pioneer species and herbaceous vines) to the longer time cycle that develops structure more slowly (such as vegetation developing structure). These shifts in energy were based on the distribution of time constraints, so that as time increased the ecosystem matured. This is important because time is a large constraint when releasing sites in the central Florida phosphate district. Models by Noon (1996), Bersok (1986), and Gutierrez and Fey (1980) and have also focused on succession.

Jackson (1999) developed a model based on the interactions within forested wetland succession after phosphate mining in central Florida. It looked specifically at the competition between pioneer and late successional species. Results of the simulation suggested that pioneer species are important for development of late successional ecosystems, and that without such pioneer species climax stages may be delayed by as much as 50 years.

Ecosystems develop complex, dynamic patterns in time and space (Richardson 1988). Throughout the literature, there are many computer simulation models that consider the organizational processes and long-term successional changes facing ecosystems. These models are often calibrated with field data in order to reflect real ecosystems. Odum (1994) suggests that succession can be measured by growth curves of the main parameters of the ecosystem, including but not limited to live biomass, nutrient storage, total organic matter storages, diversity, web parameters, total metabolism, and total energy receptor quantities. As succession progresses, there is typically a growth of total biomass, an increase of nutrient storage, and an increase in species diversity, until the stage when further growth stops, the climax or steady state (Odum and others 1997).

PLAN OF STUDY

This research, funded by the Florida Institute of Phosphate Research (FIPR), focused on quantifying the areal extent, dominance, and persistence of vines on reclaimed phosphate mined lands using two different sampling designs. The research concentrated on growth characteristics of vines, conditions favorable for their growth, and their persistence over time. The systems studied were constructed forested wetlands undergoing primary succession (Figure 6.1). The general systems diagram shows the driving energies of sunlight, wind, rain, surface and ground water, nutrients, and seed dispersal contributing to the development of storages of herbaceous vine biomass, woody vine biomass, tree biomass, wetland soil, water storage, and wetland “architectural” structure. Important pathways include the competition for sunlight and nutrients between herbaceous vines, woody vines, and trees.

Sampling was adopted to answer three main questions:

- Do vines interfere with or enhance ecological succession and community development?
- Do vines exhibit successional trends, where different species are dominant during different stages of forested wetland succession?
- Are there specific environmental conditions that favor vine dominance?
-

A chronosequence sampling design allowed for random sampling to determine what percent of the landscape vines occupied. Nine wetlands were sampled, and fieldwork included collecting both abiotic and biotic data to evaluate biophysical conditions for growth, extent of area dominated by vines, and potential management alternatives. An intensive sampling design of areas dominated by vines was conducted to answer the question of what environmental conditions favor vine growth. Six wetlands were sampled, and fieldwork involved collecting both abiotic and biotic data including the percent herbaceous vegetation cover, sunlight transmittance, vine biomass, and soil characteristics.

Data collected in the field were incorporated into a computer model of forested wetland succession. The model included tree, woody vine, and herbaceous vine biomass storages competing for sunlight and nutrients. The model was used to test theories of the role of vines in early successional wetland environments.

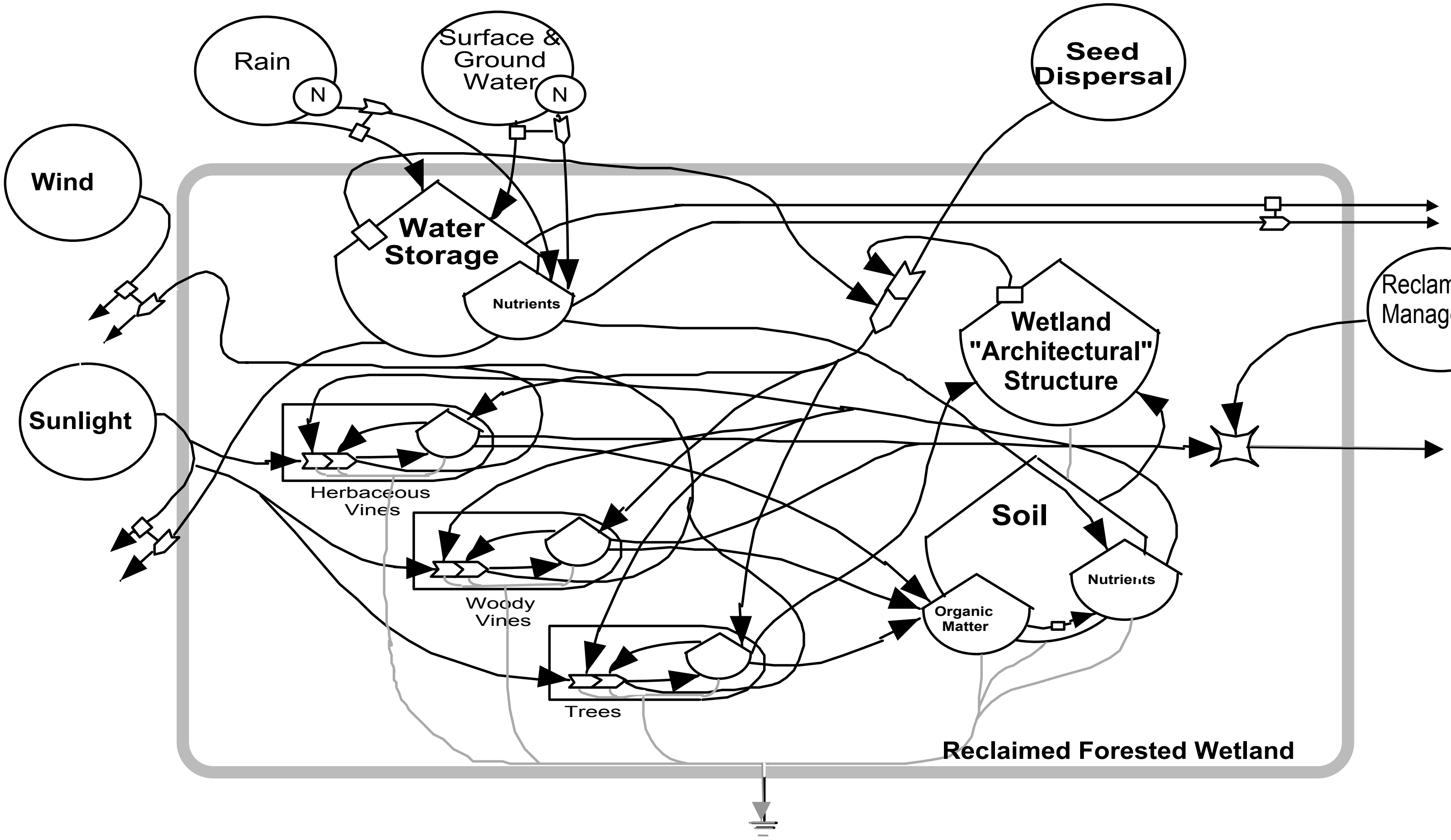


Figure 6.1. Energy Systems Diagram Showing Characteristics of Reclaimed Forested Wetlands, Highlighting Interactions Between Both Herbaceous and Woody Vines and Other Components within the Wetland Systems Boundary.

METHODS

Data on the occurrence of vines and physical and biological conditions under which they grow were collected from constructed wetland ecosystems in the central Florida phosphate district. Field data collection was organized into two parts. First, a chronological sequence (chronosequence) of nine sites was studied, recording differences in physical and biological conditions to relate to the site dominance of vines. Second, intensive sampling of sites where vines were dominant and adjacent areas without vine dominance was conducted, measuring the same parameters. In the sections that follow, the first is "Description of Study Sites" including conditions at site establishment when available. The next two parts are organized under the main headings of "Chronosequence Sampling Design" and "Intensive Sampling Design" reflecting the two parts of the field data collection. The fourth section with the heading, "Data Analysis" gives details of the methods used to analyze collected field data. The fifth section, "Simulation Modeling" provides the methodological approach to computer simulation of a successional model that includes vines.

DESCRIPTION OF STUDY SITES

Figure 6.2 shows the location of each study site, and Table 6.1 provides a summary of the study sites described below.

Cargill LP2-Phase 1 (referred to as LP2-Phase 1) is located at the Fort Meade Mine. It is a fringing forested wetland, with no standing water (0 cm water depth) at the time sampled. Sand tailings were the primary soil substrate covered with mulch/muck. It had not been treated for the control of nuisance species. The area sampled was planted in early 1998 with several tree species; however, a species list was not available. Sampling occurred in August of the first growing season in 1998.

IMC-Agrico FGGSB2 (referred to as Super Hummock) is a 15.6-hectare depressional wetland bordering a tributary of the Alafia River. It is located at the Fort Green Mine. During construction, large hummocks were created with muck, and sampling occurred randomly both on and off of the hummocks. The wetland depressional areas are comprised of sand tailings, with a mulched layer on top. Water depth at sampling ranged from 0-3 cm. The site was herbicided to control *Ludwigia peruviana* (L.) Hara. (primrose-willow) after sampling in 1998. Canopy species planted include *Acer rubrum* L. (red maple), *Carya aquatica* (Michx. F.) Nutt. (water hickory), *Catalpa bignoides* Walt. (cigar-tree), *Fraxinus caroliniana* Mill. (pop ash), *Gordonia lasianthus* (L.) Ellis. (loblolly bay), *Liquidambar styraciflua* L. (sweet gum), *Magnolia grandiflora* L. (southern magnolia), *Magnolia virginiana* L. (sweetbay), *Nyssa sylvatica* Marsh. (black gum), and *Taxodium distichum* (L.) Rich. (baldcypress). *Cephalanthus occidentalis* L. (common buttonbush) was the only shrub planted, and no herbaceous species were planted.

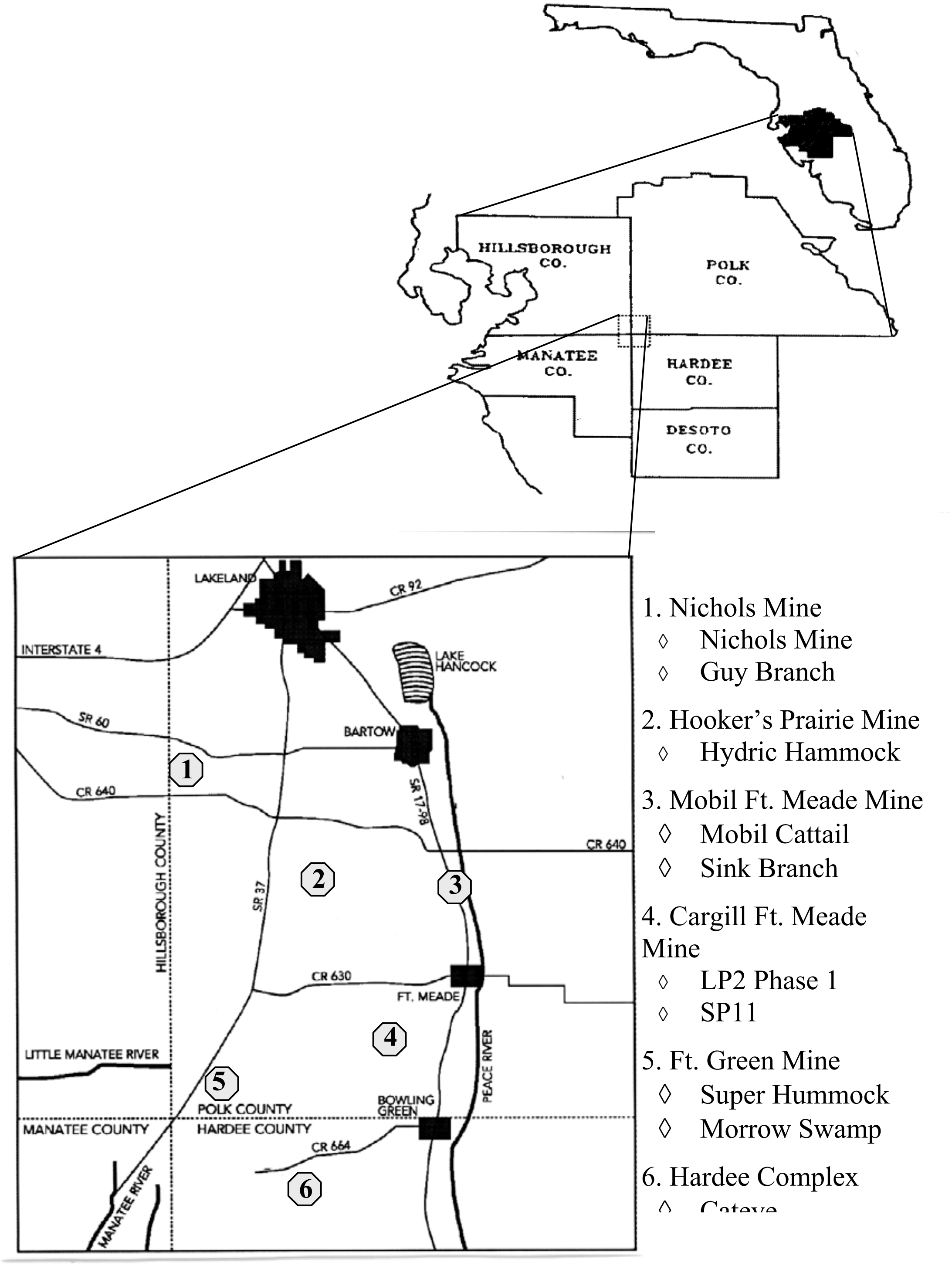


Figure 6.2. Locator Map of the Central Florida Phosphate District. Each Study Site is Located According to Phosphate Mine Location (FIPR 1997).

Table 6.1. Site Descriptions of Research Sites, Including Company Ownership, Mine Location, Year Planted, Age at Sampling, Area, Hydrology, Soils, Mulched, Understory Plantings, and Nuisance Species Control.

	Company Ownership	Mine Location	Year Planted	Sampling Date	Age at Sampling	Hectares	Hydrology	Soils	Mucked/ Mulched	Planting at Establishment	Nuisance Control
Chrono-sequence Sites											
LP2 Phase-1	Cargill	Fort Meade	1998	1998	0.5	- -	fringing	sand tailings	Yes	No	No
Super Hummock FGGSB2	IMC-Agrico	Fort Green	1996	1998	2	15.6	depressional	sand tailings	Yes	No	- -
Nichols Mine C07984	Mobil	Nichols	1993	1998	5	0.3	seepage	overburden	Yes	Yes	1997
Hydric Hammock HP5-P3	Cargill	Hooker's Prairie	1992	1998	6	0.8	fringing	- -	Yes	No	1992
East Farmland Cateye	IMC-Agrico	Phosphoria	1987	1999	12	- -	fringing	- -	- -	Yes	- -
FMSP11	Cargill	Fort Meade	1985	1999	14	- -	fringing	- -	Yes	- -	- -
Guy Branch - NSP1	Mobil	Nichols	1984	1999	15	- -	stream	- -	- -	- -	- -
Morrow Swamp - FG13	IMC-Agrico	Fort Green	1982	1999	17	60.7	depressional	sand tailings & overburden	Yes	- -	- -
Sink Branch	Mobil	Fort Meade	1980	1998	18	- -	stream	sand tailings & overburden	Yes	Speculated	No
Intensive Sites											
Nichols Mine C07984	Mobil	Nichols	1993	1999	6	0.3	seepage	overburden	Yes	Yes	1997
Hydric Hammock HP5-P3	Cargill	Hooker's Prairie	1992	1999	7	0.8	fringing	- -	Yes	No	1992
Land and Lake - Mobil Cattail FM6	Mobil	Fort Meade	1992	1999	7	- -	fringing	- -	- -	Yes	- -
CFI Primrose	CF Industries	Hardee Complex	1992	1999	7	- -	stream	- -	No	No	1997
East Farmland Cateye	IMC-Agrico	Phosphoria	1987	1999	12	- -	fringing	- -	- -	Yes	- -
FMSP11	Cargill	Fort Meade	1985	1999	14	- -	fringing	- -	Yes	- -	- -

Agrifos Consent Order 7984 (referred to as Nichols Mine) is a 0.3-hectare seepage wetland located in Agrifos' Nichols Mine. It was planted in 1993 and is adjacent to the 25-year floodplain of Thirty Mile Creek, a tributary of the North Prong of the Alafia River. The primary water inputs to this seepage wetland include groundwater seepage, rainfall, and runoff from the surrounding pasture uplands. The water depth ranged from 0-12 cm. Clayey overburden soil was used in construction to simulate a hardpan. The site was mulched prior to understory planting, with nuisance species control occurring in 1997. Canopy species planted include *Acer rubrum*, *Fraxinus caroliniana*, *Ilex cassine* L. (dahoon holly), *Magnolia virginiana*, *Myrica cerifera* L. (wax-myrtle), *Nyssa sylvatica*, *Persea palustris* (Raf.) Sarg. (swamp-bay), and *Taxodium distichum*. Shrubs planted include *Cephalanthus occidentalis* L. (common buttonbush), *Itea virginica* L. (Virginia-willow), and *Lyonia lucida* (Lam.) Koch. (fetterbush).

Cargill HP5-Phase 3 (referred to as Hydric Hammock) is a forested wetland sloping into a *Cladium jamaicensis* (sawgrass) marsh bordering a lake. Hydric Hammock is located on Cargill's Hooker's Prairie Mine. There was no standing water at the time of sampling. This 0.8-hectare fringing forested wetland was first planted in early 1992 with Acer rubrum, *Gordonia lasianthus, Ilex cassine*, *Liquidambar styraciflua*, *Magnolia virginiana*, *Persea palustris*, *Quercus laurifolia* Michx. (swamp laurel oak), and *Quercus nigra* L. (water oak). The only shrub planted was *Cephalanthus occidentalis*. *Magnolia vir*giniana was re-planted in 1992 due to poor species survival initially. No understory was planted.

Mobil MO10 FM6 Land and Lake (referred to as Mobil Cattail) is a fringing wetland planted in 1992. The mean water depth at sampling was 21 cm, with a range from 6 to 31 cm. The major tree species planted included *Taxodium distichum* and *Taxodium distichum* var. nutans (Ait.) Sweet (pondcypress).

The CFI Industries wetland (referred to as CFI Primrose) surrounds a stream. The water depth during sampling ranged from 0-2 cm. This site was never intended as a forested wetland, so no tree species were planted following site establishment. Accordingly, this site appears to be in a state of arrested succession, developmentally behind some sites, which are chronologically older.

Cargill East Farmland Cateye IMC31 (referred to as Cateye) is a fringing wetland located at the Phosphoria Mine. It had no standing water at the time of sampling (water depth 0 cm). This wetland was narrow, ranging from 15-40 meters wide and was constructed in 1987.

Mobil FM SP11 CAR 18 (referred to as SP11) is located at the Fort Meade Mine. It was planted in 1985 and is approximately 20-60 meters wide. SP11 had a depressional area through its middle perpendicular to the constructed lake it borders. At the time of sampling, there was no standing water (0 cm water depth).

Mobil Guy Branch MO3 NSP1 (referred to as Guy Branch) is the area surrounding a narrow stream located on Nichols Mine. This site is extremely wet, with the water level ranging from approximately 20-50 cm. It was planted in 1982.

IMC-Agrico Morrow Swamp FG13 (referred to as Morrow Swamp) is located on land owned and managed by Agrico Chemical Corporation at Fort Green Mine. This depressional wetland is adjacent to the floodplain of Payne Creek in southwest Polk County. This 60.7-hectare experimental wetland reclamation project was mined in 1978 and 1979. Reclamation construction ended in May 1982. The soils used in recontouring were a combination of sand tailings added to overburden piles. Revegetation techniques included the addition of topsoil mulching in several small patches, with seeding, planting, and natural invasion of wetland plants. Within the experimental area sampled, *Taxodium distichum* and *Taxodium distichum* var. nutans were planted in rows with equal spacing. These were the only two canopy trees planted in this particular area. This site is extremely wet with an average water level depth of 5 cm, with a range from 0-16 cm on the downward slope towards the fringing lake.

Mobil Sink Branch (referred to as Sink Branch) is a reclaimed stream planted in 1980. It is located on the Mobil Fort Meade Mine. During sampling two distinct stream channels were present creating an area of mixed obligated and facultative wetland species in the middle. Soils used in recontouring were a combination of different treatments including mulch, overburden, and/or sand tailings. Trees planted included *Acer rubrum*, *Fraxinus caroliniana, Magnolia virginiana*, *Pinus elliottii* (slash pine), *Quercus laurifolia*, *Quercus laevis* Walt. (turkey oak), *Quercus virginiana* Mill. (live oak), and *Taxodium distichum*. Possible understory species planted include *Panicum distichum* (maidencane), *Pontedaria cordata* (pickerel weed), and *Sagittaria* sp. (arrowhead).

CHRONOSEQUENCE SAMPLING DESIGN

Sampling in the chronosequence of sites was designed both to address the relative dominance of vines on phosphate mined lands and to determine how that dominance might change with community development. As a result, methods of data collection were designed to determine the presence and abundance of vines and the abiotic and biotic conditions that prevail where vines occur and do not occur.

Site Selection

Nine wetlands were selected representing canopy development from no canopy to completely closed canopy and an array of ages from 0.5-years to 18-years-old. Table 6.1 provides a brief description of physical characteristics and management history for each site, including site preparation, generalized wetland hydrology, species planted during construction, date of completion, and exotic/nuisance species management history. Site information was extracted from Bersok (1986), Best and others (1997), and on-site observations.

Sampling occurred between May 1998 and August 1999. Site selection began with available permit data from phosphate companies and included tours of possible research sites. The final selection was dependent primarily on site age and management history.

Elongated Quadrat Establishment

A minimum of 100 meters of elongated quadrats was established at each wetland site, with a minimum of two elongated quadrats established within each wetland. If time and resources were available, additional sampling was conducted. Each elongated quadrat was 6 meters wide. Elongated quadrats were located randomly along the perimeter of the wetland and ran perpendicular to the hydrologic gradient of the wetland. Unless otherwise noted, each elongated quadrat began in the upland/wetland ecotone margins and transitional areas and ran towards the middle of the wetland. Some wetlands were narrow, and the elongated quadrats ran through the wetland reaching the far transitional or ecotone areas of the adjacent uplands. At a random point along each 10 meter segment of the elongated quadrats, a 1 meter square quadrat was established in the middle of the elongated quadrat (Figure 6.3).

Vegetative Data Collection

Vines were identification to species, vine stems were counted, rooted vine basal diameter, was measured, above-ground biomass of vines was harvested, percent cover of understory vegetation recorded, and tree canopy cover was determined. Methods for each of these are described separately below.

Vine Species Identification

Within each square meter quadrat, all vines were identified to family, genus, and species when possible. Certain vines that were flowering or had seed heads could be identified to species. Species identification relied on numerous sources including: Alden and others (1998), Foote and Jones (1998), Carlquist (1992), Gentry (1992), Hegarty (1992), Hegarty and others (1992), Lee and Richards (1992), Teramura and others (1992), Wunderlin (1982), and Godfrey and Wooten (1981). To be counted as being present within the square meter quadrat, the vine had to occur within the volume that was created by projecting the meter square quadrat upward through the understory. This method of counting insured that vine species were identified regardless of where they were rooted. This was important when looking at the frequency of occurrence of vines throughout the landscape and for harvesting above-ground vine biomass. All three vines pictured in Figure 6.4 were included as species present within the quadrat.

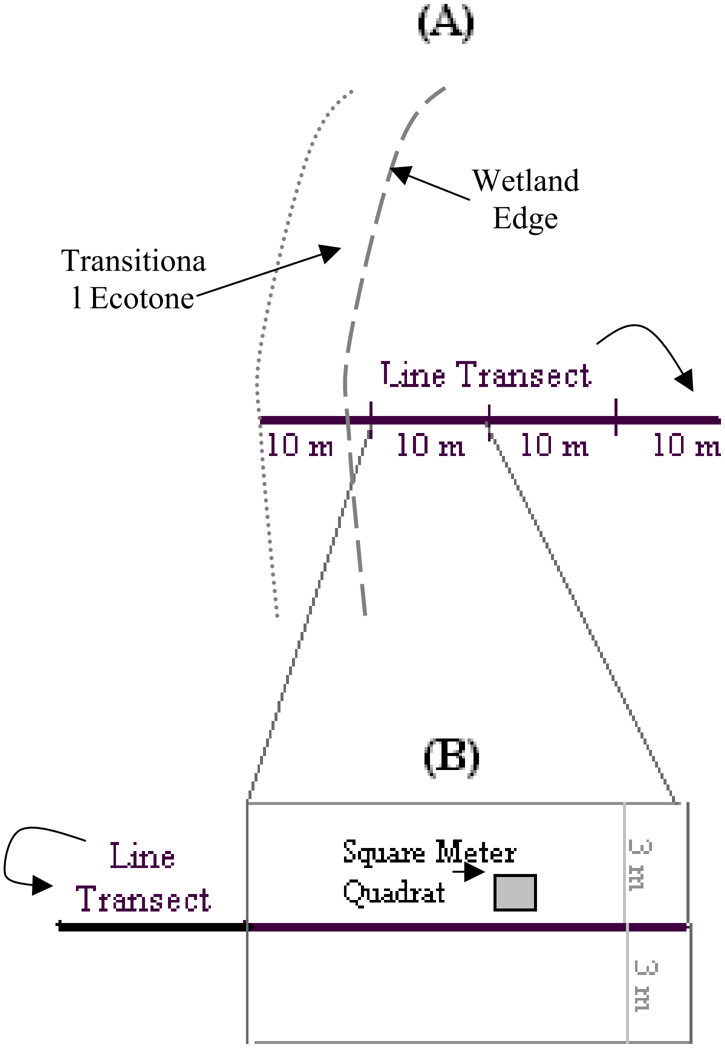


Figure 6.3. Chronosequence Field Layout and Sampling Design. (A) Elongated Quadrats Were Placed Perpendicular to the Hydrologic Gradient; (B) A Square Meter Quadrat Was Placed Randomly Within Each 10 Meter Segment of the Elongated Quadrat. Each Elongated Quadrat Was Extended Three Meters Wide on Each Side to Sample Vine Cover on Trees.

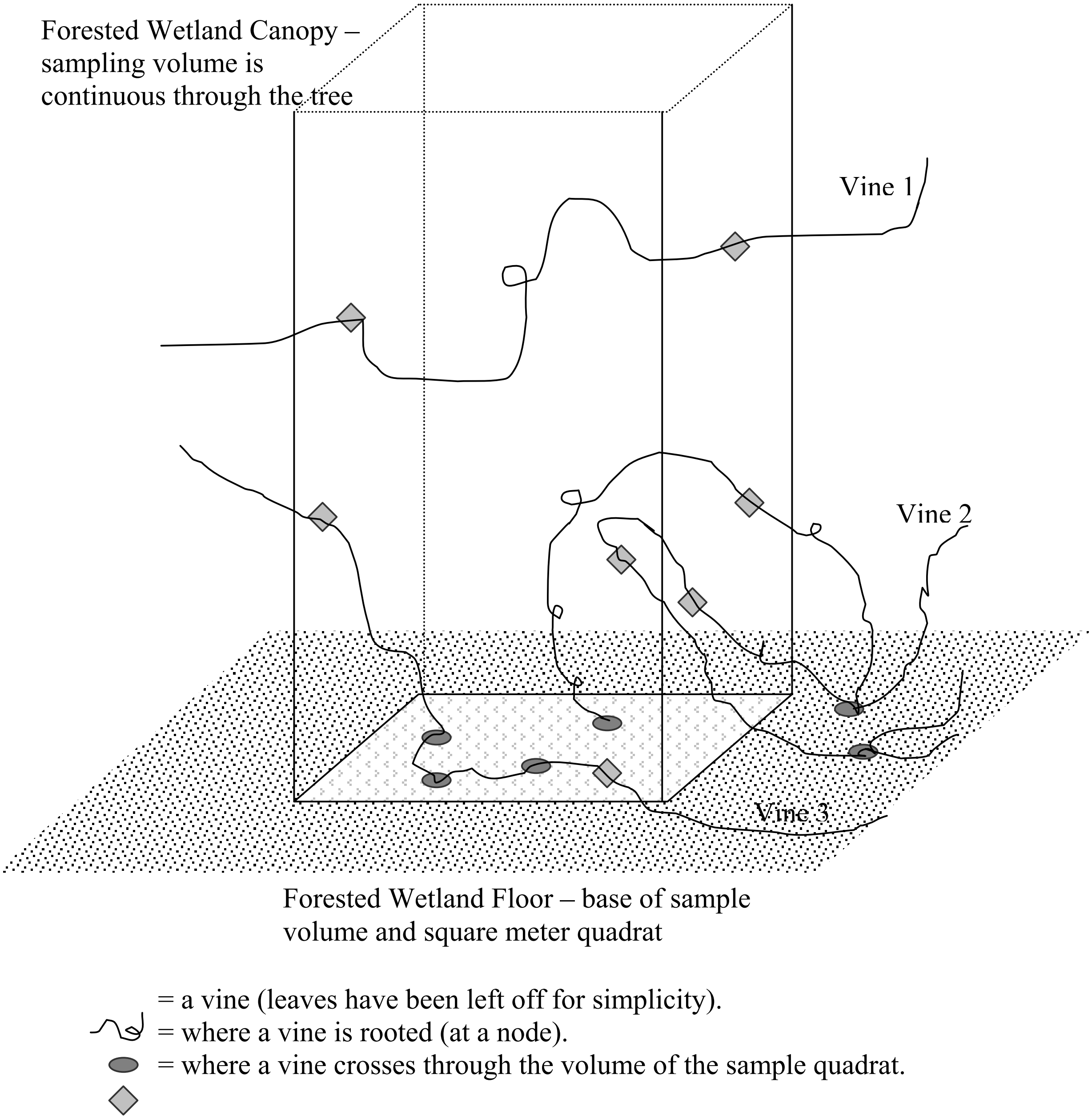


Figure 6.4. The Volume Used Within the Square Meter Quadrats Begins at the Forest Floor and Extends Beyond the Tree Canopy.

Vine Stem Counts

Vine stems, by species, were counted as present only if the largest rooted node was rooted within the square meter quadrat. Only separate stems were counted. Thus, if a vine was partially rooted within and partially rooted outside the square meter quadrat volume, then reappeared within the volume as one traced its length, it was not counted twice, as only the largest rooted node was counted. Figure 6.4 shows three sample vines falling within the quadrat sampling volume. Vine 1 was not counted as a rooted vine. Vine 2 was counted as a rooted vine; it was rooted once within the quadrat and once outside of the quadrat. Vine 3 was counted only once as a rooted vine; it was actually rooted at three nodes within the sample quadrat.

Vine Basal Diameter

Basal diameter of vines was measured within each quadrat using calipers. Basal diameter was taken as the average of two cross sectional measurements perpendicular to each other. The first basal diameter reading was taken at the widest part of the stem. This insured that oval and odd shaped stems were measured more accurately. Using Figure 6.4 as a guide, vine basal diameters were measured as follows: basal diameter was not measured for Vine 1; basal diameter was measured at the node rooted within the quadrat volume for Vine 2; and basal diameter was measured for all three rooted nodes of Vines 3, with only the largest of the rooted nodes recorded.

Above-Ground Biomass

After identification, vine biomass was harvested using clippers. Vines were harvested at the soil/detrital layer interface for those rooted within the quadrat volume. Vines were separated into bags according to species, dried, and weighed. The vines in Figure 6.4 represent the harvested above-ground biomass as follows: the biomass segment of Vine 1 falling within the square meter volume was harvested. The biomass segments of Vine 2 falling within the square meter volume were harvested. This included both the segment rooted within the sample quadrat and the piece that loops back into the sample quadrat after rooting outside of the quadrat. All of the biomass of Vine 3 falling within the volume of the square meter quadrat was harvested.

Percent Cover of Understory Vegetation

Cover of understory vegetation was estimated using a modified Braun-Blanquet (1932) cover scale. Classes of percent cover were designated as follows:

1 = < 10% cover
2 = 10 – 25 % cover
3 = 26 – 50% cover

4 = 51 - 75% cover
5 = > 75% cover.

Tree Cover by Vines

The 6 meter wide elongated quadrats (Figure 6.3) were used to assess presence or absence of vines on trees on a per area basis. A minimum of 600 square meters were sampled for tree cover by vines in each wetland. Additional sampling occurred when time and resources allowed. Tree species identification and naming relied on numerous sources including: Alden and others (1998), Foote and Jones (1998), Godfrey and Wooten (1981), and Harrar and Harrar (1962). Species and diameter at breast height (DBH) were recorded for every tree present. When vines were present, the vine species and percent cover by vines was also recorded. Percent cover of the tree canopy by vines was visually estimated, using the following modified Braun-Blanquet (1932) cover scale:

1 = < 10% cover
2 = 10 – 25 % cover
3 = 26 – 50% cover
4 = 51 - 75% cover
5 = > 75% cover.

Abiotic Data Collection

Abiotic data collected on the chronosequence sites included sunlight transmittance, mean water depth, and soil characteristics.

Sunlight Transmittance

Sunlight transmittance was measured using a LiCor 185B Quantum/Radiometer/ Photometer and a Quantum sensor that measures the photosynthetically active radiation (PAR) available. Within each meter square quadrat, five PAR measurements were taken at 50 cm above the forest floor, in the center and at each corner of the quadrat. A light reading was also taken outside the canopy cover to calculate sunlight transmittance as a percent of the available radiant energy. Sunlight transmittance was recorded between the hours of 10:00 am and 2:00 pm to insure similar conditions for each site.

Mean Water Depth

Water depth within each square meter quadrat was measured at each corner and in the center, providing a mean water depth in each square meter quadrat. Values were averaged for each chronosequence site.

Soil Characterization

Soil samples for lab analysis of physical and chemical properties were collected from each square meter quadrat. Soil moisture, bulk density, percent organic matter, pH, and plant available nutrients were determined from soil cores (3.7 cm diameter x 20 cm depth). Cores were extracted, stored in airtight plastic bags, and weighed within 24 hours of sampling. After thorough mixing of the cores, approximately 25 grams of each sample was placed in a 70ºC oven until a constant weight was obtained. These dried samples were then ground with a mortal and pestle. Approximately one gram of dried soil was placed in a crucible and dried overnight to insure no moisture was added to the soil during grinding. The soil was reweighed and then burned in a muffle furnace at 500°C for six hours. The samples were then cooled in a desiccator and weighed. The loss of weight from ignition was used as an estimate of soil organic matter content.

Soil pH was determined using a Hanna Instrument Model HI9025 pH meter and probe. In the laboratory, 10 grams of thoroughly homogenized fresh soil was dissolved in 20 ml of deionized water, homogenized, and left to equilibrate for 15 minutes. After meter calibration, pH was measured for each soil.

Soil nutrient analysis was completed at the IFAS Analytical Research Laboratory on the University of Florida campus. Nutrient analysis included the Mehlich I extractant for calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), and iron (Fe), and the KCl extractant for ammonium (NH_4-N) and nitrate (NO_3-N) (Bremner 1965). In the Mehlich I procedure, each element was analyzed by Inductively Coupled Argon Plasma (ICAP) Spectroscopy. For the preparation of each sample, 20 ml of Mehlich I extractant (a mixture of 0.05 M HCl and 0.025 N H2SO4) were added to 5 grams of thoroughly homogenized oven-dried soil and shaken for 5 minutes using a reciprocating shaker. The samples were then filtered and analyzed.

In the KCl extractant procedure, 50 ml of 1 M KCl were added to 5 grams of thoroughly homogenized fresh soil. The samples were shaken for 30 minutes, filtered, then analyzed. Wet/dry weight conversions were used to determine the mass of the fresh soil analyzed.

INTENSIVE SAMPLING DESIGN

Sampling in the intensively sampled sites was designed to determine under what conditions vines seem to flourish and what conditions do not favor vine dominance. As a result, sites were chosen that had a significant vine presence. Within these sites, vine dominated quadrats and quadrats without vine domination with the same general site conditions were chosen for field data collection. The data collected included both biotic and abiotic parameters. In the following sections, methods for data collection on these sites are provided.

Site Selection

Six wetlands were selected for intensive sampling based primarily on the abundance of vines (Figure 6.2). Table 6.1 summarizes the main characteristics of each site. Sampling occurred between May and August 1999.

Square Meter Quadrat Establishment

Within each wetland site, a minimum of six square meter quadrats was established. Additional square meter quadrats were established on sites exhibiting high heterogeneity in vine species present, and whenever available time and energy allowed. Half of the quadrats were located within areas dominated by vines, and half were located in areas of similar abiotic conditions but without vine dominance. Within each square meter quadrat, both biotic and abiotic data were collected.

Vegetative Data Collection

Data collected within each square meter quadrat included vine species identification, count of vine stems rooted within each quadrat, rooted vine basal diameter, above-ground biomass of vines, percent cover of understory vegetation, and vine leaf area. These data were collected using the methods described above under the chronosequence design.

Vine leaf area index was measured by placing a ½ inch PVC pole in the center of the quadrat and counting the number of leaves contacting the vertical pole (Bonham 1989). Theoretically, the pole represents an infinitely small point sampling point and each "touch" of a leaf represents a unit area of leaf for the same unit area of ground surface. The greatest height at which a leaf touched the pole was also recorded. If no leaves contacted the pole, a zero value was given for the number of leaves. However, if a vine leaf occurred within 10 cm of the pole the height of the tallest vine leaf was still recorded. If no leaves occurred within 10 cm of the pole, a zero value was assigned to the leaf height.

Abiotic Data Collection

Data collected within each square meter quadrat included sunlight transmittance, water depth, and soil characterization, including soil moisture, bulk density, percent organic matter, pH, and plant available nutrients. These data were collected using the methods described above under the chronosequence design.

DATA ANALYSIS

Biotic Data Analysis

Biotic data calculations included vine species richness, frequency of occurrence of vines, tree stand structure characteristics, and vine leaf area. Specific formulae are provided below.

Vine Species Richness

Vine species richness was calculated for each site using the following formula. The number of individual vines represents the cumulative vine count taken within the square meter quadrats for each site.

$$\text{Vine Species Richness} = \frac{\text{Number of Vine Species} - 1}{(\log_{10}(\text{Number of Individual Vines}))}$$

Vine Basal Diameter

The mean vine basal diameters for both herbaceous and woody vines on the chronosequence sites were compared using Minitab$^{\text{TM}}$ Statistical Software, Version 13.1 (by Minitab, Inc.) to calculate the nonparametric Kruskal-Wallis test, as described by Eddison (2000). The null hypothesis was that the median vine basal diameter was the same between site ages, and the alternative hypothesis was that the median vine basal diameter was not the same for all site ages.

Frequency of Occurrence of Vines

The frequency of occurrence of each individual vine species on each site was calculated using the following formula:

$$\text{Frequency of Occurrence} = \frac{\text{Number of 1 m}^2\text{ Quadrats Vine Species Occurs}}{\text{Total Number of Quadrats Sampled.}}$$

Stand Structure

The stand structure of trees was measured by DBH, stem density, and basal area. Stem density was calculated by dividing the total number of stems counted by the total elongated quadrat area sampled (6 meters wide * elongated quadrat length), adjusted to a hectare basis.

Tree dbh was compared for trees hosting and trees not hosting vines using MinitabTM Statistical Software to calculate the Mann-Whitney test at the 95% confidence level, as described by Eddison (2000).

Basal area was calculated for each individual tree species and as a cumulative over the entire site using the following formula (Avery and Burkhart 1994; Husch and others 1993):

$$\text{Basal Area} = \frac{(\text{dbh (cm)})^2 \times 0.7854}{\text{Total Area of Elongated Quadrats}}.$$

Vine leaf area index (an estimate of the # of leaves/m^2). Vine leaf area was calculated for each site using the following formula:

$$\text{Vine Leaf Area Index} = \frac{m^2 \text{ leaves}}{m^2 \text{ ground}}$$

Abiotic Data Analysis

Sunlight Transmittance

Percent transmittance was calculated as:

$$\%\ \text{Transmittance}_{50} = \frac{\text{mean PAR at 50 cm above the forest floor}}{\text{PAR outside of the canopy}} \times 100$$

Water Depth

Water depth was averaged for each site.

Soil Moisture

Percent soil moisture was calculated using the following formula:

$$\text{Percent Soil Moisture} = \frac{\text{Wet Weight (g)} - \text{Dry Weight (g)} \times 100}{\text{Wet Weight (g).}}$$

Bulk Density

The equation for bulk density of the soil follows:

$$\text{Dry Bulk Density} = \frac{\text{Dry Weight of Core (g)}}{\text{Volume of Core (cm}^3\text{)}}$$

A conversion factor was established for each soil core based on the percent soil moisture of the subsample. This conversion factor was then used to calculate the dry weight of the core:

Dry Weight of Core (g) = Wet Weight of Core (g) – Water Weight of Core (g),
where Water Weight of Core (g) = Wet Weight of Core (g) x % Soil Moisture.

The core volume was calculated using the formula for the volume of a cylinder:

Core Volume (cm^3) = $B \text{ x } r^2 \text{ x } l$,
where r = radius (cm) and l = length (cm).

Organic Matter

Percent organic matter was calculated using the formula:

$$\text{\% Organic Matter} = \frac{\text{(Oven Dry Weight (g) – Ashed Oven Dry Weight (g)) x 100}}{\text{Oven Dry Weight (g).}}$$

Minitab$^{\text{TM}}$ Statistical Software was used to construct a multiple regression comparing soil moisture (%), dry soil bulk density (g/cm^3), and soil organic matter (%). Minitab$^{\text{TM}}$ Statistical Software was also used to perform a Spearman correlation coefficient for rooted vines, soil moisture (%), and plant nutrients (g/m^3), as described by Eddison (2000) and Brown (1998). The Spearman correlation coefficient is an adaptation from the Pearson product-moment correlation coefficient where normality cannot be assumed.

SIMULATION MODELING

A temporal computer simulation model, was developed to mimic large scale successional trends and contributions of vine species in reclaimed forested wetlands. The model was developed to consider organizational processes and long-term successional changes and was calibrated with data from field measurements.

Systems Ecology Language

The first step in the creation of this model was diagramming the constructed forested wetland system (Figure 6.1) and aggregating the system to a scale which has the fundamental nature of the system that portrays the theories to be tested (Figure 6.5). The

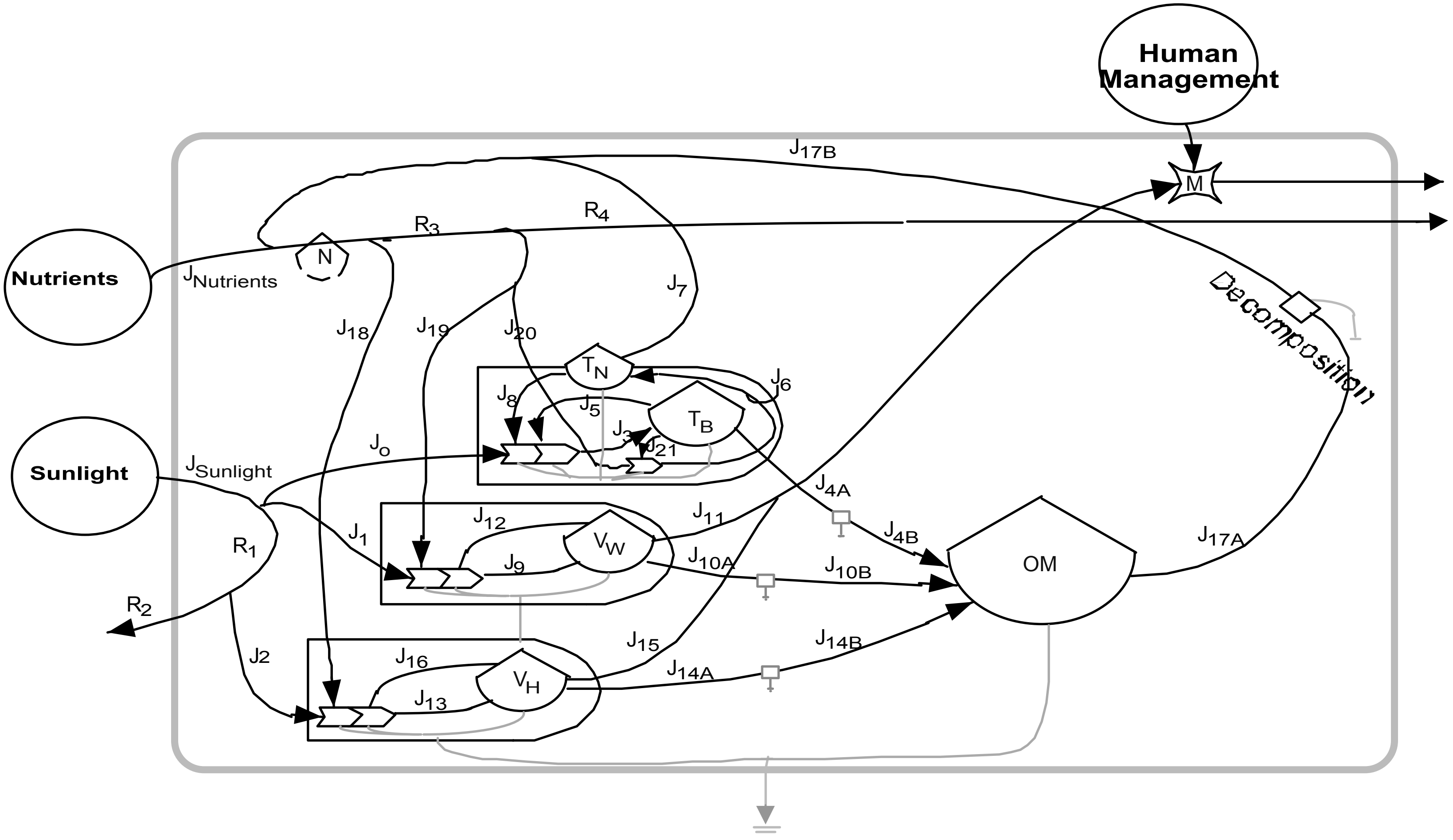


Figure 6.5. Energy Systems Diagram Showing Successional Changes in Herbaceous Vine Biomass, Woody Vine Biomass, and Tree Biomass for Constructed Forested Wetlands.

symbols for this diagram were adapted from Odum (1994) (Appendix 6.B). Table 6.2 provides the equations for each flow shown in Figure 6.5.

The model uses a reclaimed forested wetland as the system boundary. The main components in this model included storages, producers, and outside sources (forcing functions). Within the system, there are three producers, herbaceous vines, woody vines, and trees. The herbaceous and woody vines each have one storage of living vine biomass; the trees have two storages, living tree biomass and tree nutrients. This difference is used to show the more rapid turnover time (and faster organic matter production) attributed to vines versus the longer turnover time of trees (and slower organic matter production). In systems ecology language, turnover time refers to the steady state value of the storage divided by the outflows. It represents the life span of the storage.

Nutrients are shown as a flow through the system as opposed to a storage within the system because nutrients have a much faster turnover time than plant biomass (Jackson 1999). This flowing pathway of nutrients feeds the production of living biomass for vines and trees and drives the accumulation of tree nutrients. When biomass dies and is no longer part of the producers, most decays and is incorporated as soil organic matter. This organic matter is then recycled by decomposing soil microorganisms and contributes to the flow through of nutrients.

Model Calibration

Mathematical equations for this model were written according to Odum (1994) and calculated for "steady state." "Steady state" is described when a system has equal inflows and outflows and when storages are constant (Odum 1994). "Steady state" values are useful when calculating unknown pathways and calibrating coefficients. The initial "steady state" coefficients in this model were calibrated based on previous field studies, publications, and turnover times (Jackson 1999; Odum and Odum 1996; Odum 1994; Mitsch and Gosselink 1993; Myers and Ewel 1990).

Figure 6.6 shows the systems diagram with the coefficients labeled. Table 6.3 provides the values used for each coefficient, calibrated for steady state. This model simulated 200 years of development of reclaimed forested wetlands beginning at the time of wetland establishment. Some assumptions are involved, including finding acceptable average turnover times for herbaceous vines, woody vines, and trees. Additionally, during the initial stages of wetland forest development when reclaimed wetlands are initially planted, there was an assumption that some vine biomass existed on-site. This vine biomass may have entered through seeds in the mulched soil layer, through tree nursery stock, or as volunteers from nearby seed sources. Four separate simulations were run representing forested wetland succession following site establishment, forested wetland succession in the absence of vines, forested wetland succession when vine management occurs in year 7, and forested wetland succession when vine biomass is controlled when the storage of herbaceous vine biomass equals 20%.

Table 6.2. Mathematical Equations Used in the Model of the Role of Vines in Forested Wetland Succession.

	Equation	Flow Values	Definition
Change in Storage:			
$dV_{Herbaceous}$	$= J_{13} - J_{14A} - J_{15} - J_{16}$		Change in herbaceous vine biomass storage.
dV_{Woody}	$= J_9 - J_{10A} - J_{11} - J_{12}$		Change in woody vine biomass storage.
$dT_{Biomass}$	$= J_3 - J_{4A} - J_5 - J_{21}$		Change in tree biomass storage.
$dT_{Nutrients}$	$= J_6 - J_7 - J_8$		Change in tree nutrients storage.
dOM	$= J_{4B} + J_{10B} + J_{14B} - J_{17A}$		Change in organic matter storage.
Flows Internal to the System:			
J_0	$= k_0 * T_B * T_N * R_1$	4.050	Sunlight received by tree biomass.
J_1	$= k_1 * V_W * R_1 * R_4$	0.450	Sunlight received by woody vine biomass.
J_2	$= k_2 * V_H * R_2 * R_3$	0.250	Sunlight received by herbaceous vine biomass.
J_3	$= k_3 * T_B * T_N * R_1$	10.318	Production of tree biomass.
J_{4A}	$= k_{4A} * T_B$	3.695	Tree biomass litter from leaf fall, broken branches, etc.
J_{4B}	$= k_{4B} * T_B$	3.695	Tree biomass litter after preliminary decomposition.
J_5	$= k_5 * T_B * T_N * R_1$	2.131	Active respiration of tree biomass.
J_6	$= k_6 * T_B * R_4$	0.400	Uptake of nutrients by trees.
J_7	$= k_7 * T_N$	0.004	Leaching of nutrients by tree roots and fallen litter.
J_8	$= k_8 * T_B * T_N * R_1$	0.396	Consumption of nutrients by trees.
J_9	$= k_9 * V_W * R_1 * R_4$	2.508	Production of woody vine biomass.
J_{10A}	$= K_{10A} * V_W$	1.551	Woody vine biomass litter from leaf fall, broken stems, etc.
J_{10B}	$= K_{10B} * V_W$	1.551	Woody vine biomass litter after preliminary decomposition

Table 6.2. (Cont.) Mathematical Equations Used in the Model of the Role of Vines in Forested Wetland Succession.

Flows Internal to the System:

J_{11}	$= K_{11} * V_W * M$	0.000	Removal of woody vine biomass through human interventions.
J_{13}	$= k_{13} * V_H * R_2 * R_3$	11.200	Production of herbaceous vine biomass.
J_{14A}	$= K_{14A} * V_H$	7.280	Herbaceous vine litter.
J_{14B}	$= K_{14B} * V_H$	7.280	Herbaceous vine biomass litter after preliminary decomposition.
J_{15}	$= K_{15} * V_H$	0.000	Removal of herbaceous vine biomass through human interventions.
J_{16}	$= k_{16} * V_H * R_2 * R_3$	1.400	Active respiration of herbaceous vine biomass.
J_{17A}	$= K_{17A} * OM$	12.526	Recycle of nutrients in a plant available form.
J_{17B}	$= K_{17B} * OM$	0.351	Further breakdown of nutrients (ex. loss as gas exchange, leaching, etc.)
J_{18}	$= k_{18} * V_H * R_2 * R_3$	0.265	Nutrient flow available to herbaceous vines.
J_{19}	$= k_{19} * V_W * R_1 * R_4$	0.579	Nutrient flow available to woody vines.
J_{20}	$= k_{20} * T_B * R_4$	2.509	Nutrient flow available to trees.
J_{21}	$= k_{21} * T_B * R_4$	0.010	Tree biomass enhancing nutrient uptake in trees.

Remainders:

R_1	$= J_S / (1 + ((k_0 * T_B * T_N) + (k_1 * V_W * R_4)))$	0.50	Sunlight available to herbaceous vines.
R_2	$= R_1 / (1 + (k_2 * V_H * R_3))$	0.25	Albedo or unused sunlight.
R_3	$= (J_N + J_7 + J_{17B}) / (1 + (k_{18} * V_H * R_2))$	3.22	Nutrients available to woody vines and trees.
R_4	$= R_3 / (1 + ((k_{19} * V_W * R_1) + (k20 * T_B)))$	0.13	Nutrients present in runoff and leaching.

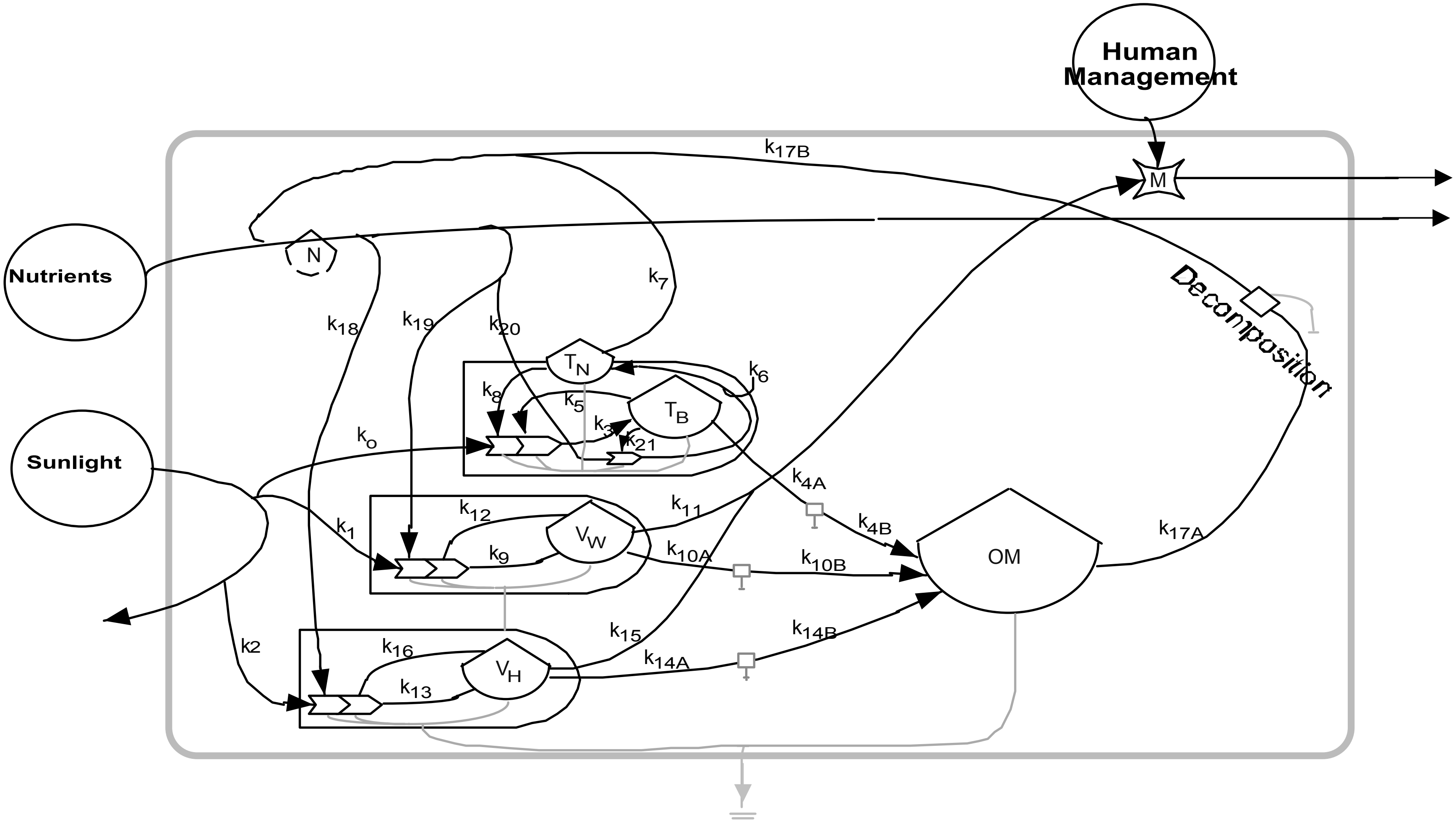


Figure 6.6. Energy Systems Diagram Showing Each Coefficient Assigned in the Model of the Role of Vines in Forested Wetland Succession.

Table 6.3. Steady-State Values Used in the Model of the Role of Vines in Forested Wetland Succession.

Symbol		Value	Other Information	
Storages				
	$dV_{Herbaceous}$	=15	Turnover time equals 1½ years.	
	dV_{Woody}	= 25	Turnover time equals 15 years.	
	$dT_{Biomass}$	= 100	Turnover time equals 50 years.	
	$dT_{Nutrients}$	= 20	Turnover time equals 50 years.	
	dOM	= 31	Turnover time equals 2½ years.	
Coefficients				
	k_0	= 0.0041	k_{12}	= 0.1122
	k_1	= .2683	k_{13}	= 0.9269
	k_2	= 0.0207	k_{14A}	= 0.4853
	k_3	= 0.0103	k_{14B}	= 0.4853
	k_{4A}	= 0.0369	k_{15}	= 0
	k_{4B}	= 0.0369	k_{16}	= 0.1159
	k_5	= 0.0021	k_{17A}	= 0.4000
	k_6	= 0.0298	k_{17B}	= 0.0112
	k_7	= 0.0002	k_{18}	= 0.0219
	k_8	= 0.0004	k_{19}	= 0.3452
	k_9	= 1.4954	k_{20}	= 0.1870
	k_{10A}	= 0.0620	k_{21}	= 0.0008
	k_{10B}	= 0.0620		
	k_{11}	= 0		
Remainders:				
	R_1	= 0.50		
	R_2	= 0.25		
	R_3	= 3.22		
	R_4	= 0.13		

RESULTS

Characteristics of constructed forested wetlands were measured in the central Florida phosphate district. First, data were collected from a chronosequence of nine sites, then from six sites specifically chosen because of the intensity of vine dominance. To test theories concerning the role of vines in forested wetland systems, a computer model was simulated.

In the following section the data from field studies of the chronosequence of sites are presented first, followed by the data from the vine dominated sites. Finally, results of the computer model simulations are given.

CHRONOSEQUENCE SAMPLING

The chronosequence sampling design includes data for nine wetlands, which were randomly sampled using transects. Presence of vines in the reclaimed landscape is addressed first, followed by edaphic site conditions where vines are present.

Vegetative Data

The combination of vine species present on each site exhibited great heterogeneity. Table 6.4 lists the 18 different genera found on the nine chronosequence sites. Of the total genera observed, 11 were recorded within square meter quadrats and two vine genera, *Cuscuta* and Passiflora, were observed on sites, but never found within the confines of the sample transects. *Aster carolinianus* was included as a vine, as it has been described as a sprawling shrub or vine (Alden and others 1998; Foote and Jones 1998), though its designation is uncertain. The herbaceous vine *Mikania scandens* was sampled or observed on 8 of the 9 chronosequence sites. The only site that *Mikania scandens* was not found on was 12-year-old Cateye. A general trend was apparent as an increase in the number of vine genera according to site age. Table 6.4 shows that the 18-year-old site Sink Branch had 12 vine genera present, followed by 8 and 7 genera occurring at 15-year old Guy Branch and 14-year-old SP11, respectively. Younger sites such as LP2 Phase 1 and Nichols Mine had the fewest vine genera present, with only *Mikania scandens* present on each site. The 2-year-old site Super Hummock had 2 vine genera recorded, but only *Mikania scandens* was present within the transect boundaries.

Vine data were grouped as herbaceous and woody vines rather than by genus or species. Figure 6.7 depicts a general trend of an increase in the number of rooted herbaceous vines through age six, followed by a decrease. The exception was the large number of rooted herbaceous vines at the 17-year-old Morrow Swamp site with over 28,000 rooted herbaceous vines per hectare. There was also a noticeable increase in the number of rooted woody vines beginning around age 6, with the greatest number of

Scientific Name (common name)	Author*	Habit*	Wetland Status**
Ampelopsis arborea (pepper-vine)	(L). Koehne	NWv	FAC, FACW
Apios americana (American potato-bean)	Medic.	PNF	FAC, FACW
Aster carolinianus (climbing aster)	Walter	PNF	OBL
Campsis radicans (trumpet-creeper)	L. Seem.	NWv	FACU, FAC
Cardiospermum microcarpum	- -	- -	- -
Clematis crispa (swamp virgin's-bower)	L.	NV	FAC, OBL
Cuscuta sp.	- -	- -	- -
Galactia elliottii (Elliott's milkpea)	Nutt.	PNF	FACU
Lygodium japonicum (Japenese climbing fern)	(Thunb.) Swartz	PIVF3	FAC, FACW
Melothria pendula (creeping cucumber)	L.	PNV	FAC, FACW
Mikania scandens (climbing hempweed)	(L.) Willd.	PNV	FACW, OBL
Momordica charantia	- -	- -	- -
Morrenia odorata	- -	- -	- -
Parthenocissus quinquefolia (Virgina creeper)	(L.) Planch.	NWv	FACU, FAC
Passiflora incarnata (purple passion-flower)	Sims	NWv	FACU, FAC
Smilax spp. (mostly *Smilax bona-nox*, saw greenbriar)	L.	NSWV	FACU, FAC
Toxicodendron radicans (poison ivy)	(L.) Kuntz	NWvS	FACU, FACW
Vitis spp. (mostly *Vitis rotundifolia*, muscadine grape)	Michx.	NWv	FAC, FACW

** Habit Characteristics or Life Form: F = forb; F3 = fern; I = introduced; N = native; P = perennial; S = shrub; V = herbaceous vine; and Wv = woody vine. Name, author, and habit according to the National Wetlands Inventory (1988).*

*** Wetland Status: UPL = obligate upland; FACU = facultative upland; FAC = facultative; FACW = facultative wetland; and OBL = obligate wetland (NWI 1988).*

◈ *= species observed on site, and found growing within the chrono-sequence transect boundaries.*

◇ *= species observed on-site, but not found growing within the chrono-sequence transect boundaries.*

Table 6.4. Vine Species Found Growing on the Chronosequence Sites.

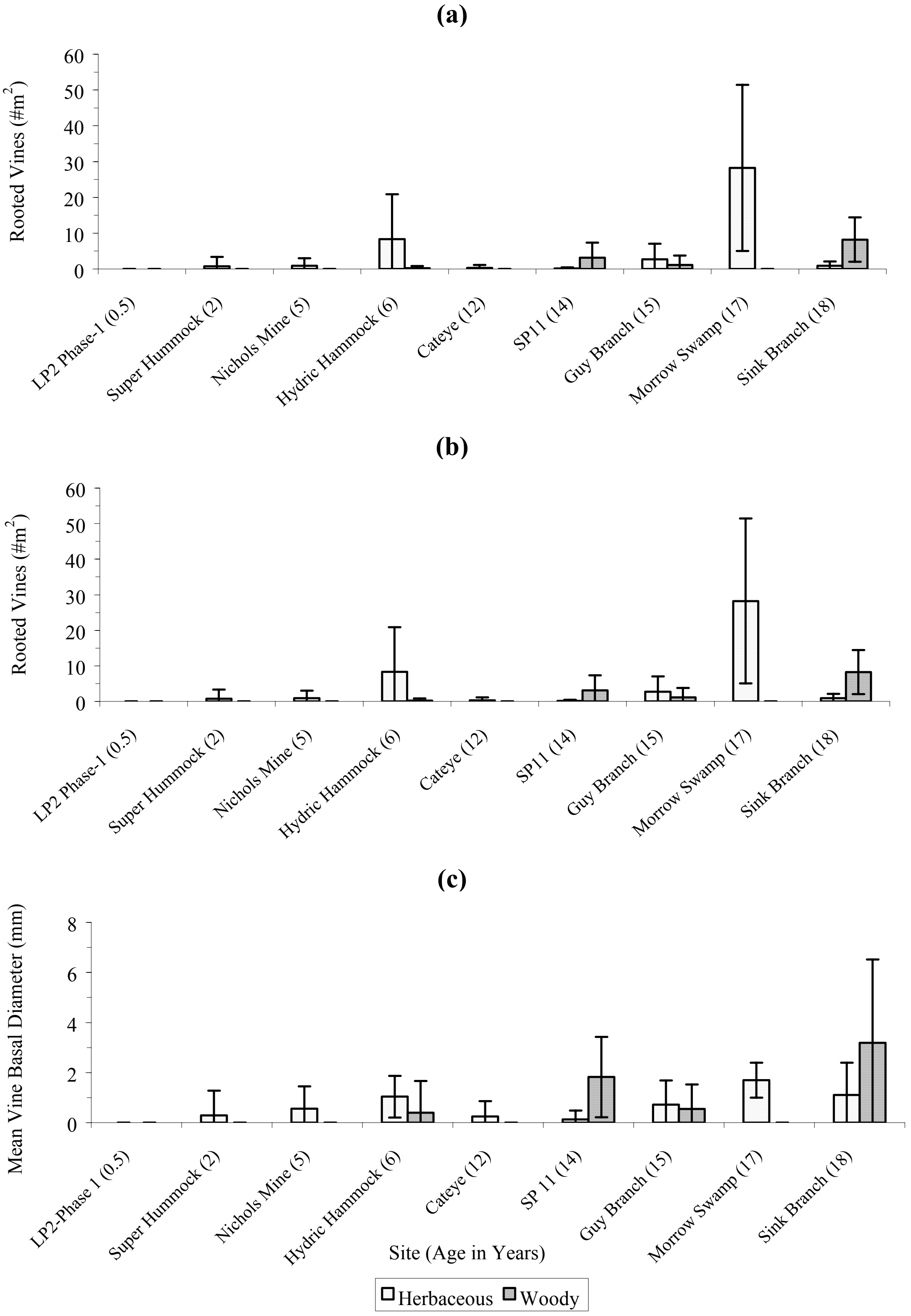


Figure 6.7. Vine Distribution Over Time on the Chronosequence Sites. (a) Mean Number of Rooted Vines; (b) Mean Dry Weight Vine Biomass; and (c) Mean Vine Basal Diameter at Each Site.

rooted woody vines occurring at the 18-year-old Sink Branch site with over 8,000 rooted woody vines per hectare.

Figure 6.7 also shows that mean vine basal diameter appeared to increase with site age. However, the standard deviations were large, and results from the Kruskal-Wallis test (Appendix 6.C) suggest there was no significant trend in increasing mean vine basal diameter for either herbaceous (HC = 4.65, df = 5, P = 0.460) or woody vines (HC = 1.75, df = 3, P = 0.625) over time.

Above ground herbaceous vine biomass increased through age six, followed by a decrease. Woody vine biomass occurred on only three of the chronosequence sites including, 6-year old Hydric Hammock, 14-year old SP11, and 15-year old Guy Branch. An exception was 17-year-old Morrow Swamp, with far greater herbaceous vine biomass than any other site sampled and no woody vine biomass. Biomass data were not collected at the oldest site, 18-year-old Sink Branch, because this was the first site sampled, and above ground biomass harvesting was added to the methods after sampling occurred.

Figure 6.8 shows vine species richness increased with increased site age, with 18-year-old Sink Branch having the greatest vine species richness value of 3.8. Fourteen-year-old SP11 had the second highest vines species richness with a value of 3.3. The three youngest sites, 0.5-year-old LP2 Phase-1, 2-year-old Super Hummock, and 5-year-old Nichols Mine, had a vine species richness values of zero.

Most vines identified within the boundaries of the transects on the chronosequence sites occurred on 3 or fewer sites, with the exception of *Mikania scandens*, which occurred on 8 of the 9 chronosequence sites. Seven genera were found on 3 sites, 5 genera on only 2 sites, and the remaining 5 genera were found on just one site.

Table 6.5 provides the frequency of occurrence data for vines present on each particular site within the square meter quadrats. Only 13 vine genera occurred within the square meter quadrats and were included in frequency of occurrence calculations. The two youngest sites, LP2 Phase-1 and Super Hummock, had no vines present in the square meter quadrats, and the 5-year-old Nichols Mine site had only one vine, *Mikania scandens*, present at 30% of the quadrats. Mi*k*ania *scandens* occurred within the square meter quadrats on 6 of the 9 sites, occurring 90% of the time at Morrow Swamp. Five sites, including LP2 Phase-1, Super Hummock, Nichols Mine, Cateye, and Morrow Swamp, had no woody vines present within the square meter quadrats. At the oldest site, Sink Branch, the total frequency for all vines was 100%, suggesting that every square meter of this site contained vines.

Table 6.6 provides the climbing mechanisms and families of the vine genera found on the sample sites. Six tendrillar genera were sampled and 5 twining genera. The least common climbing mechanisms of vines sampled included adventitious root climbers with aerial roots, adventitious root climbers with tendrils and adhesive disks, and twisting

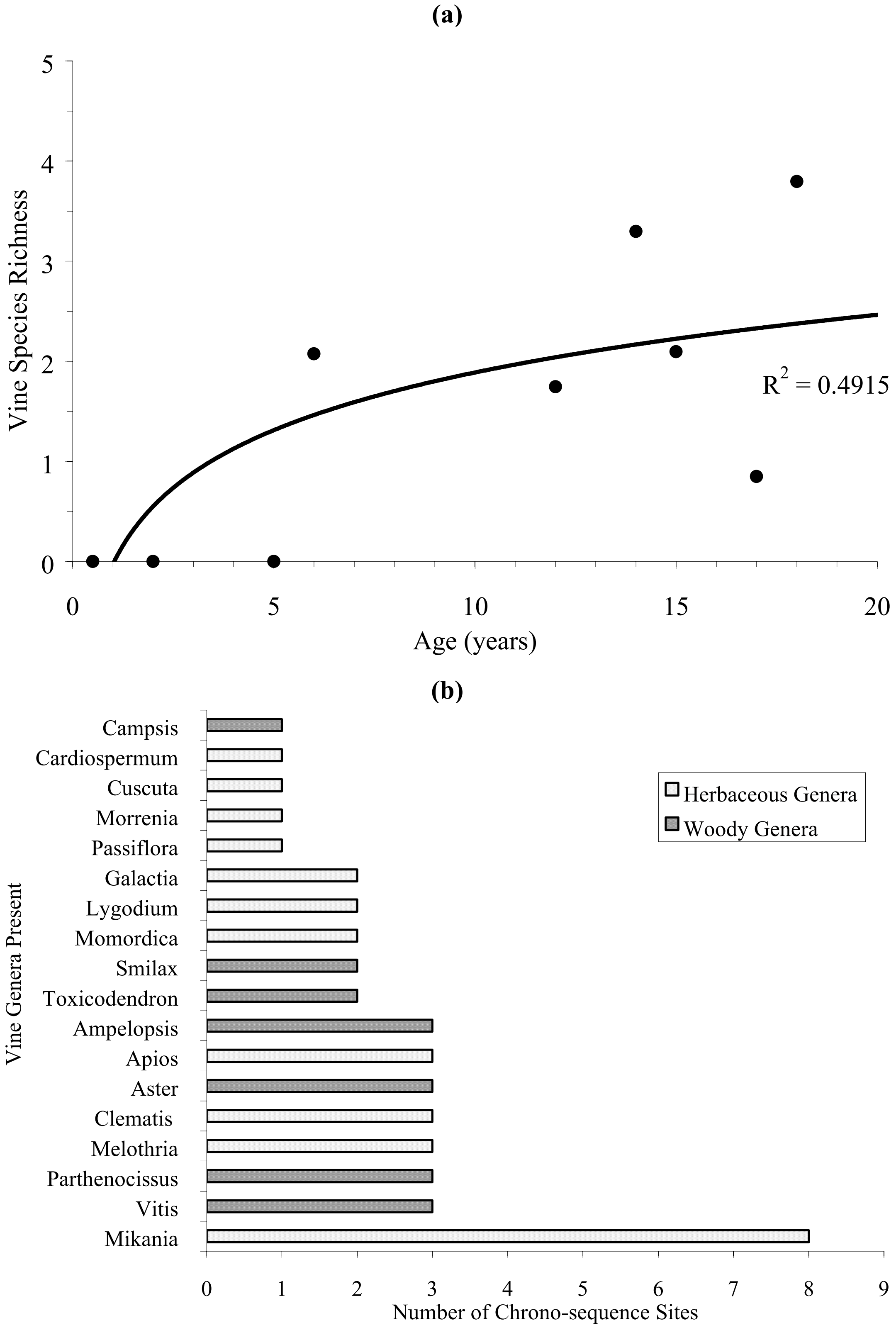


Figure 6.8. Vine Presence on the Chronosequence Sites. (a) Vine Species Richness Increases with Increasing Site Age; (b) Vines Representing 18 Genera Were Identified throughout the Nine Chronosequence Sites.

Table 6.5. Frequency of Occurrence for the Vines Present in the Square Meter Quadrats Sampled on the Chronosequence Sites.

Site	LP2 Phase 1	Super Hummock	Nichols Mine	Hydric Hammock	Cateye	SP11	Guy Branch	Morrow Swamp	Sink Branch
Age (years)	0.5	2	5	6	12	14	15	17	18
Number of Quadrats	17	12	19	10	6	8	7	8	14
Herbaceous Vines									
Apios americana	0	0	0	0.40	0	0	0	0	0.21
Clematis crispa	0	0	0	0.70	0	0	0.29	0	0.29
Galactia elliottii	0	0	0	0	0	0	0.14	0	0
Melothria pendula	0	0	0	0	0.17	0	0	0	0
Mikania scandens	0	0	0.32	0.20	0	0.13	0.43	0.88	0.07
Momordica charabtia	0	0	0	0.10	0.17	0	0	0	0
Morrenia odorata	0	0	0	0	0	0.25	0	0	0
Woody Vines									
Ampelopsis arborea	0	0	0	0	0	0	0.29	0	0.57
Campsis radicans	0	0	0	0	0	0	0	0	0.14
Parthenocissus quinquefolia	0	0	0	0	0	0.50	0	0	0.64
Smilax spp.	0	0	0	0	0	0	0	0	0.43
Toxicodendron radicans	0	0	0	0	0	0.38	0	0	0.36
Vitis spp.	0	0	0	0.10	0	0.13	0	0	0.07
Compiled Frequency of Occurrence									
All herbaceous vines	0	0	0.32	0.80	0.33	0.13	0.43	0.88	0.57
All woody vines	0	0	0	0.10	0.33	0.75	0.29	0	0.93
All vines	0	0	0.32	0.80	0.50	0.88	0.57	0.88	1.00

Table 6.6. The Climbing Mechanisms of Vines Found on Reclaimed Forested Wetlands.

Climbing Mechanism:	Family
Adventitious Root Climber / Aerial Roots	
[1] *Campsis radicans*	Bignoniaceae
[1, 2] *Toxicodendron radicans*	Anacardiaceae
Adventitious Root Climber / Tendrils with Adhesive Disks	
[1, 2] *Parthenocissus quinquefolia*	Vitaceae
Clasping Leaves	
[3] *Aster carolinianus*	Asteraceae
Lacking Obvious Speciealized Climbing Mechanism	
[4] *Cuscuta* sp.	Convolvulaceae
Tendrils	
[1] *Ampelopsis arborea*	Vitaceae
[5, 6] *Melothria pendula*	Cucurbitaceae
[5, 6] *Momordica charantia*	Cucurbitaceae
[1] *Passiflora incarnata*	Passifloraceae
[1, 2, 4] *Smilax* spp.	Liliaceae
[1, 2] *Vitis* spp.	Vitaceae
Twisting Leaf Stalks	
[1, 2, 4] *Clematis crispa*	Ranunculaceae
[7] *Morrenia odorata*	
Twining	
[5] *Apios americana*	Leguminosae
[7, 8, 9] *Cardiospermum microcarpum*	Sapindaceae
[7] *Galactia elliottii*	Leguminosae
[7, 10] *Lygodium japonica*	Schizaeaceae
[4, 6] *Mikania scandens*	Asteraceae

Sources:

[1] Teramura et al. 1992

[2] Carter et al. 1987

[3] Alden et al. 1998

[4] Gentry 1992

[5] Godfrey and Wooten 1981

[6] Carlquist 1992

[7] personal field observation 1998 and 1999

[8] Hegarty 1992

[9] Hegarty et al. 1992

[10] Lee and Richards 1992

leaf stalks. *Cuscuta* sp. in the Convolvulaceae family lacks any obvious specialized climbing mechanisms (Gentry 1992).

Figure 6.9 shows that the percent herbaceous ground cover in each square meter quadrat had little effect on the number of 1.0 m^2 quadrats with rooted vines or vine biomass within each square meter quadrat. Herbaceous vines occurred in almost every category of herbaceous understory cover, except in areas with <10% cover. Woody vines occurred only in areas with >75% herbaceous ground cover. No vines occurred when vegetative cover was less than 10%.

Changes in the frequency of vines with site age were described with the chronosequence data. Figure 6.10 shows the portion of the quadrats where vines occurred according to increasing site age. The portion of the quadrats hosting vines generally increased with increasing site age. The youngest site, 0.5-year-old LP2 Phase 1, had no vine cover within the sampled quadrats; whereas the oldest site, 18-year-old Sink Branch, had 57% of the quadrats with rooted herbaceous vines and 93% of the quadrats with rooted woody vines. A total vine frequency greater than 100% is possible because both herbaceous and woody rooted vines could be recorded within the same square meter quadrat. Rooted herbaceous vines peak at 6-year-old Hydric Hammock occurring in approximately 80% of the quadrats, and rooted woody vines increase with site age starting at six years old with Hydric Hammock.

The Presence of Vines on Trees

Table 6.7 summarizes tree data on the chronosequence sites, including number of tree genera, number of individual trees sampled, tree species richness, stem density (trees/ha), basal area (m^2/ha), trees hosting vines (%), mean vine cover on trees (%), canopy height (m), water depth (cm), and number of vine genera. Note that Sink Branch had no vine cover recorder, as this was the first site sampled, and methods were later altered to include vine cover on trees.

Each wetland sampled had a unique combination of tree species present, closely reflecting the variety of species planted during site establishment. Table 6.8 shows a total of 15 tree genera were found, including 6 obligate wetland, 7 facultative wetland, and 2 upland trees (designated according to NWI 1988). *Acer rubrum* was the most common tree found, occurring on 8 of the 9 sites. Four tree species, *Carya* sp., Cel*tis laevigata*, *Cornus florida*, and *Prunus serotina*, were found on only one site each, suggesting some natural recruitment. Nichols Mine had the highest number of tree genera at 10, followed by Sink Branch with 9. Morrow Swamp had the lowest number of tree genera present, with only 1 tree genus, *Taxodium* sp., present. Both *Taxodium distichum* and *Taxodium ascendens* were present.

Figure 6.11 describes the affinity each particular tree species had for hosting vines. *Magnolia virginiana* and *Taxodium* spp. trees were most often hosts to vines with 43% and 42% of the trees hosting some extent of vine cover, respectively. Forty percent

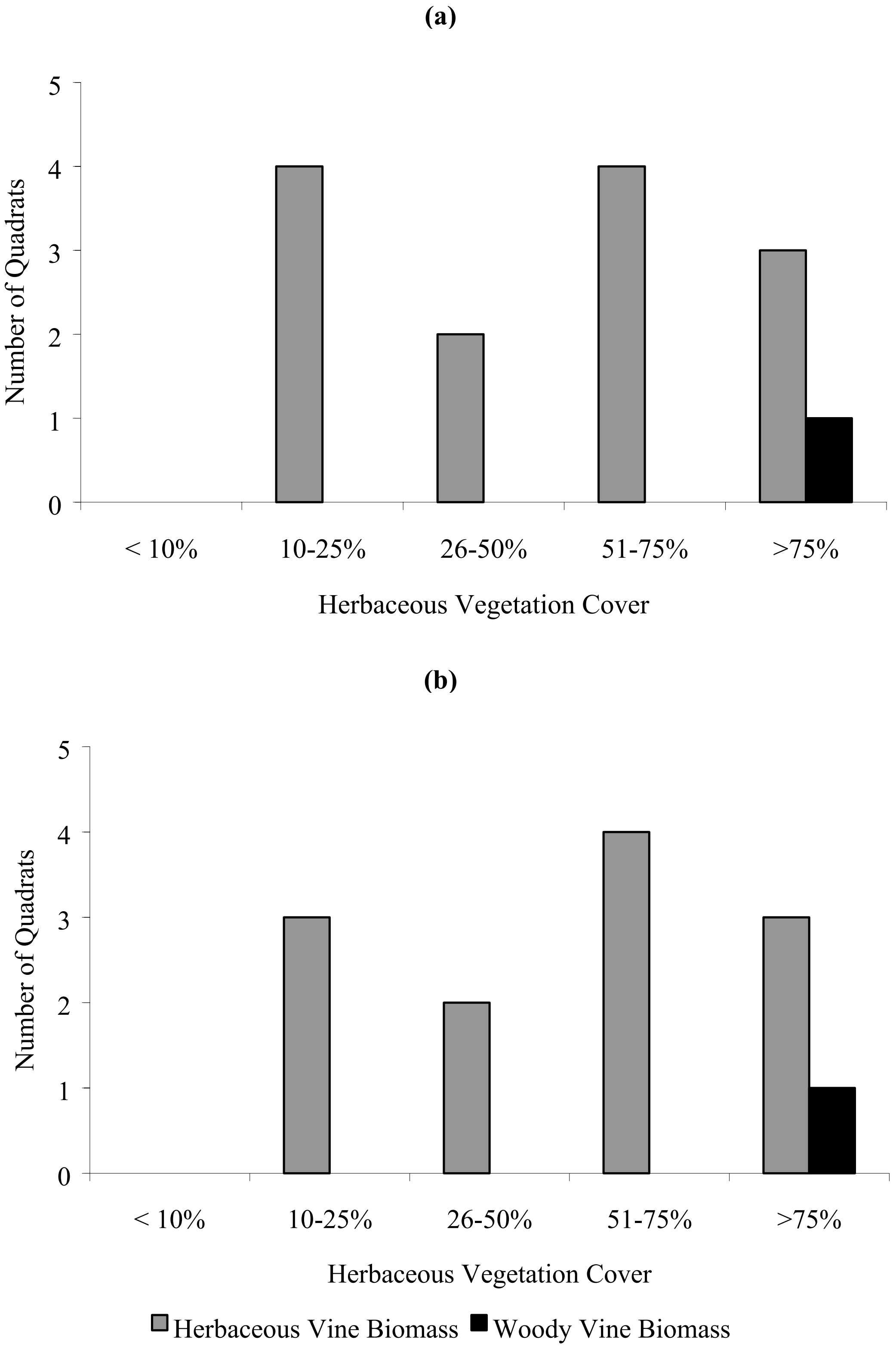


Figure 6.9. Presence of Vines in Relation to Understory Herbaceous Cover on the Chronosequence Sites. (a) Rooted Vines; (b) Vine Biomass.

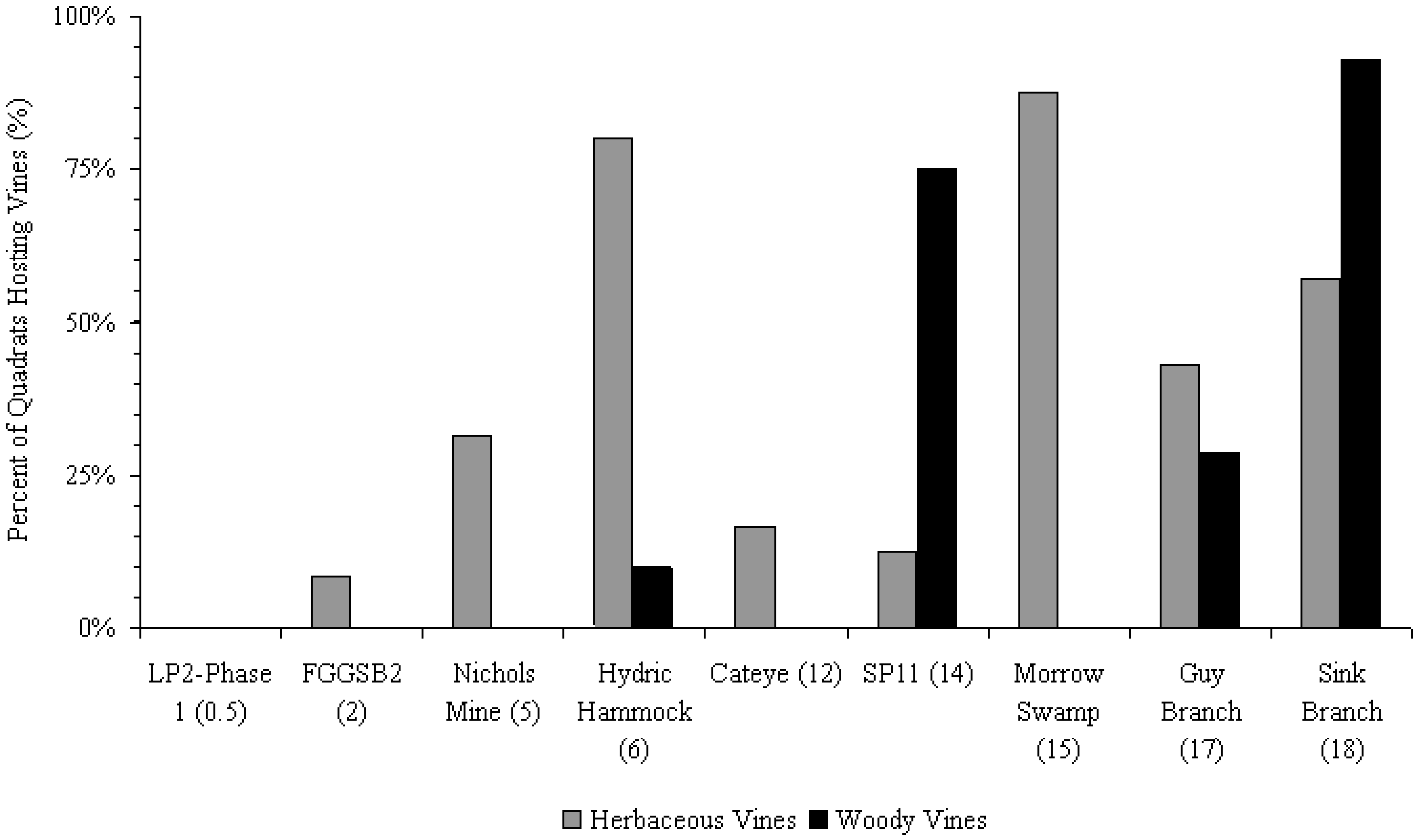


Figure 6.10. Percent of Quadrats Containing Vine Increases in Relation to Increasing Site Age Along the Chronosequence of Sites. It Is Possible that the Total Frequency of Herbaceous Vines and Woody Vines Exceed 100% Because Both Herbaceous and Woody Vines Could Be Recorded in the Same Quadrat.

Table 6.7. Summary Table for Tree Parameters on the Chronosequence Sites.

Site	Age	# of Tree Genera	# of Individual Trees Sampled	Tree Species Richness	Stem Density (trees/ha)	Basal Area (m^2/ha)
LP2 Phase 1	0.5	8	123	3.3	1207	0.06
Super Hummock	2	7	85	3.1	1083	0.09
Nichols Mine	5	10	133	4.2	1099	0.30
Hydric Hammock	6	5	78	2.1	1218	3.58
Cateye	12	6	57	2.8	1592	5.00
SP11	14	5	90	2.0	1896	18.22
Guy Branch	15	2	66	0.5	1528	9.50
Morrow Swamp	17	1	51	0	1056	10.34
Sink Branch	18	9	163	3.6	1005	12.03

Site	Trees Hosting Vines	Mean Vine Cover on Trees	Canopy Height (m)	Water Depth (cm)	# of Vine Genera
LP2 Phase 1	0%	0%	0.8	0	1
Super Hummock	5%	<10%	1.0	0.7	2
Nichols Mine	4%	<10%	2.2	9.3	1
Hydric Hammock	58%	25-50%	3.6	0	6
Cateye	0%	0%	6.5	0	4
SP11	0%	0%	8.2	0	7
Guy Branch	20%	10-25%	9.2	40	8
Morrow Swamp	69%	50-75%	7.7	5	3
Sink Branch	96%	25-50%	9.8	0	12

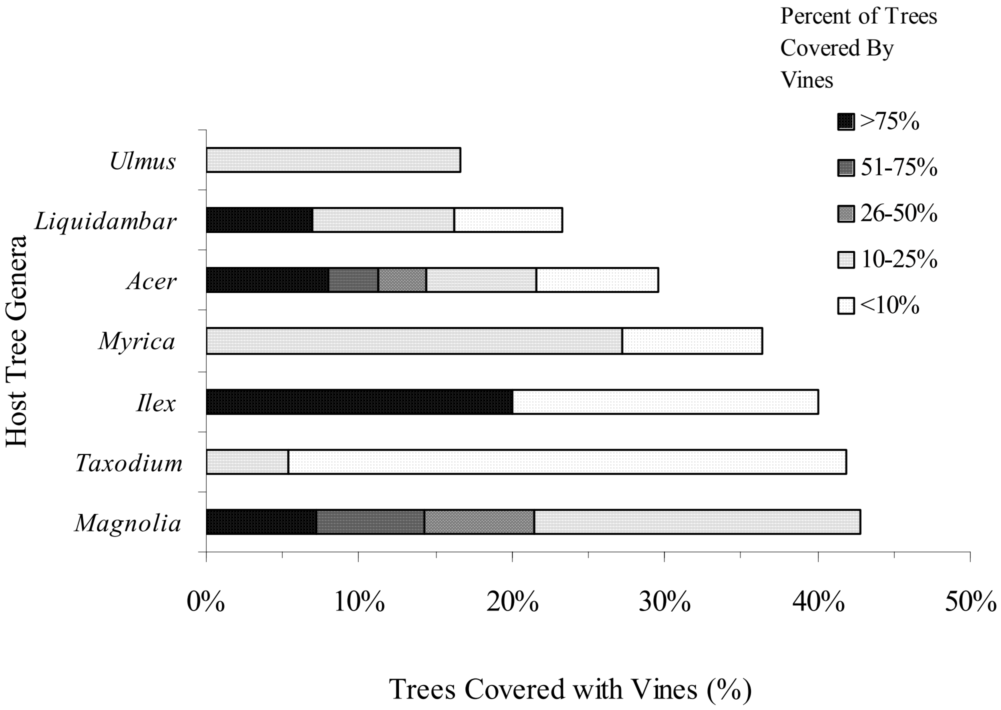
Table 6.8. Tree Genera Found Distributed Throughout the Chronosequence Sites.

			Site (Age in Years)								
Tree Genera	Wetland Status*	Habit**	LP2 Phase-1 (0.5)	Super Hummock (2)	Nichols Mine (5)	Hydric Hammock (6)	Cateye (12)	SP11 (14)	Guy Branch (15)	Morrow Swamp (17)	Sink Branch (18)
Acer rubrum (red maple)	FAC	NT	◈	◈	◈	◈	◈	◈	◈		◈
Carya spp. (likely *C. aquatic*, water hickory)	OBL	NT					◈				
Celtis laevigata (sugar-berry)	FACW	NT	◈								
Cornus florida (dogwood)	FAC	NT									◈
Fraxinus caroliniana (Carolina ash)	OBL	NETS		◈	◈		◈				◈
Ilex cassine (dahoon holly)	FACW	NT	◈	◈		◈	◈				
Liquidambar styraciflua (sweet gum)	FAC	NT	◈		◈	◈		◈			◈
Magnolia virginiana (sweetbay magnolia)	FACW	NT			◈	◈					
Nyssa spp. (likely *N. sylvatica*, black gum)	OBL	NT	◈	◈	◈						
Persea palustris (swamp bay)	FACW	NT	◈	◈	◈						
Pinus elliottii (slash pine)	FACW	NT			◈			◈			◈
Prunus serotina (black cherry)	FACU	NT									◈
Quercus sp. (combination of *Q. laurifolia* and *Q. nigra*)			◈	◈	◈	◈	◈	◈			◈
Q. laurifolia (laurel oak)	FACW	NT									
Q. nigra (water oak)	FAC	NT									
Taxodium sp. (combination of *T. ascendens* and *T. distichum*)					◈		◈	◈	◈	◈	◈
T. ascendens (pond cypress)	OBL	NET									
T. distichum (bald cypress)	OBL	NET									
Ulmus americana (American elm)	FACW	NT	◈	◈	◈						◈

** OBL = obligate; FACW = facultative wetland; FAC = facultative; and FACU = facultative upland (National Wetlands Inventory 1988).*

*** Habit: E = emergent; N = native; S = shrub; and T = tree (National Wetlands Inventory 1988).*

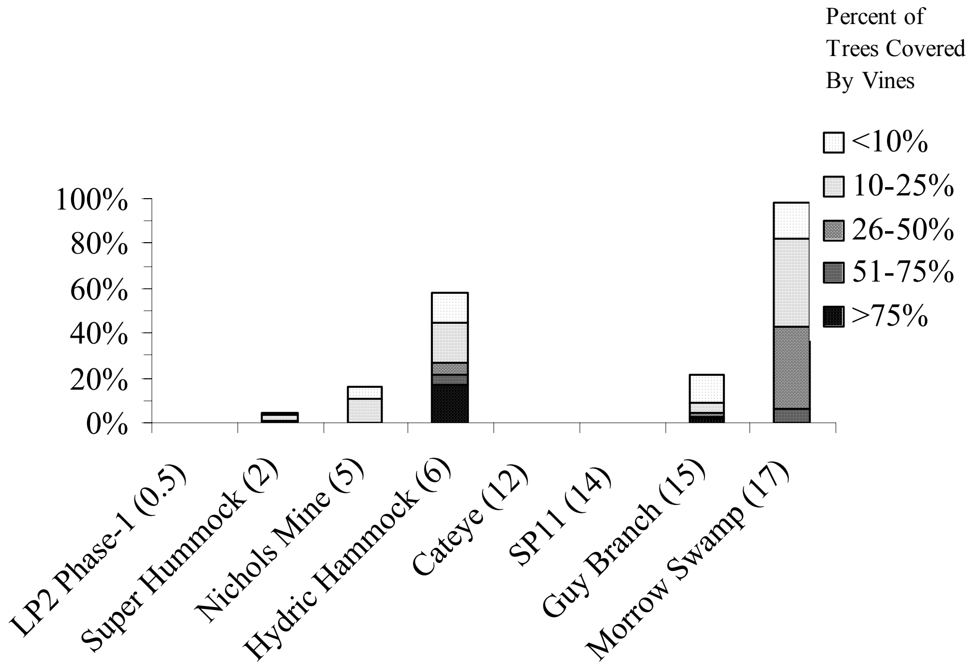
◈ *= species observed on site, and found growing within the chrono-sequence transect boundaries.*



(a)

(b)

Figure 6.11. The Percent Cover of Vines on Trees. When a Tree Has Some Amount of Vine Biomass Growing on It, (a) Shows the Affinity for Each Host Tree Species To Be Covered in Vines, and (b) Shows the Probability of Vine Cover for a Tree at a Given Age. Data Were Not Available for Sink Branch.



of the *Ilex cassine* trees hosted vines though the percentage of vine cover on each tree host varied. For instance, over 30% of *Taxodium* spp. had less than 10% vine cover, whereas 20% of *Ilex cassine* had over 75% vine cover.

Table 6.9 provides the percentage of sampled trees throughout the landscape hosting vines. A large percentage of trees on the oldest sites hosted vines with 98% and 96% of the trees at the two oldest sites, 17-year-old Morrow Swamp and 18-year-old Sink Branch, hosting vines. However, these trees hosted a range of vine cover from <10% to >75%.

The percent vine cover of trees was categorized based on all trees on a particular site. Figure 6.11 depicts the general increase in the total percent vine cover with increasing site age. Only 4% of all trees at 2-year-old Super Hummock had any vine cover, whereas 98% of the trees at 17-year-old Morrow Swamp had some vine cover. Fifteen-year-old Guy Branch was an exception, with only 23% of the trees having some degree of vine cover.

Despite increasing vine cover on trees with site age, Figure 6.12 shows that the mean dbh of trees not hosting and trees hosting vines are similar. Trees not hosting vines were not found to have greater dbhs at the 95% confidence level. The exception was *Taxodium distichum* at Morrow Swamp with trees not hosting vines (median1 = 12.35) having slightly greater dbhs than those trees hosting vines (median2 = 9.10, W = 499.5, n1 = 16, n2 = 35, P = 0.0459). Specific values for the Mann-Whitney test at the 95% confidence level used to test the null hypothesis that the median dbh of trees not hosting vines is greater than the median dbh for trees hosting vines are provided in Appendix 6.D.

Abiotic Data

Sunlight Transmittance

While the greatest number of rooted vines and dry weight vine biomass occurred at the highest percent sunlight transmittance, there was no clear trend in vine biomass or number of vines with percent sunlight transmittance apparent. Figure 6.13 shows that vines were rooted throughout the range of available sunlight transmittance, with some number of rooted vines occurring between 20-85% transmittance. Small quantities of vine biomass occurred throughout the 10-80% sunlight transmittance range. The two greatest quantities of vine biomass both occurred around 85% transmittance.

Figure 6.14 illustrates that both herbaceous and woody-rooted vines and dry weight vine biomass occurred throughout the entire range of tree basal area (m^2/ha). There was also a trend for decreasing sunlight transmittance with greater tree basal area, probably because of a positive relationship between basal area and crown area or canopy

Table 6.9. Percent of Trees Throughout the Landscape Hosting Vines. Dashed Lines Signify that the Particular Tree Did Not Occur Within the Particular Elongated Quadrat.

Tree Species	LP2 Phase-1 (0.5)	Super Hummock (2)	Nichols Mine (5)	Hydric Hammock (6)	Cateye (12)	SP11 (14)	Guy Branch (15)	Morrow Swamp (17)	Sink Branch (18)
Acer rubrum	0%	12%	0%	68%	0%	0%	17%	- -	100%
Carya spp.	- -	- -	- -	- -	0%	- -	- -	- -	- -
Celtis laevigata	0%	- -	- -	- -	- -	- -	- -	- -	- -
Cornus florida	- -	- -	- -	- -	- -	- -	- -	- -	100%
Fraxinus caroliniana	- -	2%	7%	- -	0%	- -	- -	- -	100%
Ilex cassine	0%	0%	- -	100%	0%	- -	- -	- -	- -
Liquidambar styraciflua	0%	- -	0%	56%	- -	0%	- -	- -	100%
Magnolia virginiana	- -	- -	0%	44%	- -	- -	- -	- -	- -
Nyssa spp.	0%	- -	0%	- -	- -	- -	- -	- -	- -
Persea borbonia	- -	0%	- -	- -	- -	- -	- -	- -	- -
Persea palustris	0%	- -	0%	- -	- -	- -	- -	- -	- -
Pinus elliottii	- -	- -	0%	- -	- -	0%	- -	- -	100%
Prunus serotina	- -	- -	- -	- -	- -	- -	- -	- -	100%
Quercus laurifolia	0%	- -	- -	0%	0%	0%	- -	- -	84%
Quercus nigra	0%	- -	- -	0%	0%	- -	- -	- -	- -
Quercus spp.	- -	0%	0%	- -	- -	- -	- -	- -	- -
Taxodium spp.	- -	- -	5%	- -	0%	0%	30%	98%	100%
Ulmus americana	0%	17%	0%	- -	- -	- -	- -	- -	100%
Unknown	- -	0%	33%	- -	- -	- -	- -	- -	- -
All Trees	0%	5%	4%	58%	0%	0%	20%	98%	96%

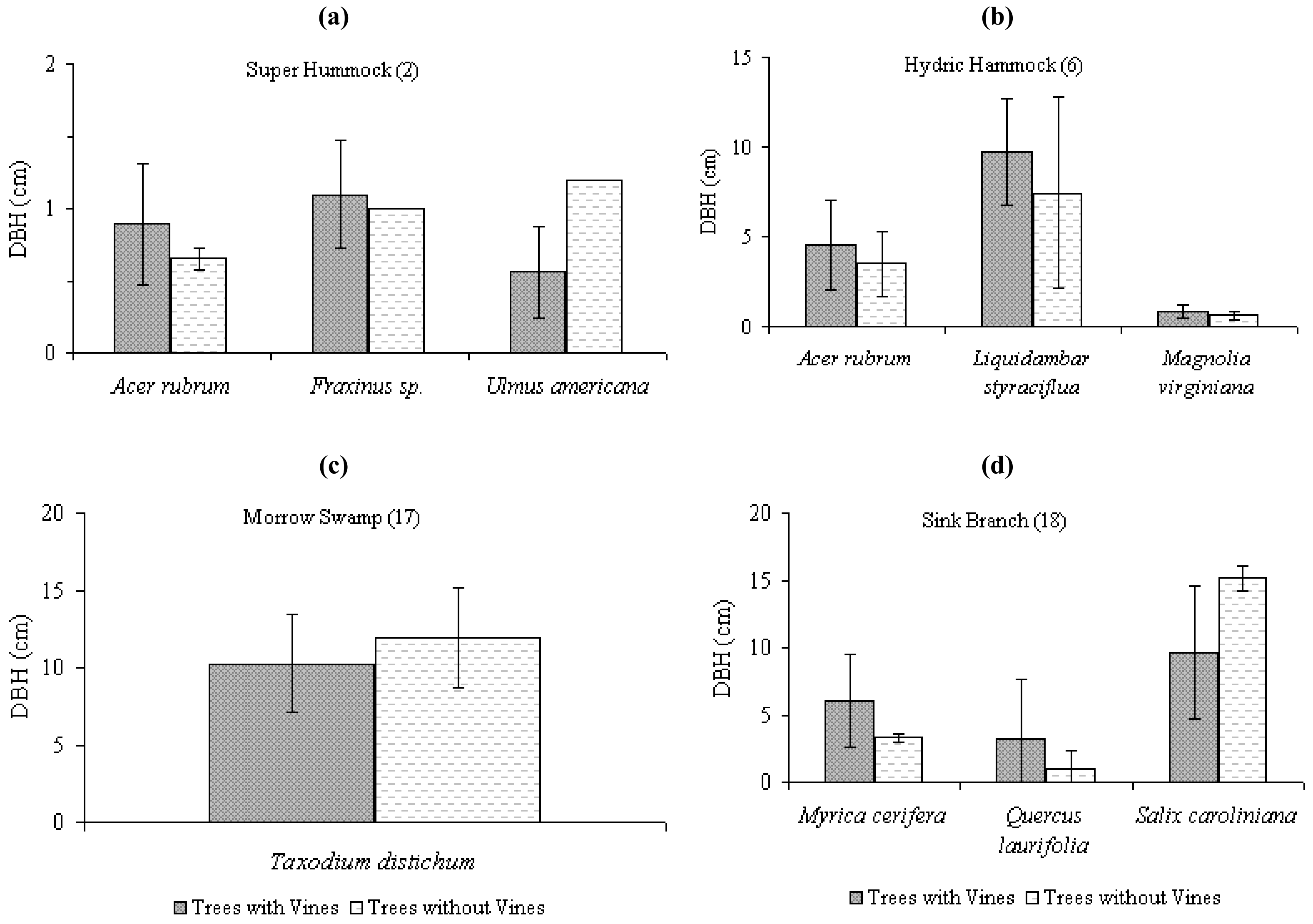


Figure 6.12. Mean DBH for Trees Hosting Vines and Trees Not Hosting Vines.

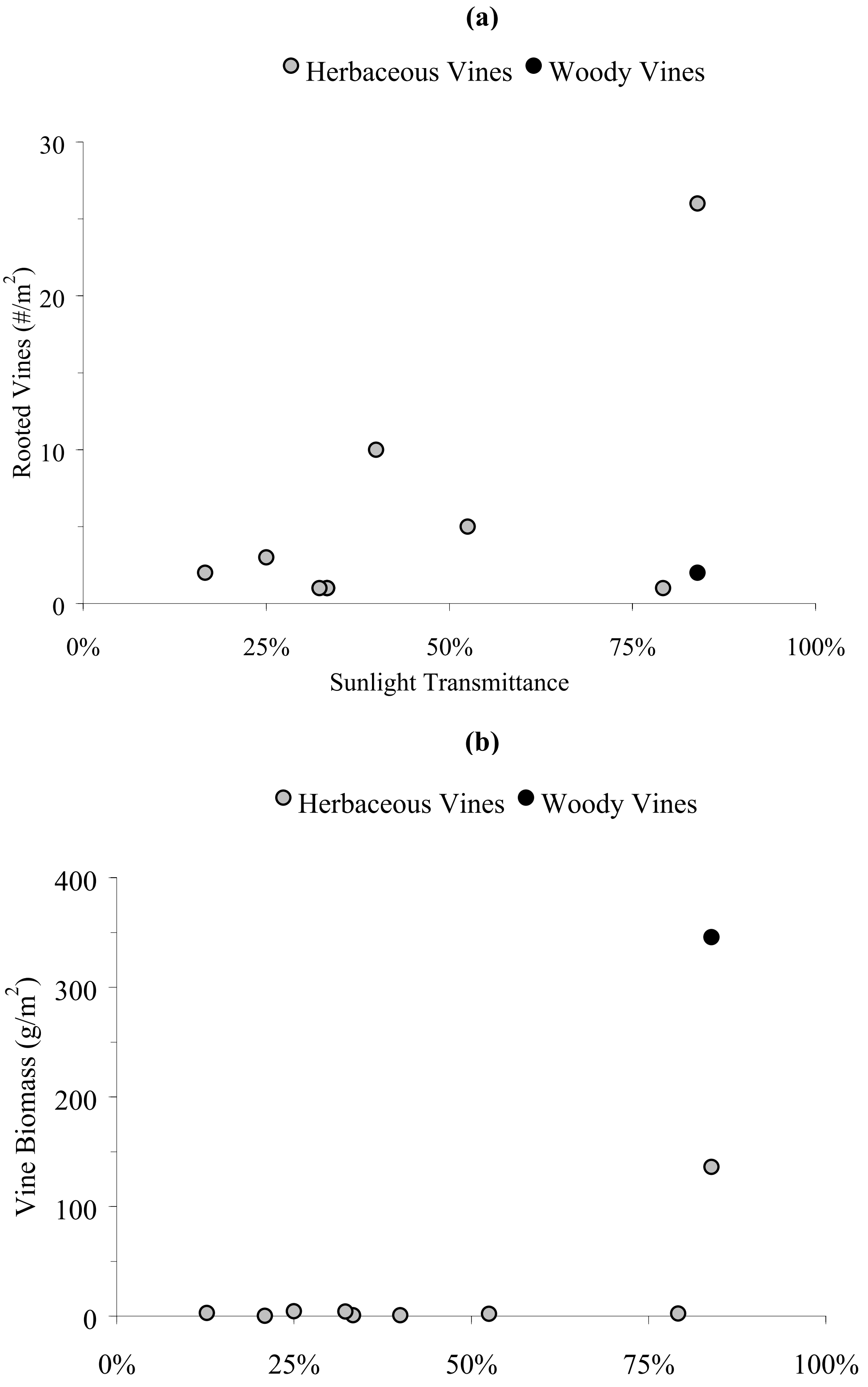


Figure 6.13. Vine Presence According to Sunlight Transmittance (%) on the Chronosequence Sites. (a) Compares the Rooted Vines (#/m^2) and (b) the Weight of Vine Biomass (g/m^2).

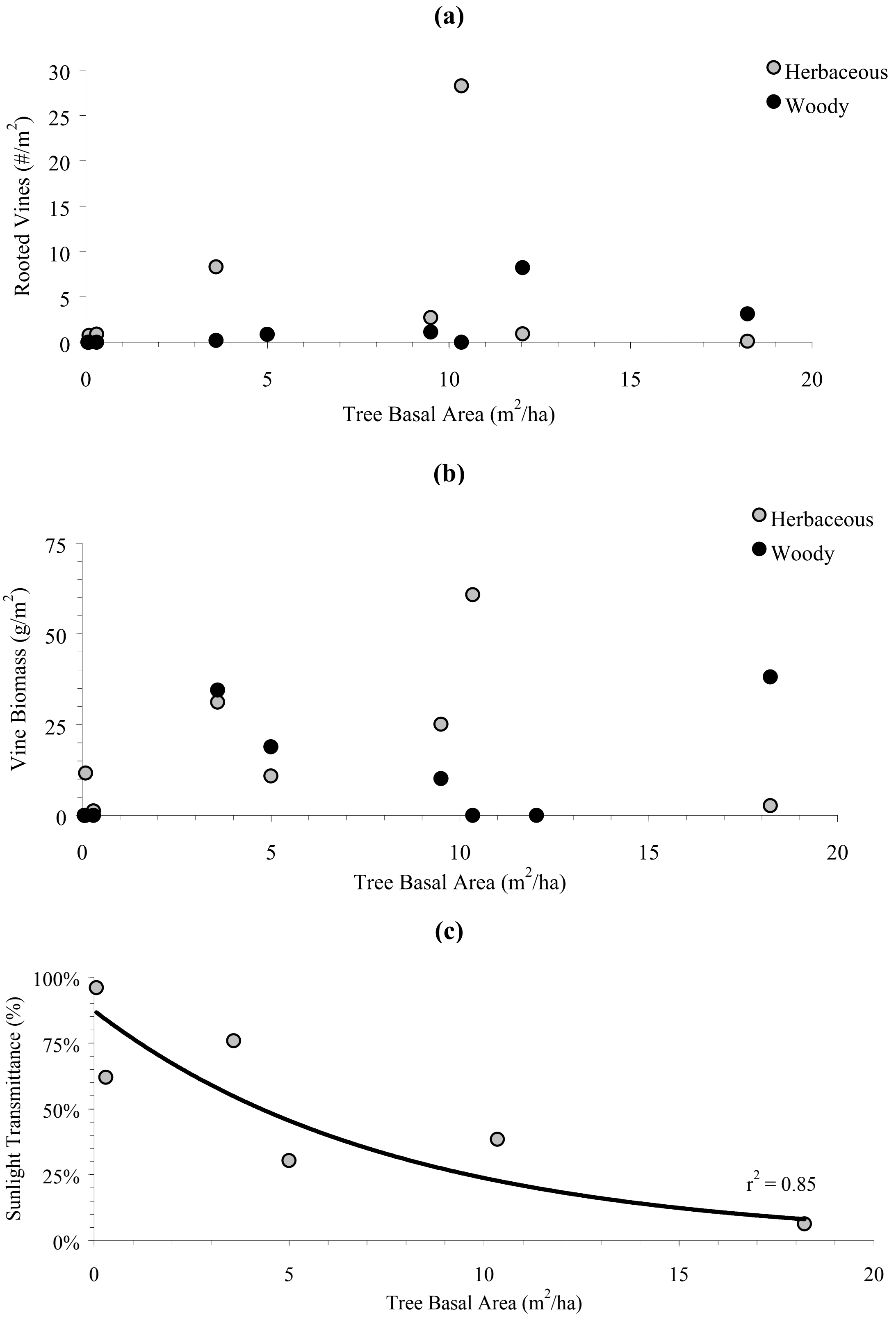


Figure 6.14. Vine Distribution in the Landscape According to the Soil Moisture Correlating with Tree Basal Area. (c) Shows the Correlation Between Increased Basal Area and Decreased Sunlight Transmittance.

cover. Stand characteristics such as stem density, tree basal area, and canopy height throughout the chronosequence sites are given in Table 6.7.

Soil Characteristics

Soils data from all of the square meter quadrats were analyzed to explore what conditions support vine growth. Soil moisture, bulk density, percent organic matter, pH, and plant available nutrients were determined from soil cores taken within each square meter quadrat. Some threshold levels and trends were apparent. All of the soil parameters have been compared to both the number of rooted vines and dry weight vine biomass.

Table 6.10 summarizes the data for soil moisture, dry bulk density, and soil organic matter for the chronosequence sites. Values given are the mean for each site ± the standard deviation. Values without standard deviations have been calculated using a single soil core. Some of the soil cores were excluded due to possible improper field techniques or laboratory processing. Note the unusually low mean dry bulk density of 0.52 (± 0.44) g/cm^3 at Guy Branch.

Although soil moisture data result from synoptic sampling and does not represent absolute soil moisture associated with vine rooting it does indicate vine rooting zonation based on a range of soil moisture. Figure 6.15 shows all of the herbaceous and woody rooted vines occurred within the range of 5%-45% soil moisture, with a range of 0-60 herbaceous vines and 0-20 woody vines rooted per square meter. The herbaceous rooted vines were concentrated within the 25-45% soil moisture range, while the woody rooted vines were concentrated within the 5-25% soil moisture range. Three outliers occurred between 83-85% soil moisture. All three samples were from cores taken at Guy Branch. Most likely these values were incorrect due to the mean standing water depth of 40 cm at Guy Branch, and difficulty in the field separating standing water from soil cores. All of the harvested vine biomass occurred in areas with soil moisture ranging between 5-45%, with the exception of the same three outliers from Guy Branch.

Profiles of each transect beginning in the upland-transitional ecotone regions and progressing into the wetlands suggest a zone of soil moisture that favors vine growth. Figures 6.16 and 6.17 illustrate soil moisture trends on transects from Hydric Hammock and Sink Branch, respectively. The remaining transect profiles relating to soil moisture are provided in Appendix 6.E. Figure 6.16(B) shows that when the soil moisture is below 20% there are less than 5 rooted vines per meter square, yet when soil moisture increases to 25% there are nearly 30 rooted vines per meter square. Figure 6.17 depicts a similar trend evident at Sink Branch. On transect 2, when the soil moisture ranges from 10-20% there are approximately 10-20 rooted vines per square meter. However, as soil moisture increases to over 30%, less than 5 vines are rooted per square meter.

Figure 6.18 provides the less evident threshold levels of dry soil bulk density (g/cm^3), suggesting that soil substrate is not a dominant factor in determining vine

Table 6.10. Summary Soil Data for the Chronosequence Sites, Including Soil Moisture (%), Dry Bulk Density (g/cm^3), and Soil Organic Matter (%). Values Represent the Mean Value ± 1 Standard Deviation.

Site	LP2 Phase 1	Super Hummock	Nichols Mine	Hydric Hammock	Cateye
Age (years)	0.5	2	5	6	12
Soil Moisture (%)					
No Rooted Vines	10.71 ± 2.62	24.88 ± 5.71	13.57 ± 4.01	25.68 ± 11.85	25.40 ± 11.32
Rooted Herbaceous Vines	- -	26.16	15.48 ± 4.82	17.36 ± 8.61	24.77
Rooted Woody Vines	- -	- -	- -	27.76	- -
Dry Bulk Density (g/cm^3)					
No Rooted Vines	1.62 ± 0.09	1.21 ± 0.20	1.26 ± 0.16	0.77 ± 0.04	0.88 ± 0.36
Rooted Herbaceous Vines	- -	1.38	1.07 ± 0.14	0.95 ± 0.30	0.92
Rooted Woody Vines	- -	- -	- -	0.73	- -
Soil Organic Matter (%)					
No Rooted Vines	2.16 ± 0.76	4.85 ± 3.18	1.81 ± 0.66	11.28 ± 0.49	7.27 ± 5.40
Rooted Herbaceous Vines	- -	4.52	2.30 ± 0.68	5.95 ± 4.34	6.65
Rooted Woody Vines	- -	- -	- -	12.85	- -
Number of Quadrats with Vines					
No Rooted Vines	17	11	13	2	5
Rooted Herbaceous Vines	0	1	6	8	1
Rooted Woody Vines	0	0	0	1	0

Table 6.10 (Cont.) Summary Soil Data for Chronosequence Sites, Including Soil Moisture (%), Dry Bulk Density (g/cm^3), and Soil Organic Matter (%). Values Represent the Mean Value ± 1 Standard Deviation.

Site		SP11	Guy Branch	Morrow Swamp	Sink Branch
Age (years)		14	15	17	18
Soil Moisture (%)					
	No Rooted Vines	13.10	48.16 ± 31.48	27.48	- -
	Rooted Herbaceous Vines	12.86	70.18 ± 24.57	36.56 ± 6.16	19.67 ± 10.85
	Rooted Woody Vines	19.29 ± 5.81	- -	62.53 ± 29.27	17.12 ± 9.67
Dry Bulk Density (g/cm^3)					
	No Rooted Vines	1.47	0.52 ± 0.44	1.15	- -
	Rooted Herbaceous Vines	1.36	0.24 ± 0.27	0.83 ± 0.24	1.06 ± 0.36
	Rooted Woody Vines	1.29 ± 0.13	- -	0.33 ± 0.31	1.11 ± 0.31
Soil Organic Matter (%)					
	No Rooted Vines	3.17	6.77 ± 6.35	3.42	- -
	Rooted Herbaceous Vines	4.49	21.71 ± 12.78	4.56 ± 2.07	4.85 ± 5.40
	Rooted Woody Vines	3.42 ± 1.07	- -	15.85 ± 10.98	4.45 ± 4.22
Number of Quadrats with Vines					
	No Rooted Vines	1	4	1	0
	Rooted Herbaceous Vines	1	7	3	8
	Rooted Woody Vines	6	2	0	13

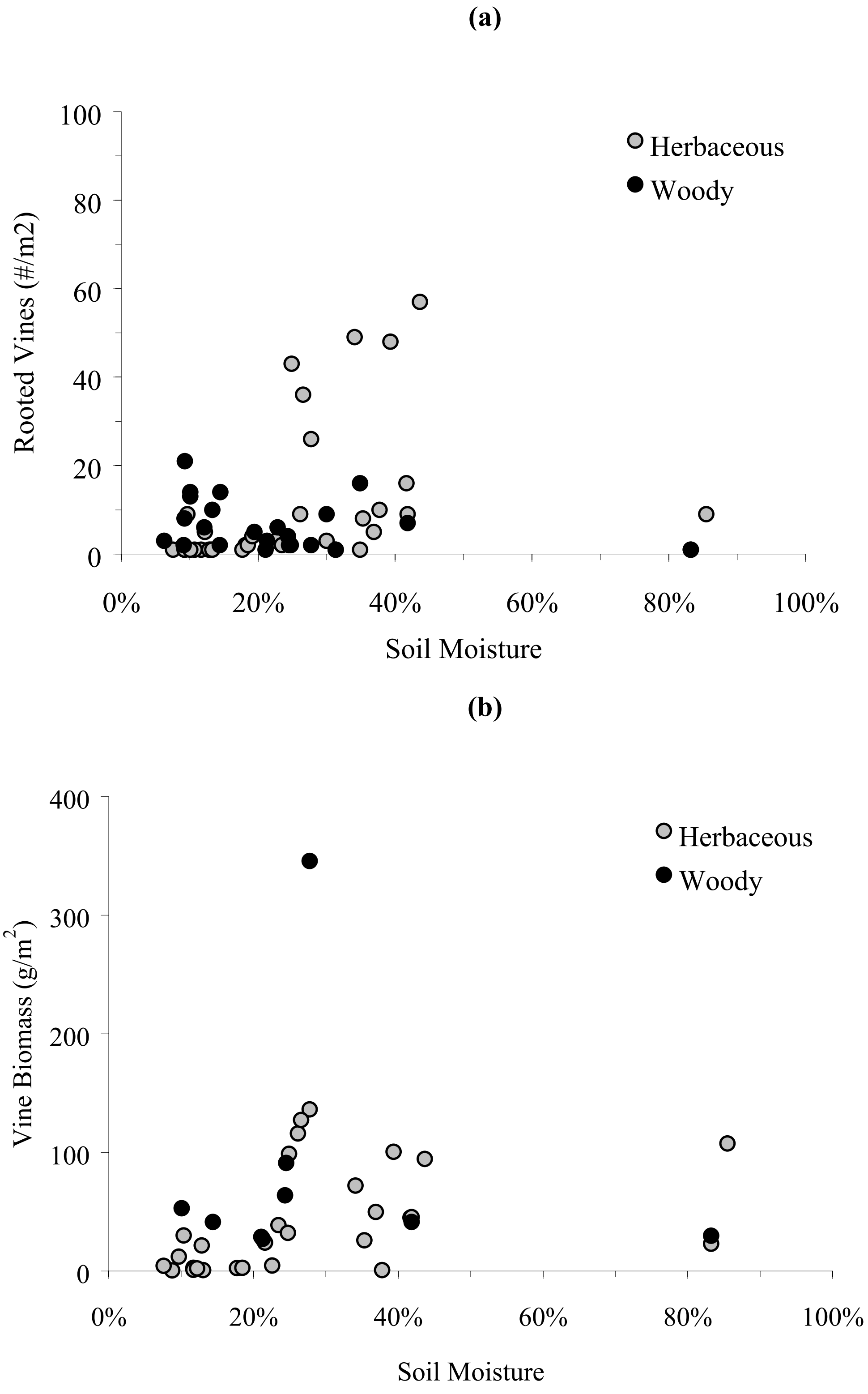


Figure 6.15. Vine Distribution in the Landscape According to the Soil Moisture on the Chronosequence Sites. (a) Compares the Rooted Vines (#/m^2) and (b) the Dry Weight of Vine Biomass (g/m^2).

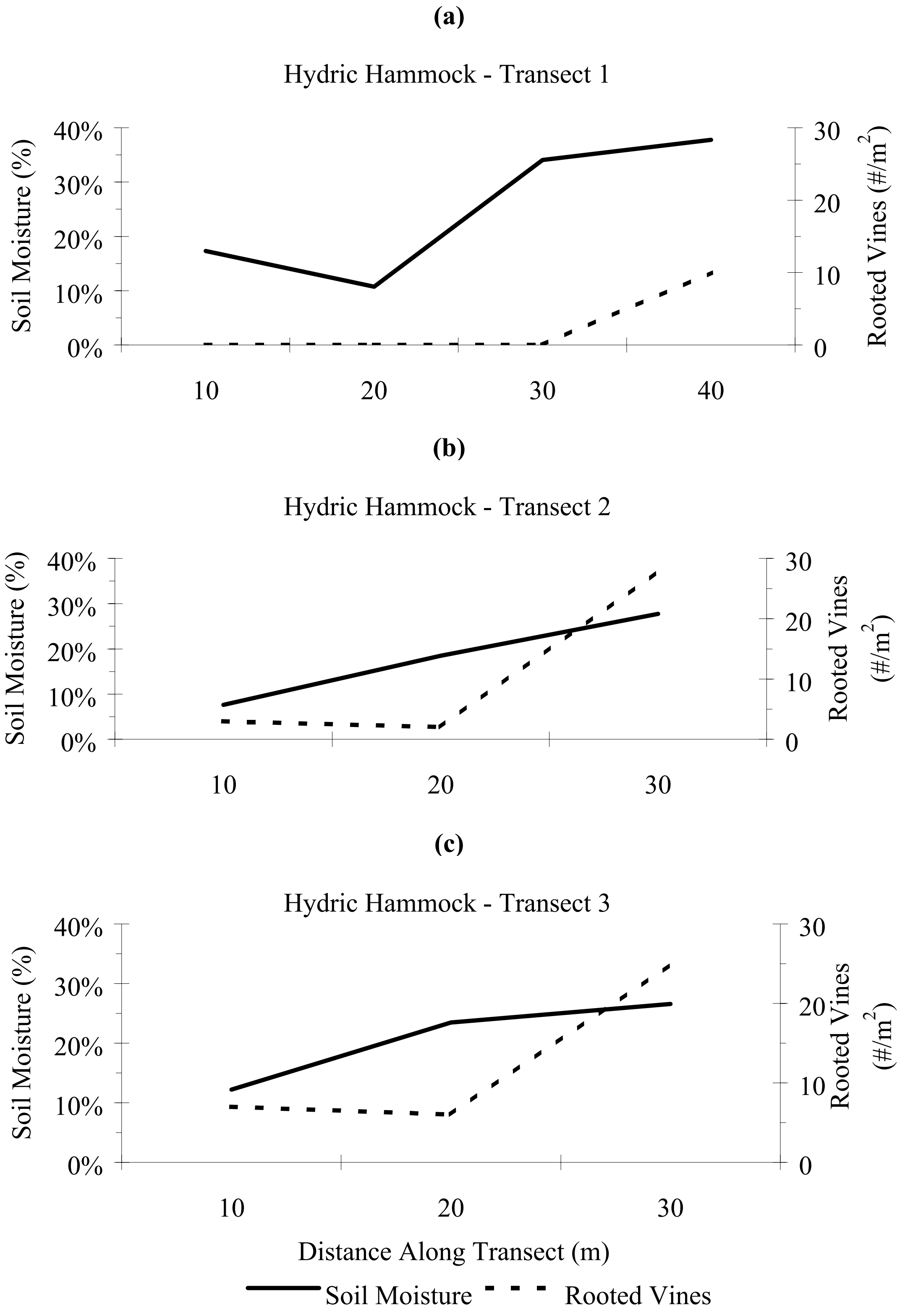


Figure 6.16. The Number of Rooted Vines Relating to Soil Moisture on Gradients Through the Wetland. Hydric Hammock is a Fringing Wetland. (a) Shows the 40 Meter Long Transect 1; (b) Shows the 30 Meter Long Transect 2; (c) Shows the 30 Meter Long Transect 3.

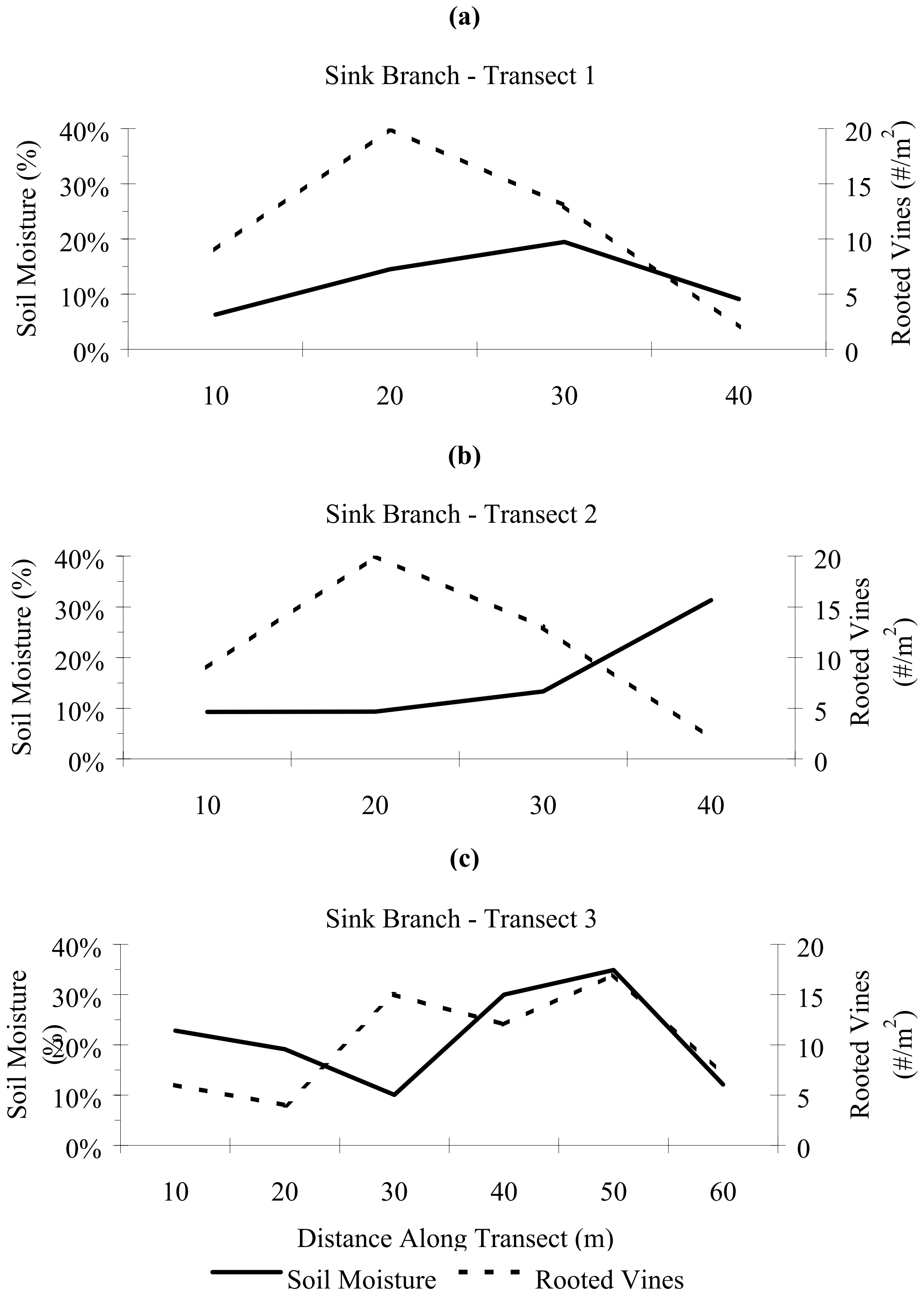


Figure 6.17. The Number of Rooted Vines Relating to Soil Moisture on Gradients Through the Wetland. Sink Branch Borders Two Stream Channels. (a) Shows the 40 Meter Long Transect 1; (b) Shows the 40 Meter Long Transect 2; (c) Shows the 60 Meter Long Transect 3.

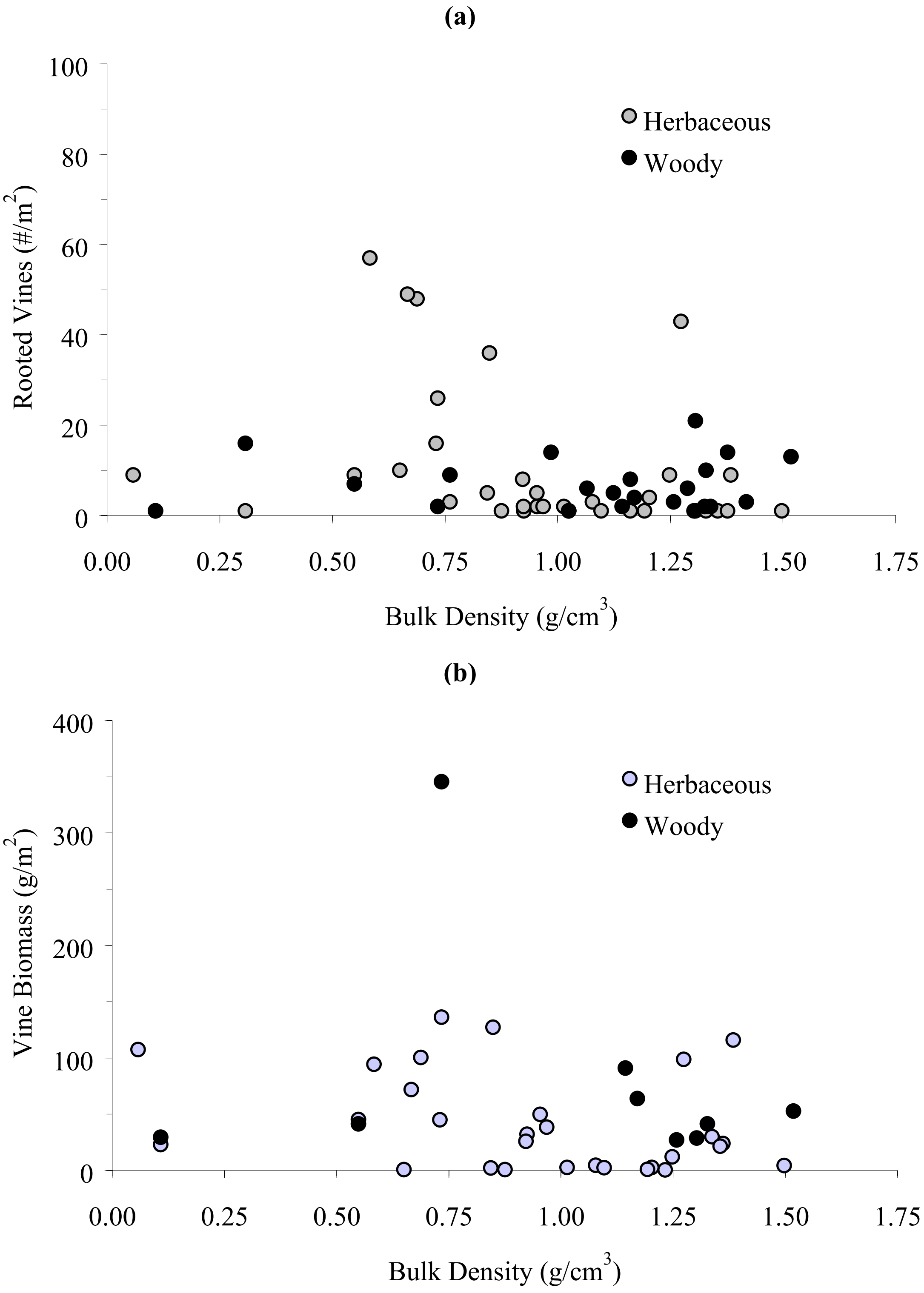


Figure 6.18. Vine Distribution in the Landscape According to the Dry Soil Bulk Density on the Chronosequence Sites. (a) Compares the Rooted Vines (#/m^2) and (b) the Dry Weight of Vine Biomass (g/m^2).

abundance. The outliers are again values from Guy Branch, and are most likely inaccurate.

Figure 6.19 shows that herbaceous rooted vines and vine biomass occurred predominantly in areas with 5-15% soil organic matter. The majority of the woody vines occurred in the range of 0-10% soil organic matter. The three outliers falling between 24-33% soil organic matter were again samples taken from Guy Branch, and may be inaccurate. Additionally, the square meter quadrat with 0% organic matter with 24 grams of herbaceous biomass was recorded at Super Hummock. This sample quadrat fell randomly on a hummock, which may explain the zero value for organic matter content due to oxidation on the elevated area.

The plant-available nutrients calcium, magnesium, potassium, phosphorus, and iron, show possible threshold ranges based on the presence of vines. Table 6.11 provides a summary of available nutrients where no rooted vines, herbaceous rooted vines, and woody rooted vines occur throughout the chrono-sequence sites. Figure 6.20 shows that vines do not seem to show a preference for soil calcium levels growing in areas ranging from 100-8,000 g calcium/m^3, with a concentration of rooted vines between 100-6,000 g calcium/m^3. Vine biomass follows a similar pattern, with calcium concentrations ranging from 100-9,000 g calcium/m^3.

Figure 6.21 illustrates that herbaceous and woody vines grew in soils with magnesium ranges from 15-625 g magnesium/m^3, yet there were more rooted vines concentrated within the 200-375 g magnesium/m^3 range. Vine biomass does not appear concentrated, ranging from 15-625 g magnesium/m^3. The square meter quadrat with the largest quantity of woody vine biomass with 346 grams had a soil magnesium concentration of 182 g magnesium/m^3. However, this does not appear to be a representative sample.

Figure 6.22 shows soil potassium had a concentration of rooted vines between 5-35 g potassium/m^3, with fewer rooted vines at potassium concentrations greater than 35 g potassium/m^3. Vine biomass followed a similar pattern, with the greatest concentration of vine biomass between 5-30 g potassium/m^3.

Figure 6.23 depicts the greatest concentration of rooted vines concerning soil phosphorus concentrations occurred in a range of 1,500-2,500 g phosphorus/m^3, including both herbaceous and woody vines. However, vines were rooted throughout the entire soil phosphorus range of 0-3,000 g phosphorus/m^3. The greatest concentration of herbaceous vine biomass occurred in the range of 1,000-2,000 g phosphorus/m^3. Woody vine biomass appeared concentrated between 0-500 g phosphorus/m^3. The three soil cores with high concentrations between 2,700-3,350 g phosphorus/m^3 represent soil samples from three different sites (Hydric Hammock, Cateye, and Morrow Swamp) implying that soil phosphorus level may fluctuate naturally on these reclaimed forested wetland sites.

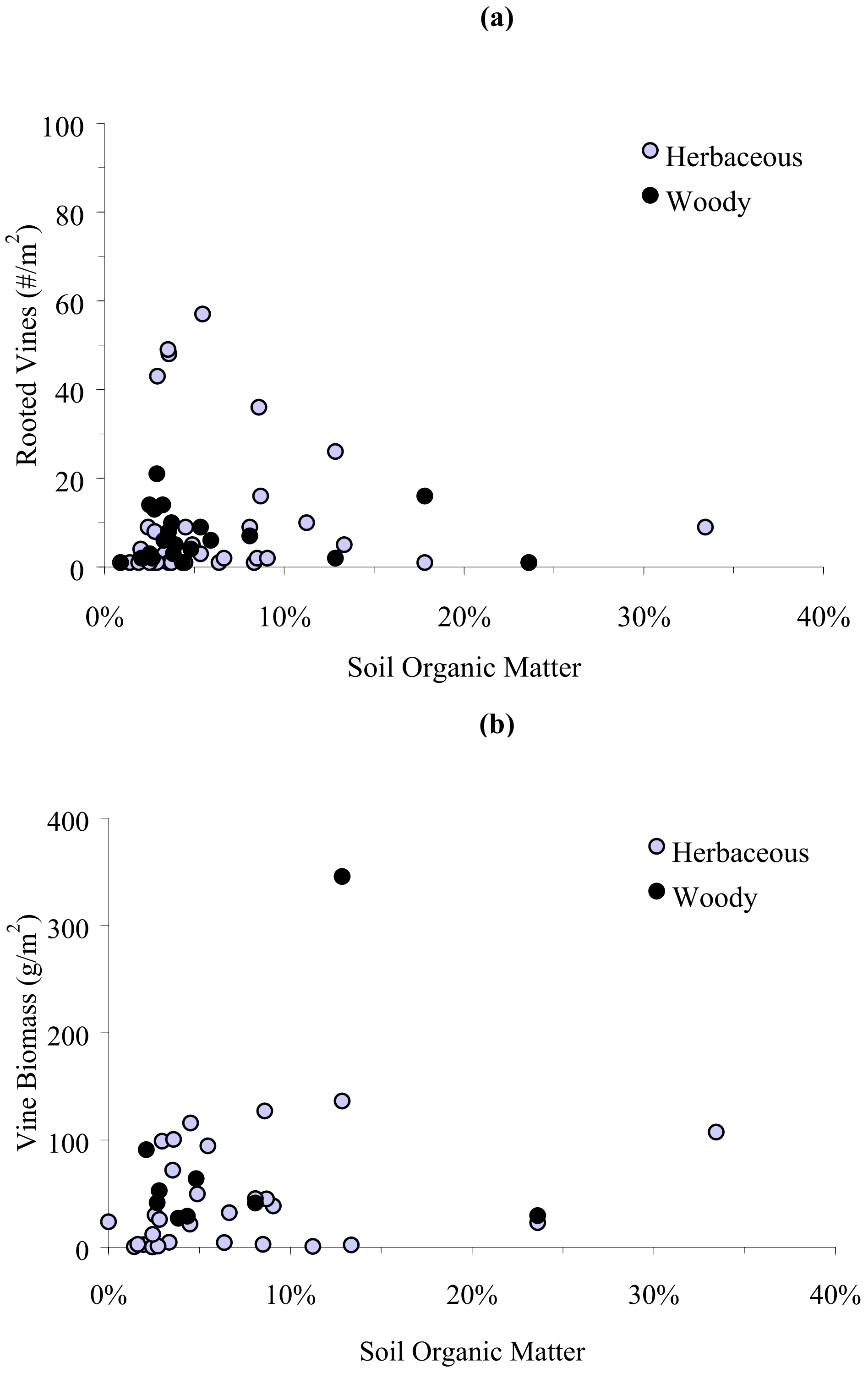


Figure 6.19. Vine Distribution in the Landscape According to the Soil Organic Matter Content on the Chronosequence Sites. (a) Compares the Rooted Vines (#/m^2) and (b) the Dry Weight of Vine Biomass (g/m^2).

Table 6.11. Summary of the Soil Nutrient Data for the Chronosequence Sites. Values in g/cm3 Represent the Mean Value ± 1 Standard Deviation.

	LP2 Phase 1	Super Hummock	Nichols Mine	Hydric Hammock	Cateye	SP11	Guy Branch	Morrow Swamp	Sink Branch
	0.5	2	5	6	12	14	15	17	18
Calcium									
No Rooted Vines	1939 ± 1542	3401 ± 1394	3144 ± 1992	2279 ± 185	4855 ± 2736	3616	3186 ± 2373	5762	- -
Rooted Herbaceous Vines	- -	4914	3242 ± 2172	3264 ± 1802	3096	5312	1383 ± 1549	4839 ± 1554	4644 ± 1675
Rooted Woody Vines	- -	- -	- -	2150	- -	436 ± 317	- -	1882 ± 1818	4627 ± 1763
Magnesium									
No Rooted Vines	202 ± 191	386 ± 175	107 ± 61	153 ± 50	166 ± 37	77	382 ± 269	576	- -
Rooted Herbaceous Vines	- -	515	151 ± 103	167 ± 84	136	77	320 ± 254	335 ± 153	305 ± 152
Rooted Woody Vines	- -	- -	- -	182	- -	39 ± 22	- -	410 ± 281	304 ± 148
Potassium									
No Rooted Vines	26.27 ± 11.93	8.13 ± 1.45	33.50 ± 19.00	15.77 ± 4.10	25.97 ± 6.08	12.79	11.41 ± 4.91	16.68	- -
Rooted Herbaceous Vines	- -	11.63	28.56 ± 16.49	23.37 ± 11.06	13.68	22.09	22.39 ± 19.96	12.48 ± 7.54	29.28 ± 17.91
Rooted Woody Vines	- -	- -	- -	24.44	- -	16.74 ± 5.30	- -	30.72 ± 19.51	29.40 ± 15.41
Phosphorus									
No Rooted Vines	734 ± 664	915 ± 597	1268 ± 854	497 ± 128	1565 ± 1223	1602	839 ± 694	1702	- -
Rooted Herbaceous Vines	- -	1523	1248 ± 848	1090 ± 759	1174	2005	140 ± 226	1652 ± 624	1655 ± 791
Rooted Woody Vines	- -	- -	- -	465	- -	255 ± 132	- -	209 ± 271	1586 ± 710
Iron									
No Rooted Vines	74.63 ± 33.92	63.58 ± 25.30	87.66 ± 22.10	20.95 ± 2.80	44.67 ± 13.38	37.48	19.82 ± 20.43	51.75	- -
Rooted Herbaceous Vines	- -	56.1	74.87 ± 12.83	46.53 ± 30.59	80.78	38.20	0.96 ± 0.34	61.50 ± 27.34	54.48 ± 29.45
Rooted Woody Vines	- -	- -	- -	14.80	- -	63.60 ± 40.03	- -	209.32 ± 271.46	58.97 ± 33.15
Ammonium (NH_4-N)									
No Rooted Vines	0.35 ± 0.44	0.44 ± 0.16	0.34 ± 0.11	1.11 ± 0.77	3.36 ± 6.65	0.52 ± 0.45	0.08 ± 0.10	0	- -
Rooted Herbaceous Vines	- -	0.75	0.34 ± 0.21	0.54 ± 0.30	3.79	0.45	0.07 ± 0.01	0.10 ± 0.05	0.41 ± 0.27
Rooted Woody Vines	- -	- -	- -	1.01	- -	0.55 ± 0.33	- -	0.07 ± 0.02	0.50 ± 0.39
Nitrate (NO_3-N)									
No Rooted Vines	0.27 ± 0.29	0.76 ± 1.06	1.37 ± 1.37	1.24 ± 1.61	2.18 ± 1.94	1.72	0.21 ± 0.26	0.15	- -
Rooted Herbaceous Vines	- -	0.37	0.92 ± 0.85	1.34 ± 1.21	0.36	0.15	0.06 ± 0.10	0.21 ± 0.18	2.93 ± 2.53
Rooted Woody Vines	- -	- -	- -	0.10	- -	0.14 ± 0.19	- -	0.08 ± 0.12	2.45 ± 2.05

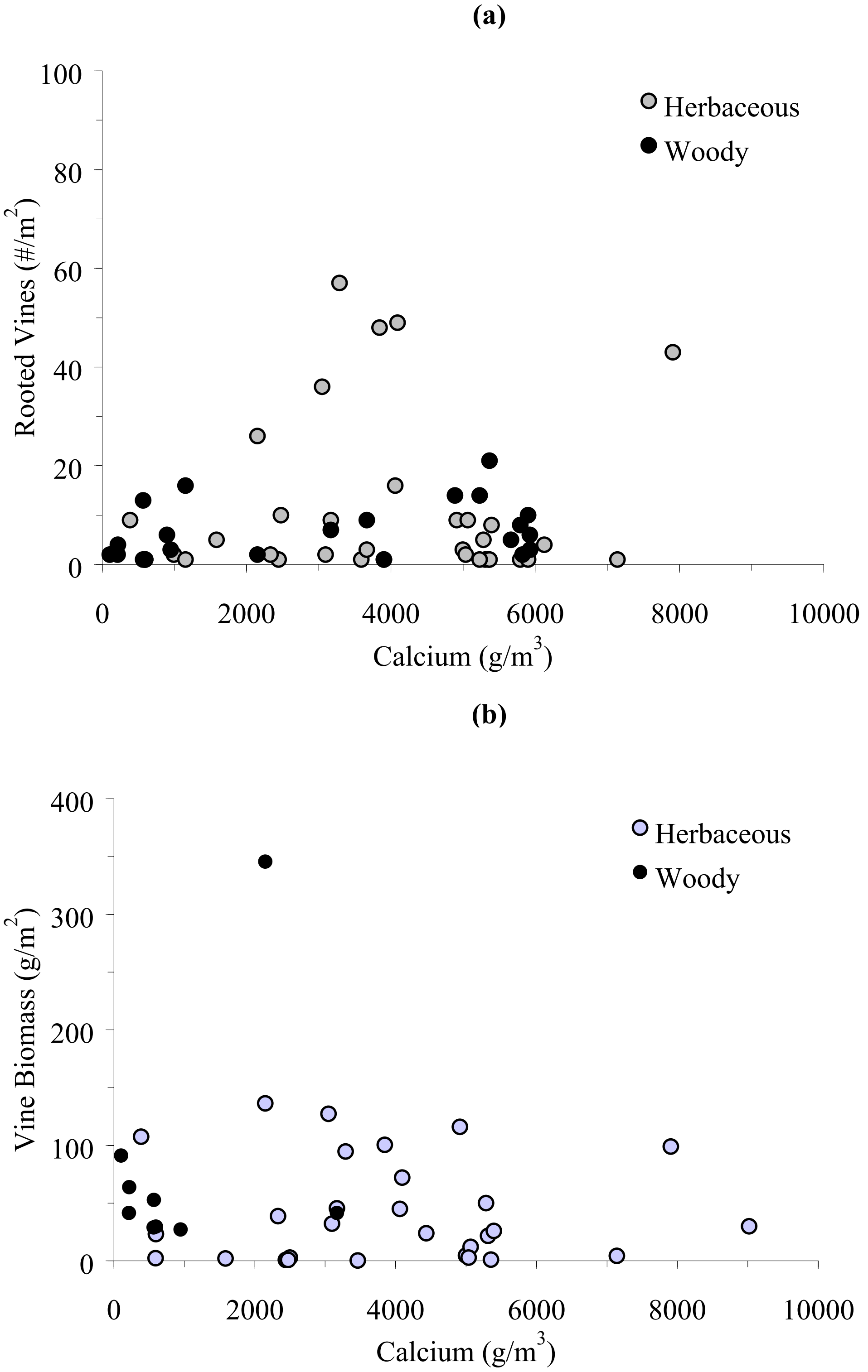


Figure 6.20. Vine Distribution in the Landscape According to the Soil Calcium Concentrations on the Chronosequence Sites. (a) Shows the Rooted Vines (#/m^2) and (b) the Dry Weight of Vine Biomass (g/m^2).

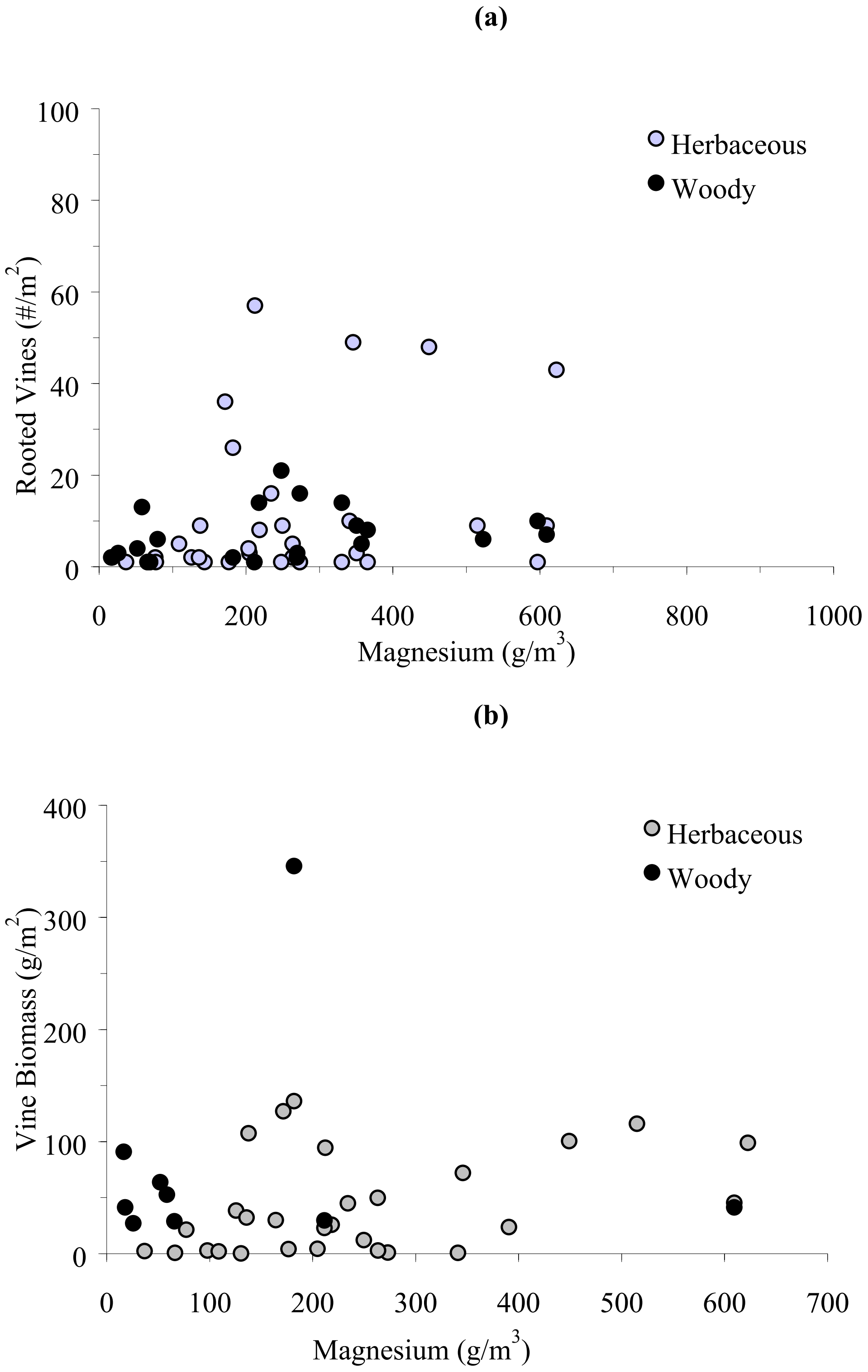


Figure 6.21. Vine Distribution in the Landscape According to the Soil Magnesium Concentrations on the Chronosequence Sites. (a) Shows the Rooted Vines (#/m^2) and (b) the Dry Weight of Vine Biomass (g/m^2).

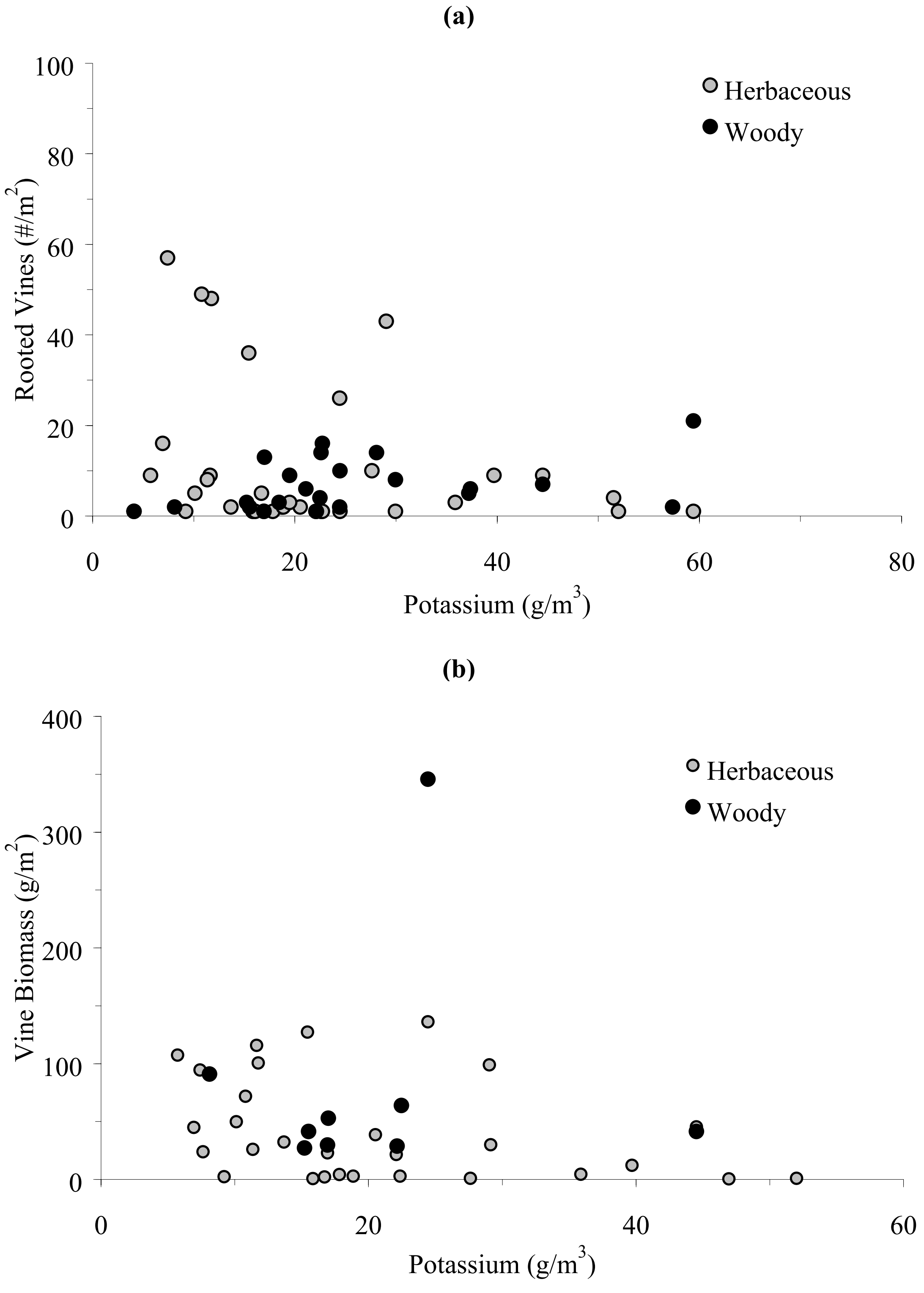


Figure 6.22. Vine Distribution in the Landscape According to the Soil Potassium Concentrations on the Chronosequence Sites. (a) Shows the Rooted Vines (#/m^2) and (b) the Dry Weight of Vine Biomass (g/m^2).

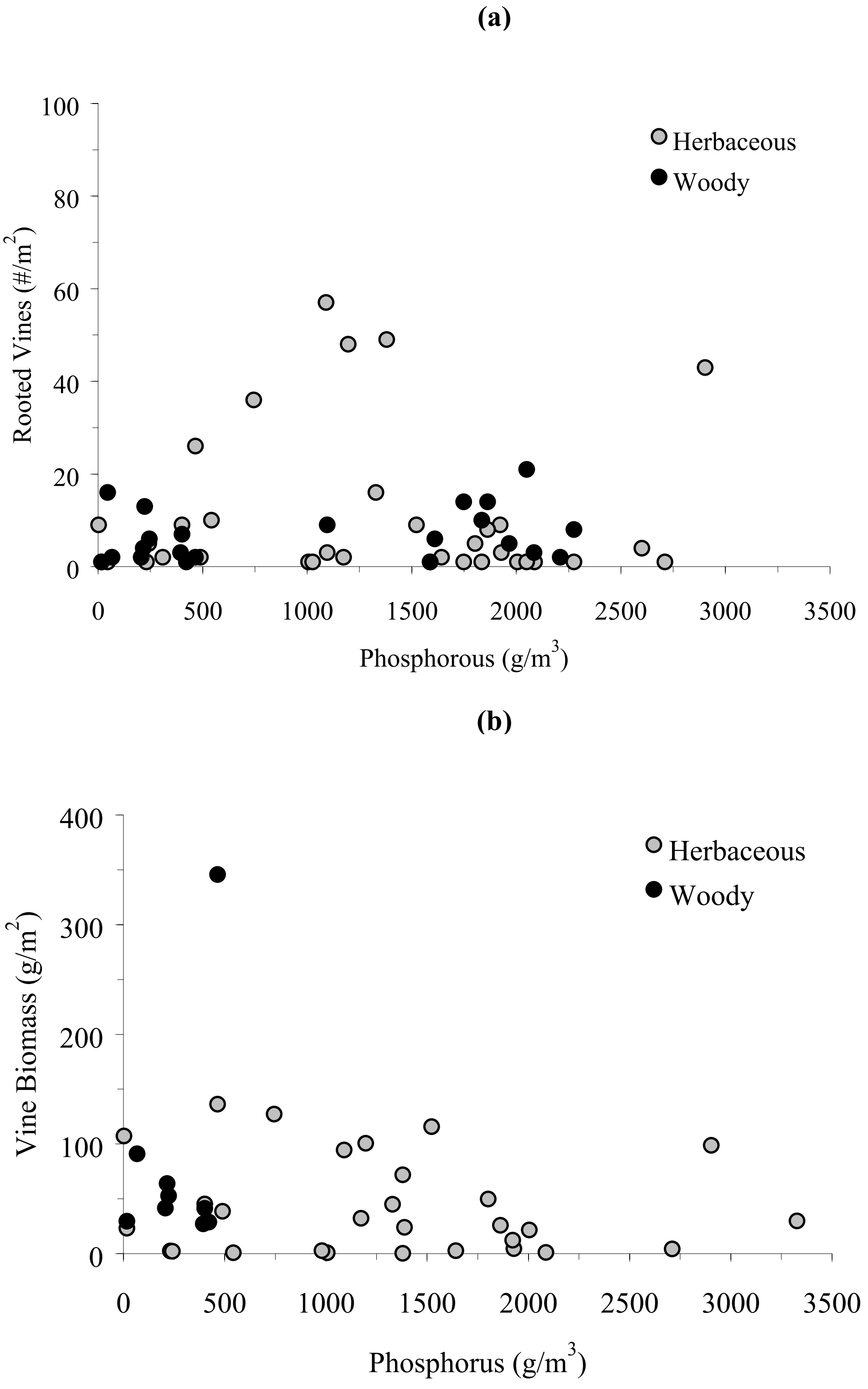


Figure 6.23. Vine Distribution in the Landscape According to the Soil Phosphorus Concentrations on the Chronosequence Sites. (a) Shows the Rooted Vines (#/m^2) and (b) the Dry Weight of Vine Biomass (g/m^2).

Figure 6.24 shows that the number of herbaceous and woody vines rooted and vine biomass appeared uniform throughout the entire 1-133 g iron/ m^3 range of soil iron concentrations. The three samples with iron concentrations greater than 100 g iron/ m^3 occurred at three different sites (SP11, Morrow Swamp, and Sink Branch) again suggesting natural inter-site variability.

Soil nitrogen concentrations as ammonium (NH_4-N) and nitrate (NO_3-N) were compared to occurrence of rooted vines and dry weight vine biomass. Figure 6.25 shows that almost all of the rooted vines and dry weight vine biomass were located in areas of 0-1 g NH_4-N/ m^3. Only five data points had concentrations greater than 1 g NH_4-N/ m^3 hosting both herbaceous and woody vines. Similarly, Figure 6.26 illustrates that a majority of the rooted vines and dry weight vine biomass were located within the 0-2 g NO_3-N/ m^3 range. However, many vines were scattered throughout the entire soil nitrate range of 0-4 g NO_3-N/ m^3.

INTENSIVE SAMPLING DESIGN

Six wetlands were sampled with an intensive sampling design for rooted vines and dry weight vine biomass, mean vine basal diameter, vegetative cover, vine leaf area, sunlight transmittance, water depth, and soil parameters.

Vegetative Data

Figure 6.27 shows that every site sampled intensively had at least 2.5 rooted herbaceous vines per square meter, and over 20 grams of dry weight herbaceous vine biomass per square meter. Only three intensive sample sites had rooted woody vines, including Hydric Hammock with 2.5 rooted woody vines, Cateye with 3.5 rooted woody vines, and SP11 with 2 rooted woody vines per square meter. There was greater woody biomass at both Hydric Hammock and Cateye than herbaceous vine biomass. However, SP11 was dominated by herbaceous biomass. The standard deviations of both rooted vines and vine biomass are extremely large, suggesting great heterogeneity throughout the landscape. Figure 6.27 also shows that the mean vine basal diameter varied considerably, with no significant differences between sites.

Figure 6.28 illustrates that vines occurred throughout all class of herbaceous understory vegetative cover. Herbaceous vines occurred throughout quadrats with greater than 10% herbaceous understory cover, and no woody vines occurred in areas of 10-25% herbaceous understory cover. Quadrats with no vines were represented by herbaceous ground cover greater than 25%.

Vine leaf area appears to show a weak correlation with site age. Figure 6.29 shows that the greatest leaf area (number of leaves per square meter) occurred around age 7 years, with a decrease in the vine leaf area as a site ages. Additionally, mean vines leaf area was not significantly different throughout varying degrees of vegetative cover. The

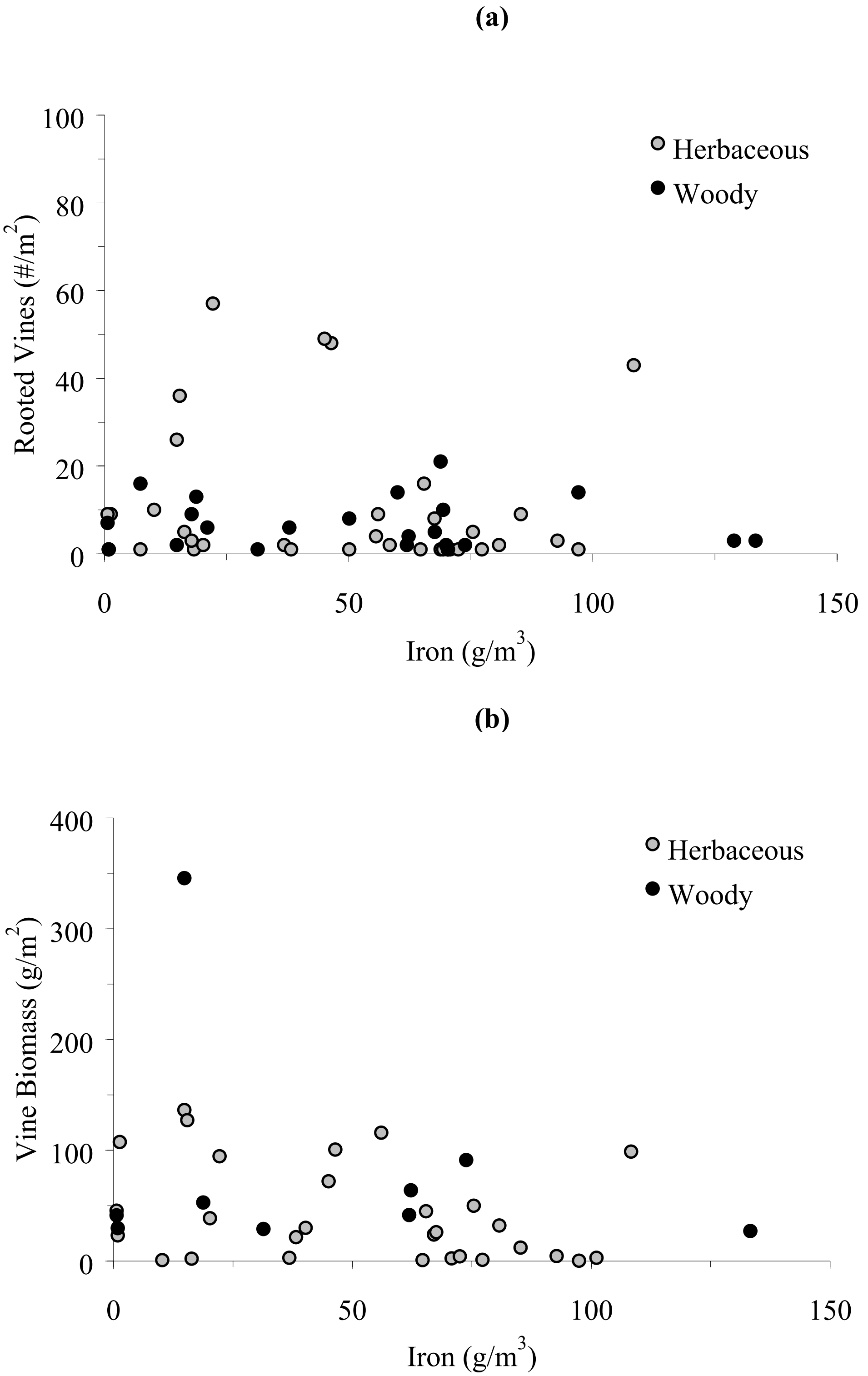


Figure 6.24. Vine Distribution in the Landscape According to the Soil Iron Concentrations on the Chronosequence Sites. (a) Shows the Rooted Vines and (b) the Dry Weight of Vine Biomass.

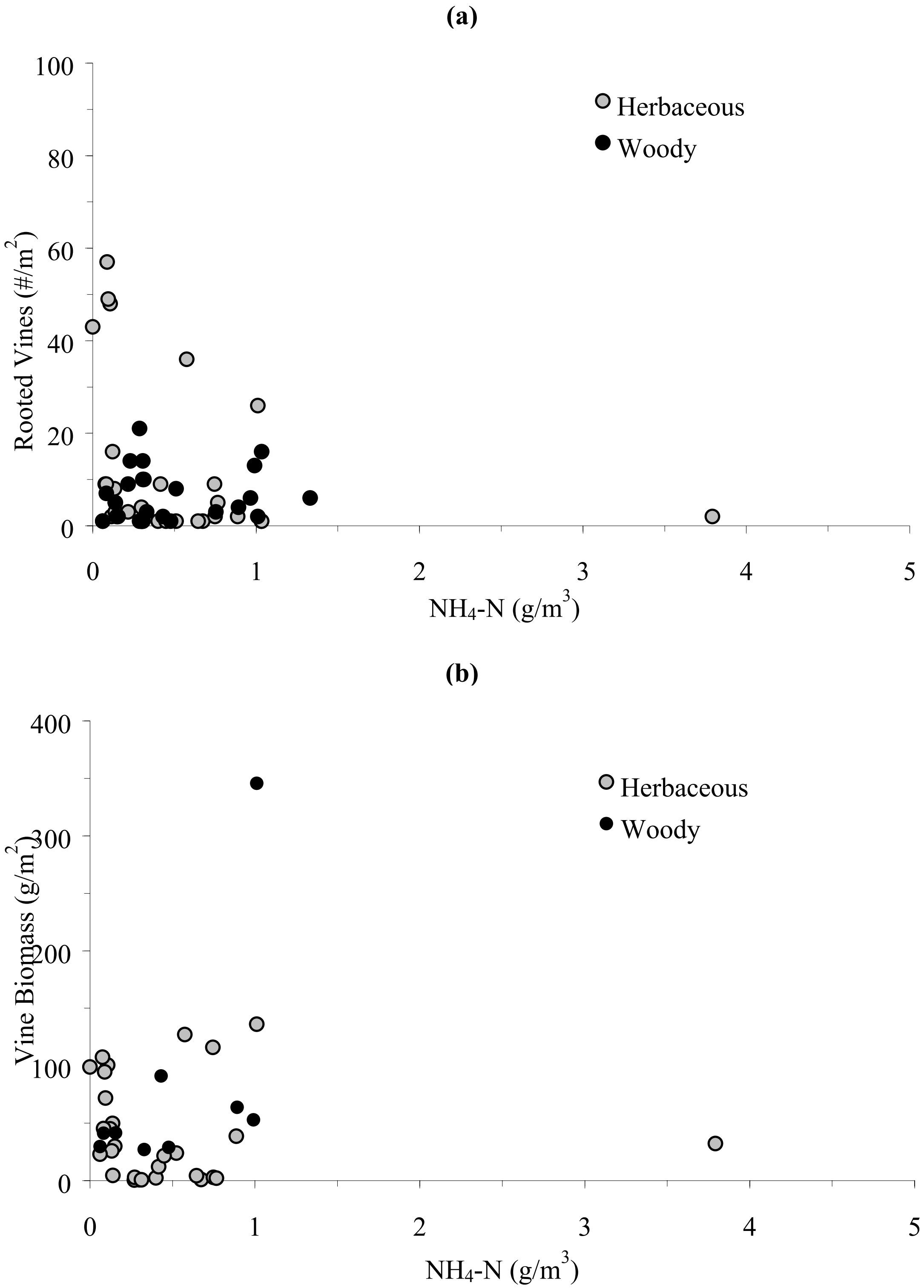


Figure 6.25. Vine Distribution in the Landscape According to the Soil Ammonium (NH_4-N) Concentrations on the Chronosequence Sites. (a) Shows the Rooted Vines (#/m^2) and (b) the Dry Weight of Vine Biomass (g/m^2).

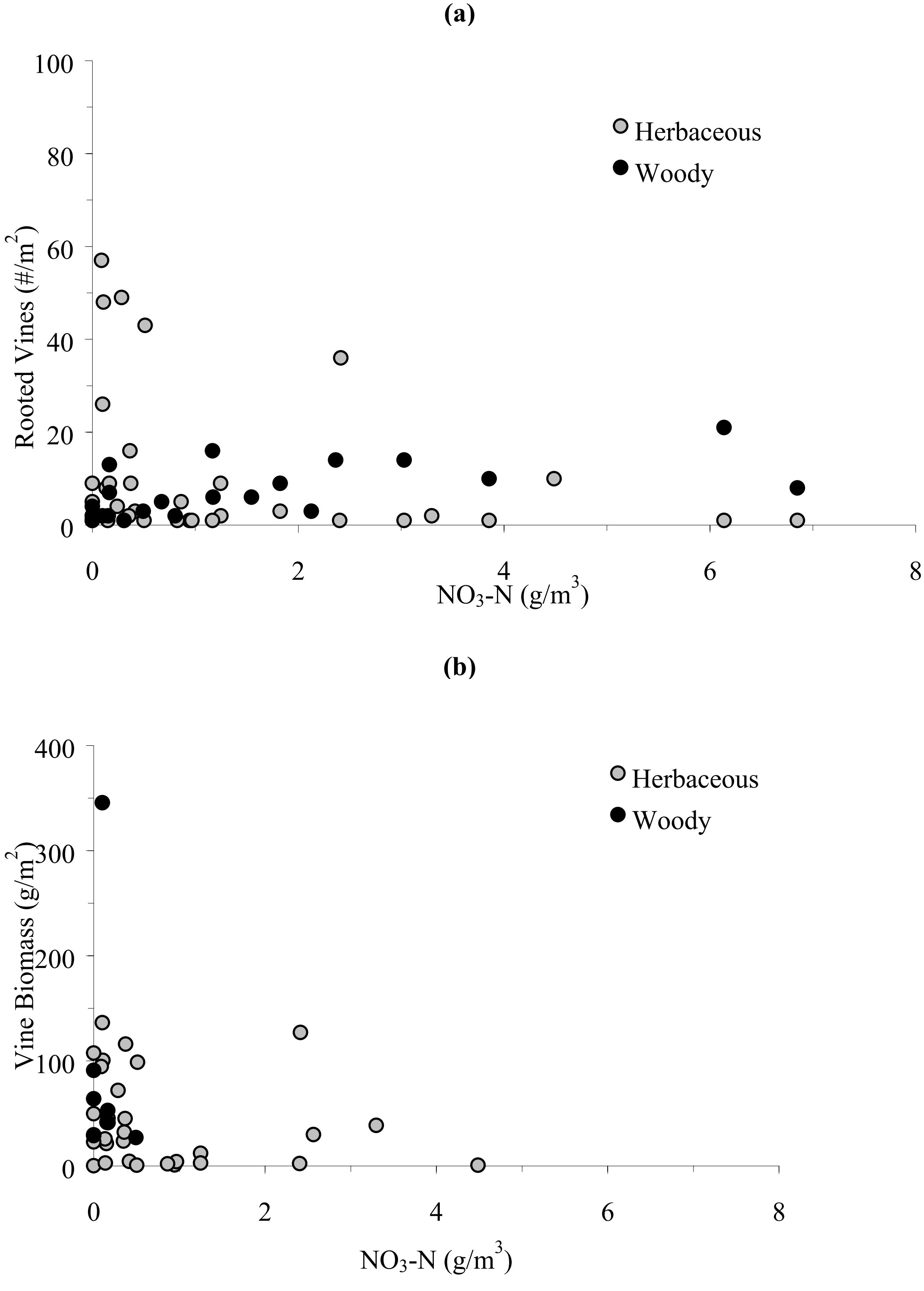


Figure 6-26. Vine Distribution in the Landscape According to the Soil Nitrate (NO_3-N) Concentrations on the Chronosequence Sites. (a) Shows the Rooted Vines (#/m2) and (b) the Dry Weight of Vine Biomass (g/m^2).

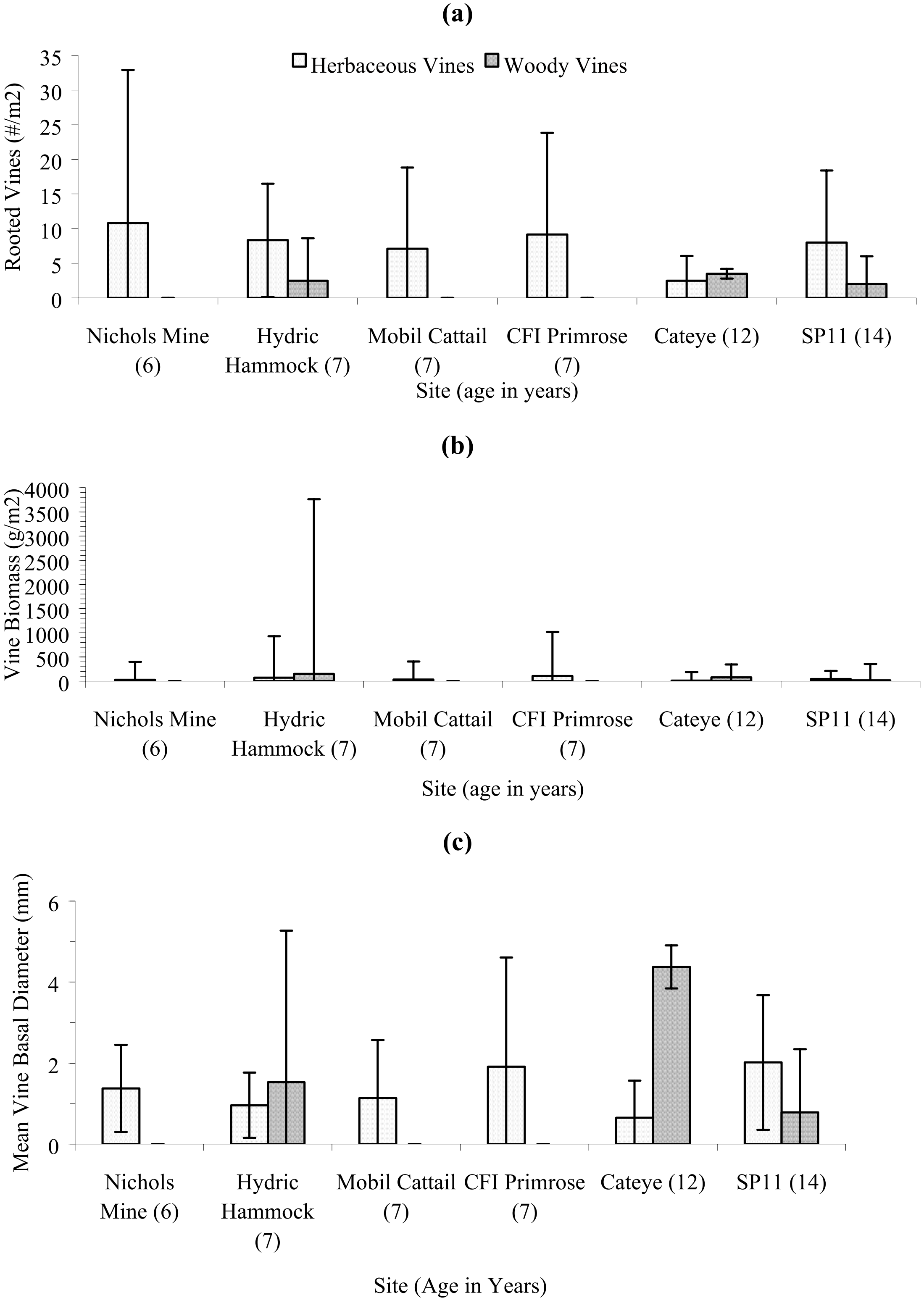


Figure 6.27. Vine Distribution on the Intensive Sites. (a) Shows the Mean Number of Rooted Vines; (b) Shows the Mean Dry Weight Vine Biomass; (c) Shows the Mean Vine Basal Diameter at Each Site.

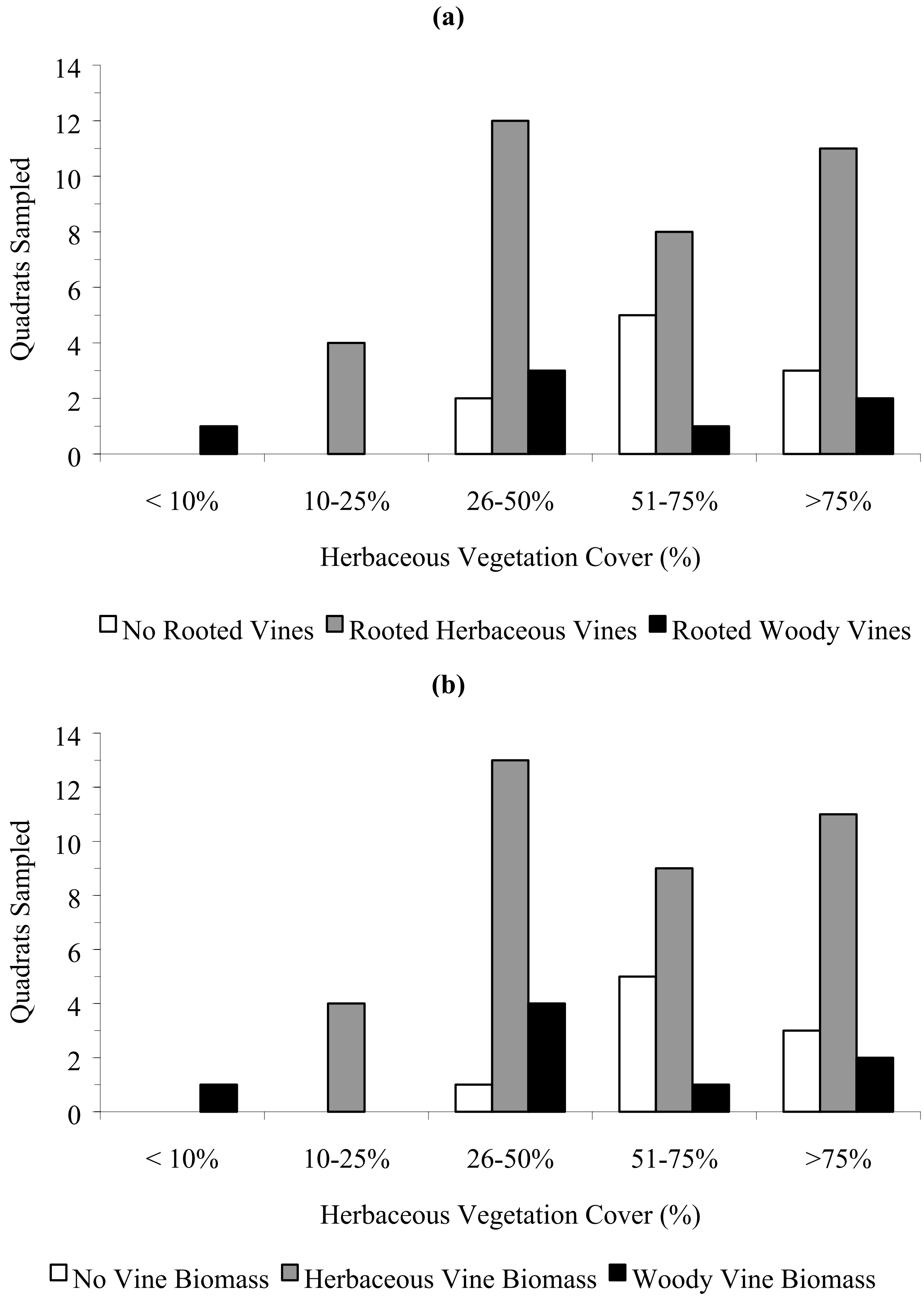


Figure 6.28. Vine Presence According to the Understory Herbaceous Cover on the Intensive Sites. (a) Represents Quadrats with No Rooted Vines, Rooted Herbaceous Vines, and Rooted Woody Vines; (b) Shows Quadrats with No Harvested Vine Biomass, Herbaceous Vine Biomass, and Woody Vine Biomass.

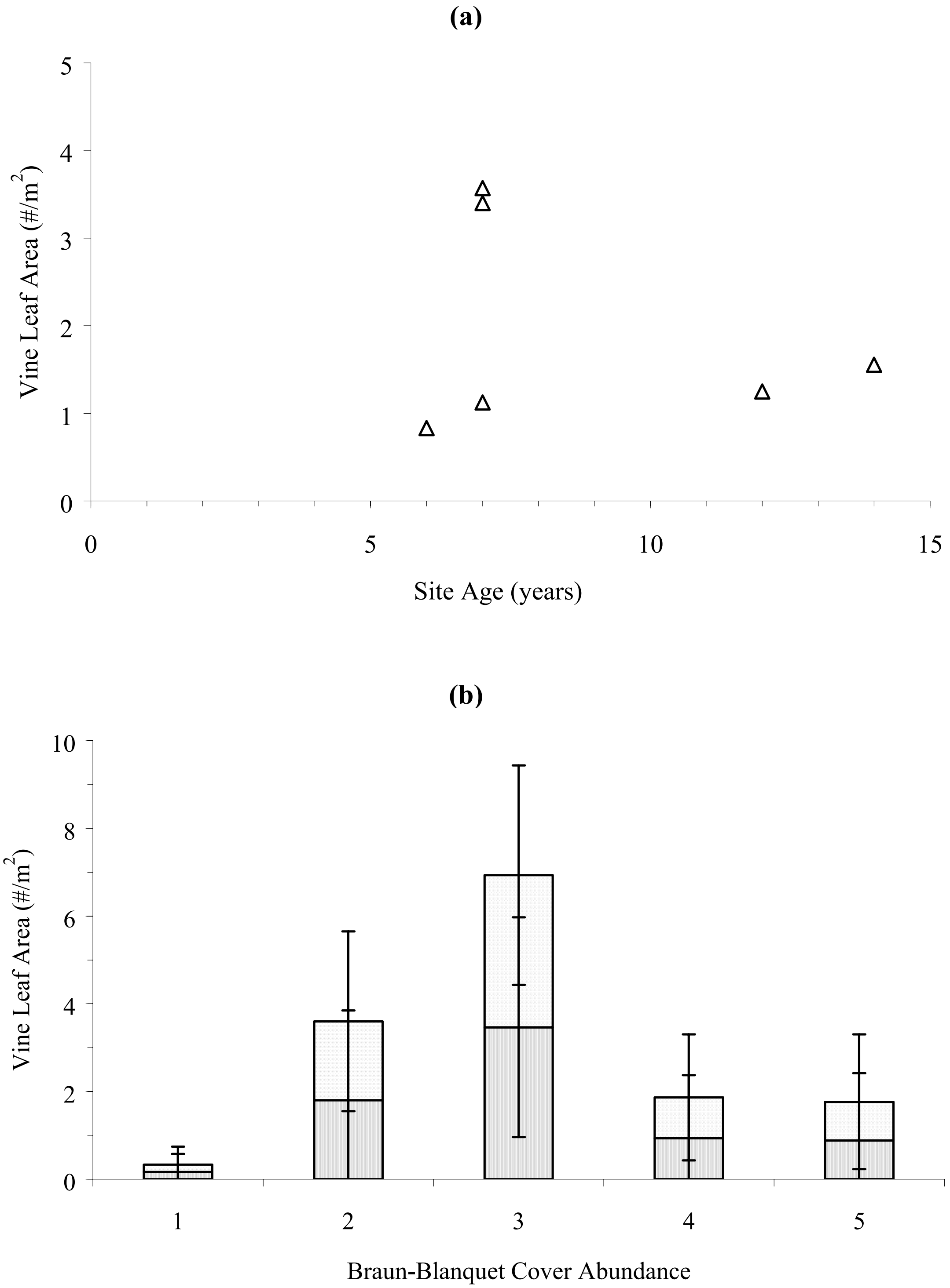


Figure 6.29. The Mean Vine Leaf Area (# of Leaves/m^2) According to (a) Site Age (Years) and (b) the Braun-Blanquet Cover Abundance on the Intensive Sites. 1 (< 10% Cover), 2 (0-25% Cover), 3 (25-50% Cover), 4 (50-75% Cover) and 5 (75-100% Cover).

greatest mean leaf area with 3.5 leaves/m^2 occurred in areas with 26-50% herbaceous understory vegetative cover.

Abiotic Data

Sunlight Transmittance

Figure 6.30 shows the distribution of rooted vines throughout the entire range of sunlight transmittance. However, most rooted vines occur when sunlight transmittance is less than 50%. This also appears true for vine biomass, with the greatest concentration of vine biomass occurring in the range of 5-50% sunlight transmittance. This does not include vine biomass that may have already reached the canopy which may be a higher light environment.

Water Depth

Figure 6.31 illustrates that no distinct pattern relating rooted vines and vine biomass to water depth were apparent. The only vine found rooted in any level of standing water was the herbaceous vine *Mikania* scan*d*ens.

Soil Characteristics

Soils data from the square meter quadrats from the intensive sites were used to explore what conditions support vine growth. Soil moisture, bulk density, percent organic matter, pH, and plant available nutrients were determined from soil cores taken within each square meter quadrat. Some threshold levels and trends are apparent. Table 6.12 provides a summary of soil moisture (%), dry bulk density (g/cm^3), and soil organic matter (%), which have been averaged for quadrats without rooted vines, with rooted herbaceous vines, and with rooted woody vines.

Figure 6.32 shows the soil moisture conditions where vines occur. There is no apparent significant difference between soil moisture ranges of areas not hosting or hosting vines. Additionally, herbaceous vines and woody vines show great similarity in ranges of acceptable soil moisture. There is little intra-site variability where vines are and are not rooted, yet there is great inter-site variability in soil moisture ranges. Figure 6.33 depicts similar trends for rooted vines and dry soil bulk density (g/cm^3), and Figure 6.34 shows the presence of rooted vines according to soil organic matter content (%). Neither soil bulk density nor soil organic matter levels seem to restrict the presence of rooted herbaceous or woody vines. Figure 6.35 provides the equation for the relationship between soil moisture (%), dry bulk density (g/cm^3), and organic matter content (%), explaining 78.3% of the soil cores sampled.

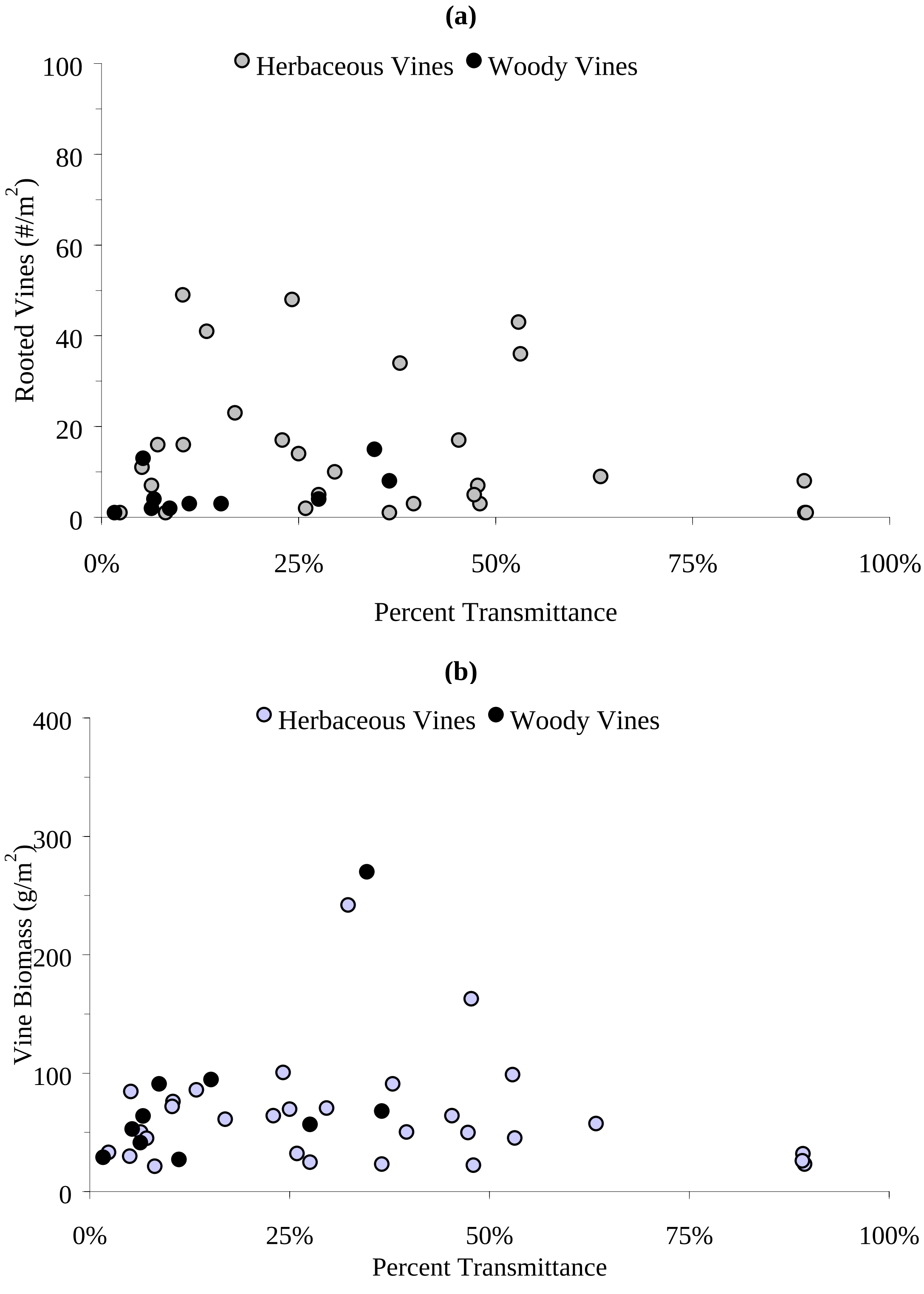


Figure 6.30. Vine Presence According to Sunlight Transmittance (%) on the Intensive Sites. (a) Compares the Rooted Vines (#/m^2) and (b) the Dry Weight of Vine Biomass (g/m^2).

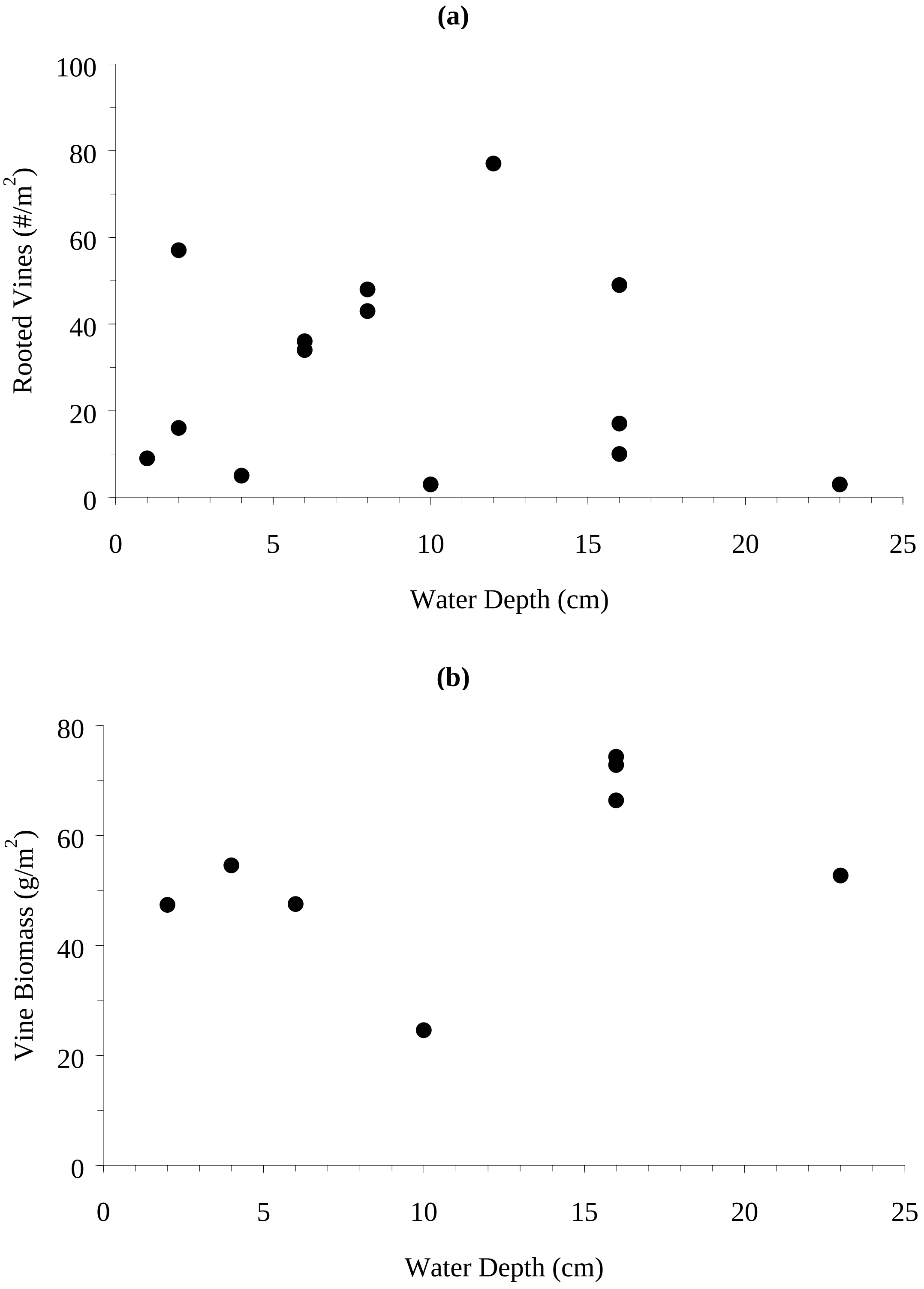


Figure 6.31. Vine Presence in Relation to Water Depth (cm) Within Each Square Meter Quadrat. (a) Rooted Vines (#/m^2) and (b) Vine Biomass (g/m^2). Only the Herbaceous Vine *Mikania scandens* (Climbing Hemp Vine) Was Found Rooted in Standing Water.

Table 6.12. Summary Soil Data for Intensive Sites, Including Soil Moisture (%), Dry Bulk Density (g/cm3), and Soil Organic Matter (%). Values Represent the Mean Value ± 1 Standard Deviation.

	Nichols Mine	Hydric Hammock	Mobil Cattail	CFI Primrose	Cateye	SP11
	6	7	7	7	12	14
Soil Moisture (%)						
No Rooted Vines	27.40 ± 14.23	51.97	57.64 ± 9.72	33.05 ± 4.19	- -	- -
Rooted Herbaceous Vines	38.02 ± 16.60	35.52 ± 14.18	54.29 ± 22.28	29.60 ± 3.96	7.62	15.46 ± 8.48
Rooted Woody Vines	- -	33.77	- -	- -	8.13 ± 0.72	8.43
Dry Bulk Density (g/cm^3)						
No Rooted Vines	0.78 ± 0.13	0.39	0.37 ± 0.16	0.53 ± 0.12	- -	- -
Rooted Herbaceous Vines	0.62 ± 0.19	0.74 ± 0.40	0.45 ± 0.30	0.43 ± 0.10	1.37	1.16 ± 0.13
Rooted Woody Vines	- -	0.33	- -	- -	1.38 ± 0.01	1.22
Soil Organic Matter (%)						
No Rooted Vines	3.01 ± 2.25	19.86	20.81 ± 9.47	6.40 ± 0.60	- -	- -
Rooted Herbaceous Vines	5.44 ± 4.65	12.43 ± 6.31	19.14 ± 15.24	7.73 ± 1.22	2.97	3.02 ± 0.97
Rooted Woody Vines	- -	25.48	- -	- -	3.00 ± 0.05	3.35
Number of Quadrats with Vines						
No Rooted Vines	4	1	5	3	0	0
Rooted Herbaceous Vines	9	4	4	4	1	4
Rooted Woody Vines	0	1	0	0	2	1

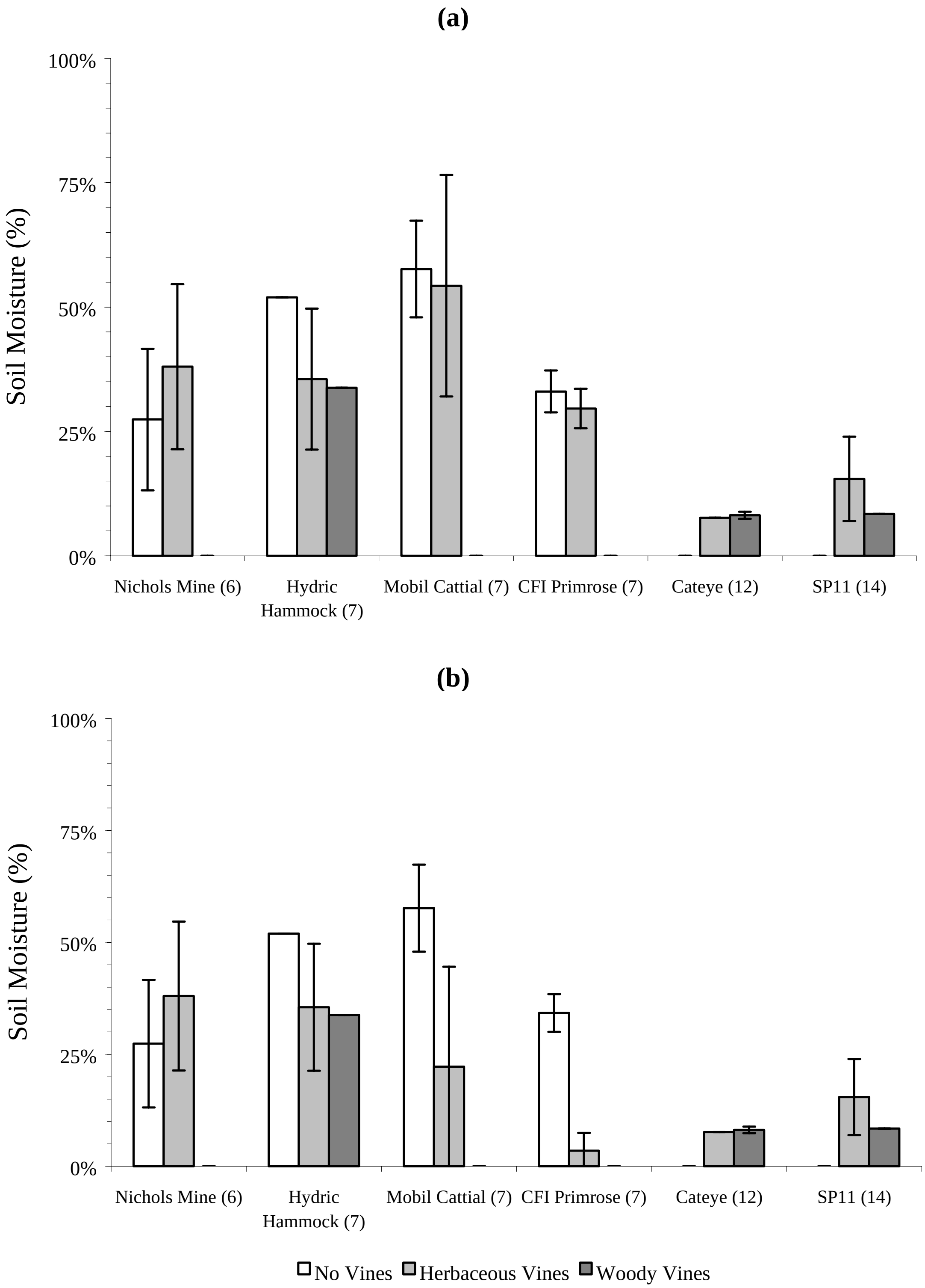


Figure 6.32. Vines Occur in Various Ranges of Soil Moisture on the Intensive Sites. (a) Shows the Mean Soil Moisture in Quadrats with No Rooted Vines, Rooted Herbaceous Vines, and Rooted Woody Vines; (b) Shows the Mean Soil Moisture in Quadrats Where No Vine Biomass, Herbaceous Vine Biomass, and Woody Vine Biomass Were Harvested.

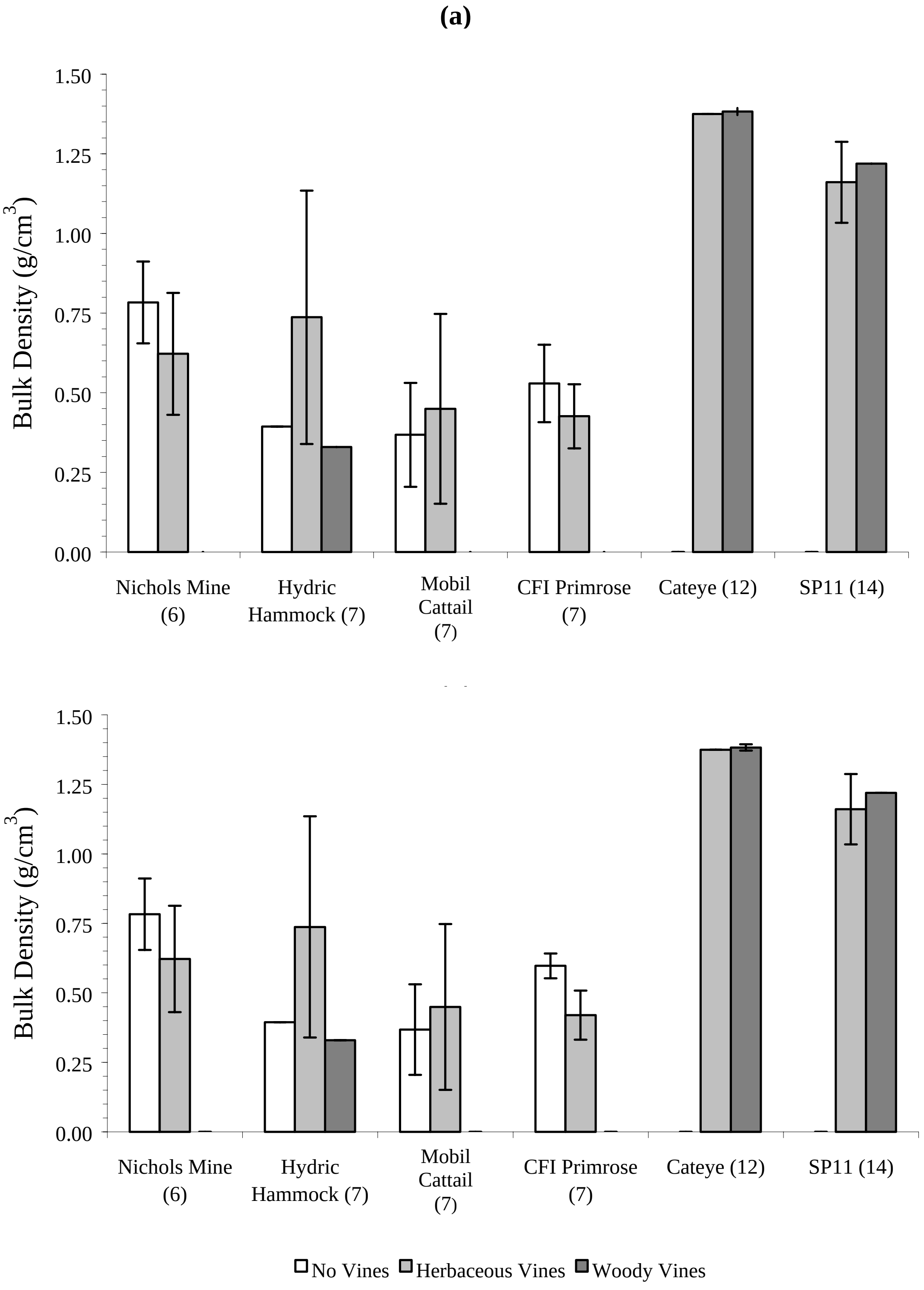


Figure 6.33. **Vines Occur in Various Ranges of Soil Bulk Density (g/cm^3) on the Intensive Sites. (a) Shows the Mean Bulk Density in Quadrats With No Rooted Vines, Rooted Herbaceous Vines, and Rooted Woody Vines; (b) Shows the Mean Bulk Density in Quadrats Where No Vine Biomass, Herbaceous Vine Biomass, and Woody Vine Biomass Were Harvested.**

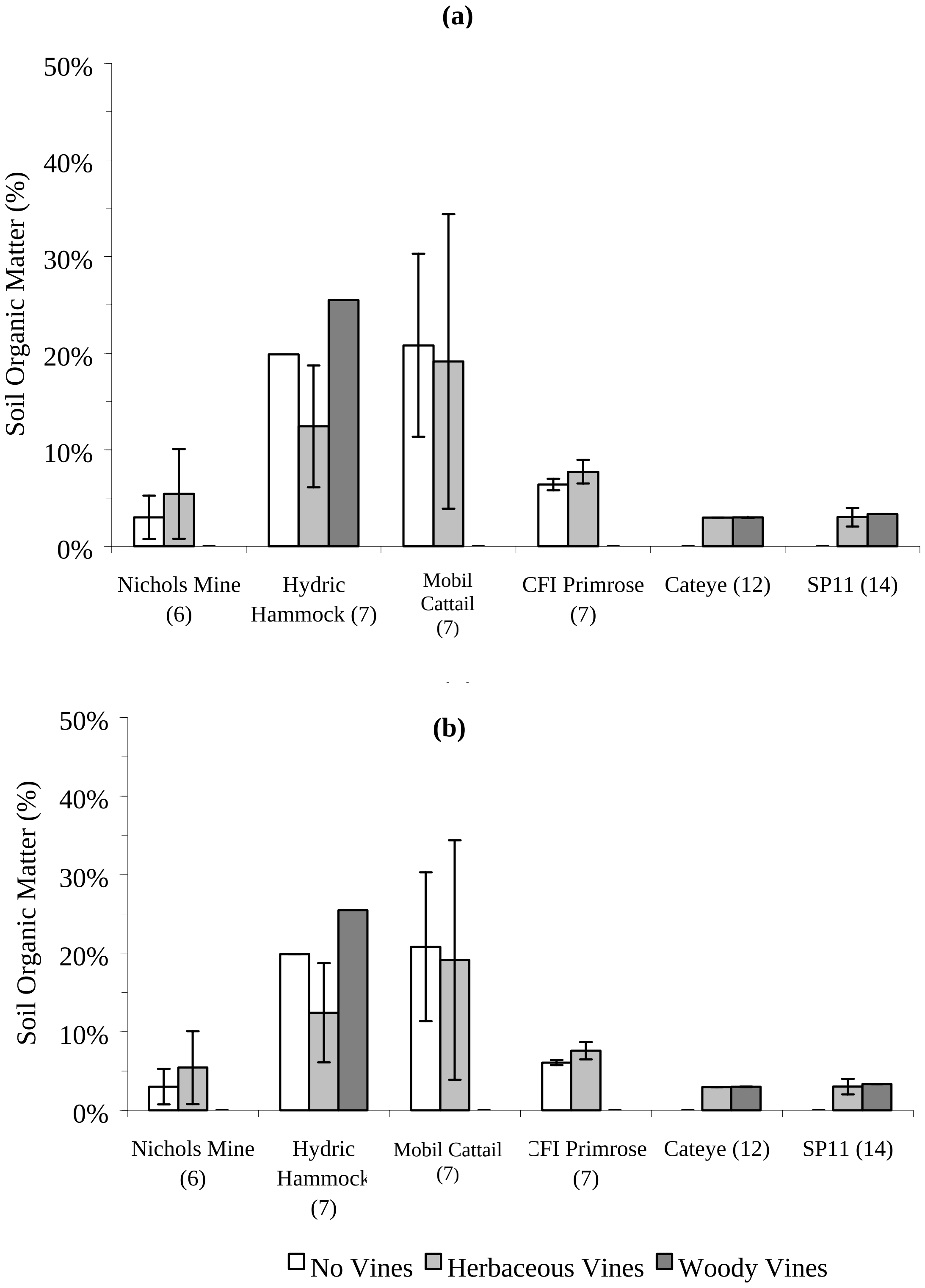


Figure 6.34. Vines Occur in Various Ranges of Soil Organic Matter (%) on the Intensive Sites. (a) Shows the Mean Soil Moisture in Quadrats with No Rooted Vines, Rooted Herbaceous Vines, and Rooted Woody Vines; (b) Shows the Mean Soil Moisture in Quadrats Where No Vine Biomass, Herbaceous Vine Biomass, and Woody Vine Biomass Were Harvested.

% Soil Moisture = 0.464 – 0.290 Dry Bulk Density + 0.866 Soil Organic Matter
R-Sq = 78.3%

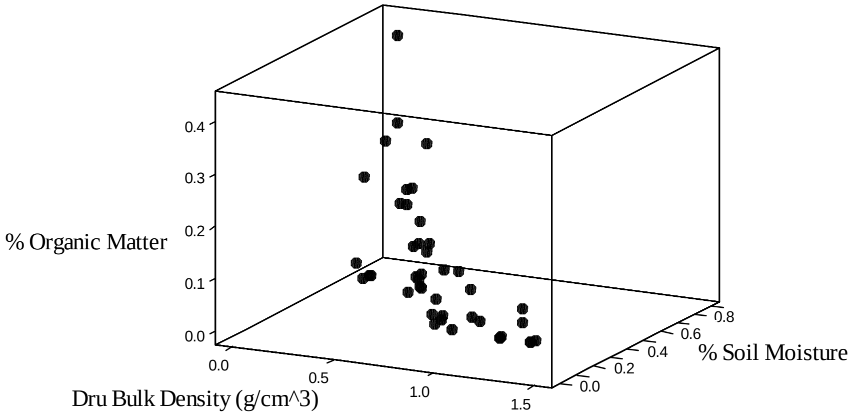


Figure 6.35. The Relationship Between Soil Moisture, Bulk Density, and Organic Matter Content.

The plant-available nutrients calcium, magnesium, potassium, phosphorus, and iron, show possible threshold ranges based on the presence of vines. Table 6.13 provides a summary of the mean values of plant available nutrients at each site according to whether herbaceous or woody vines were or were not rooted. The following figures reflect only areas where vines occur, as zero value for rooted vines and vine biomass were excluded.

Figure 6.36 shows that herbaceous vines grew throughout a broad range of soil calcium concentrations from 100-8,500 g calcium/m^3, yet woody rooted vines had a narrower range, growing predominantly in areas with 7,500-8,500 g calcium/m^3. Figure 6.37 shows that vines grew in soil magnesium ranges from 10-800 g magnesium/m^3, yet there was a concentration of rooted vines within the 10-300 g magnesium/m^3 range. Woody vines occurred in soils with lower magnesium concentrations, ranging from 10-150 g magnesium/m^3. Figure 6.38 illustrates the distribution of vines throughout the 5-70 g potassium/m^3 range of soil concentrations. Few rooted vines occurred at potassium concentrations below 10 g potassium/m^3, with the greatest concentration of vines in the range of 10-35 g potassium/m^3.

Figure 6.39 shows that the greatest concentration of vines occurred in the 0-1,000 g phosphorus/m^3 range, with a few outliers in areas greater than 1,000 g phosphorus/m^3. Figure 6.40 displays the uniform distribution of rooted vines and vine biomass throughout the entire 10-100 g iron/m^3 range of soil iron concentrations. Only 6-year-old Nichols Mine recorded vines at soil iron concentrations greater than 75 g iron/m^3.

Ammonium-nitrogen concentrations (NH_4-N) ranged between 0-8 g NH_4-N/m^3 with woody vines occurring at this elevated soil ammonium-nitrogen level. Figure 6.41 shows that soil ammonium-nitrogen levels may have little bearing on vine presence. Figure 6.42 displays similar results for soil nitrate-nitrogen concentrations (g NO_3-N/m^3). A majority of the rooted vines and dry weight vine biomass were located within the 0-4 g NO_3-N/m^3 range, with various soil nitrate-nitrogen levels in quadrats without vine, with rooted herbaceous vines, and with rooted woody vines.

Table 6.14 provides the Spearman coefficients correlating soil parameters and whether no vines, herbaceous vines, or woody vines were rooted. A positive 1.000 value such as between g NO_3-N/m^3, g Ca/m^3, and g Mg/m^3 means that a perfect positive correlation exists, and values of zero suggest that no correlation exists (Eddison 2000). Rooted vines and soil moisture have a –0.377 correlation ($P = 0.013$), and rooted vines have positive correlations with the available soil nutrients. The nutrients NH_4-N ($rS = 0.412$, $P = 0.006$) and Fe ($rS = 0.108$, $P = 0.489$) appear to correlate the greatest with rooted vines, with the remaining plant-available nutrients Ca, Mg, K, P, and NO_3-N having Spearman correlation coefficients < 0.065.

SIMULATION MODELING

To test the hypothesis concerning the role and management of vines in constructed forested wetlands, a systems diagram and simulation model were developed.

Table 6.13. Summary of the Soil Nutrient Data for Intensive Sites. Values in g/m3 Represent the Mean Value ± 1 Standard Deviation.

	Nichols Mine	Hydric Hammock	Mobil Cattail	CFI Primrose	Cateye	SP11
	6	7	7	7	12	14
Calcium						
No Rooted Vines	2279 ± 969	1423	1738 ± 1107	3278 ± 822	- -	- -
Rooted Herbaceous Vines	1600 ± 1117	3372 ± 2196	2174 ± 1311	2587 ± 640	8206	380 ± 245
Rooted Woody Vines	- -	708	- -	- -	7969 ± 336	475
Magnesium						
No Rooted Vines	91 ± 24	721	159 ± 52	619 ± 161	- -	- -
Rooted Herbaceous Vines	69 ± 35	202 ± 42	176 ± 76	531 ± 165	134	28 ± 7
Rooted Woody Vines	- -	50	- -	- -	115 ± 27	25
Potassium						
No Rooted Vines	22.54 ± 7.48	13.28	7.22 ± 6.65	66.43 ± 6.75	- -	- -
Rooted Herbaceous Vines	23.69 ± 8.46	15.25 ± 3.36	12.50 ± 7.26	63.10 ± 10.99	35.74	14.78 ± 2.82
Rooted Woody Vines	- -	10.47	- -	- -	35.74 ± 0.00	12.07
Phosphorus						
No Rooted Vines	758 ± 399	38	369 ± 419	769 ± 178	- -	- -
Rooted Herbaceous Vines	557 ± 380	877 ± 784	517 ± 369	609 ± 91	3162	254 ± 132
Rooted Woody Vines	- -	56	- -	- -	3103 ± 82	236
Iron						
No Rooted Vines	65.92 ± 19.25	2.87	18.97 ± 12.56	4.18 ± 0.57	- -	- -
Rooted Herbaceous Vines	60.51 ± 20.98	36.05 ± 29.57	28.79 ± 29.51	3.92 ± 0.68	46.46	19.39 ± 12.25
Rooted Woody Vines	- -	12.68	- -	- -	44.37 ± 2.96	9.96
Ammonium (NH_4-N)						
No Rooted Vines	0.27 ± 0.06	0.19	0.05 ± 0.06	0 ± 0	- -	- -
Rooted Herbaceous Vines	0.18 ± 0.15	1.26 ± 2.19	0.31 ± 0.38	0 ± 0	0.45	0.77 ± 0.65
Rooted Woody Vines	- -	7.94	- -	- -	0.52 ± 0.10	0.27
Nitrate (NO_3-N)						
No Rooted Vines	0.52 ± 0.83	0.84	0.88 ± 1.25	2.14 ± 1.93	- -	- -
Rooted Herbaceous Vines	0.57 ± 0.50	2.72 ± 1.95	0.77 ± 0.89	3.82 ± 1.32	2.10	0.04 ± 0.08
Rooted Woody Vines	- -	0.15	- -	- -	1.42 ± 0.96	0

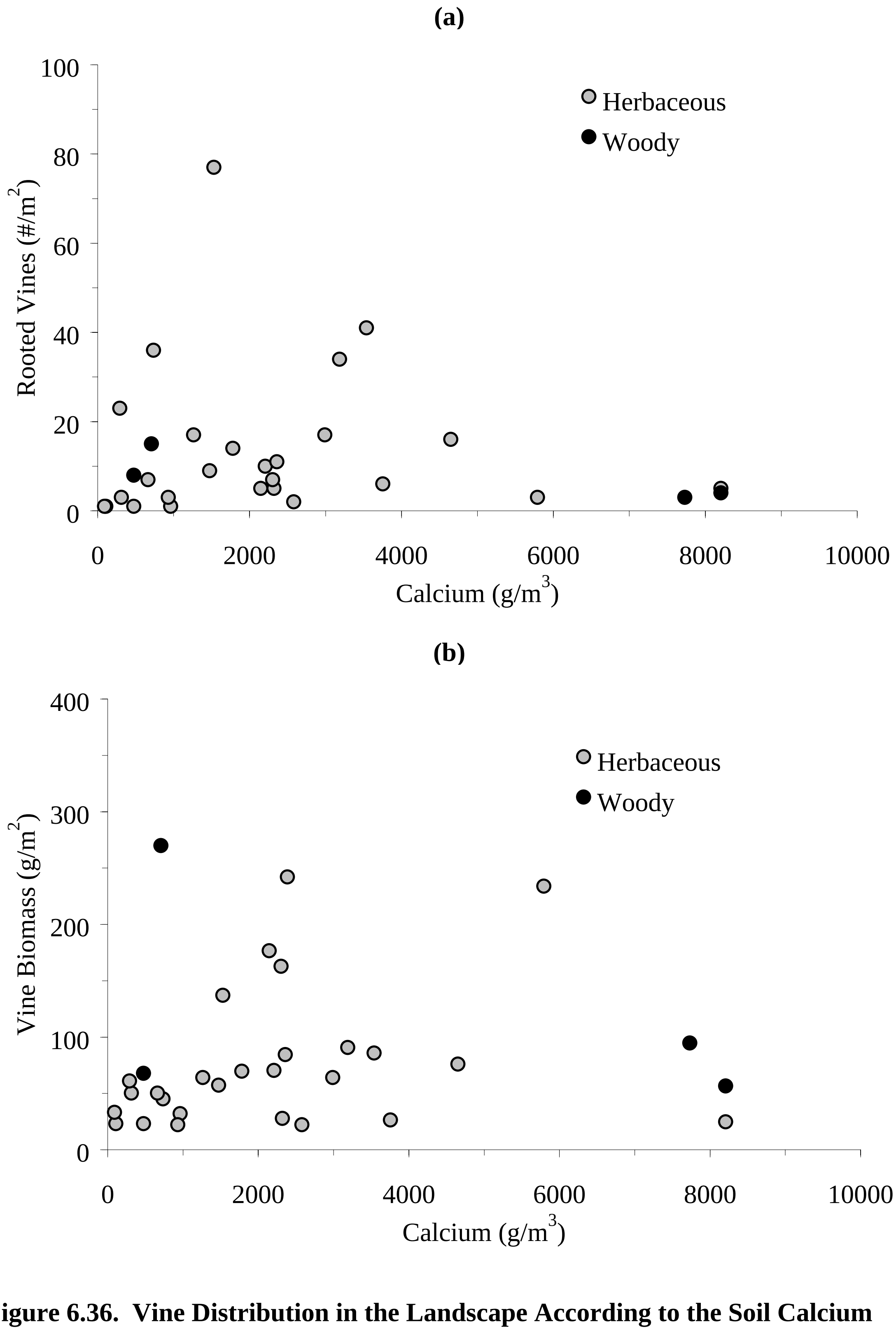


Figure 6.36. Vine Distribution in the Landscape According to the Soil Calcium Concentrations on the Intensive Sites. (a) Shows the Rooted Vines (#/m^2) and (b) the Dry Weight of Vine Biomass (g/m^2).

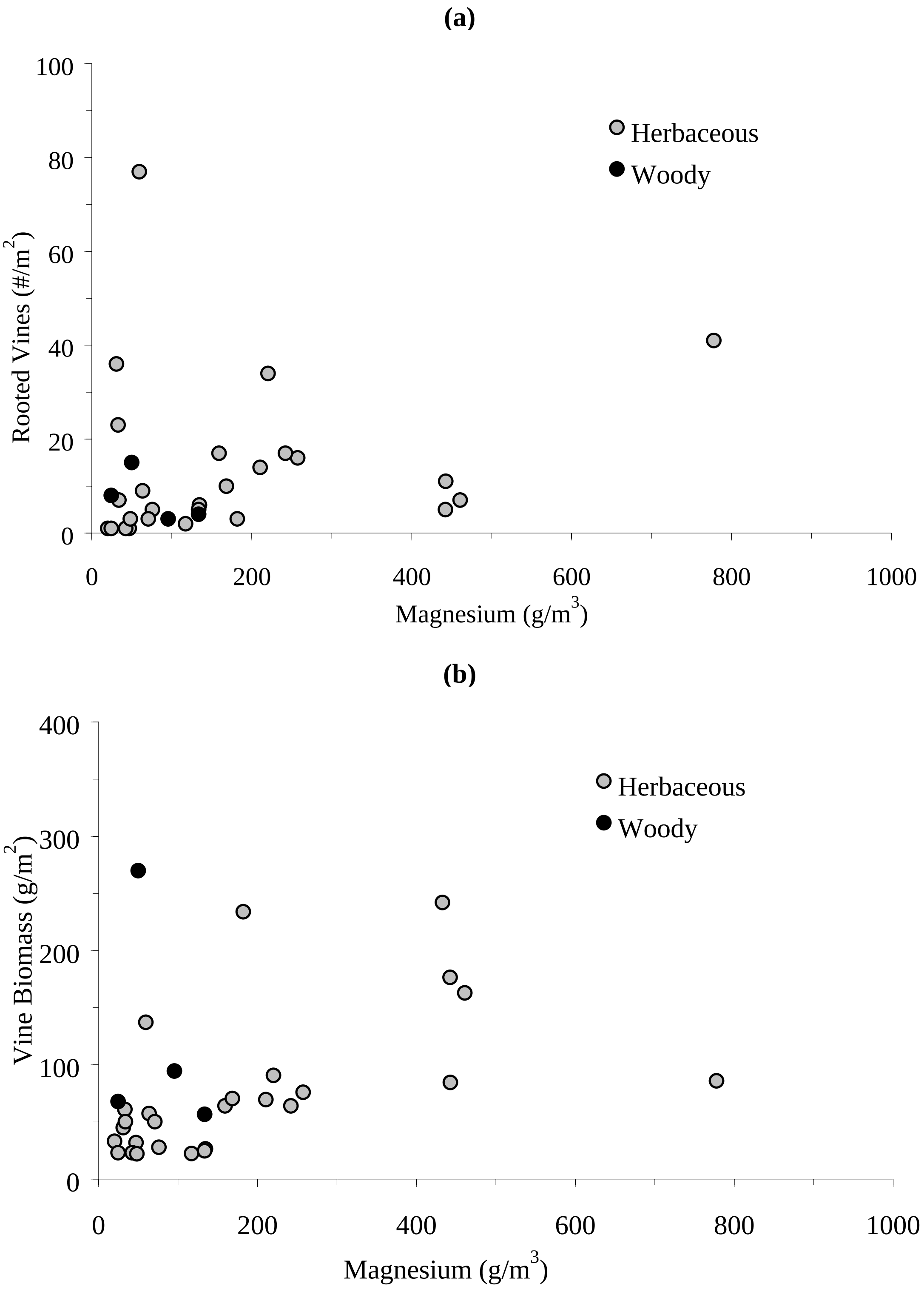


Figure 6.37. Vine Distribution in the Landscape According to the Soil Magnesium Concentrations on the Intensive Sites. (a) Shows the Rooted Vines (#/m^2) and (b) the Dry Weight of Vine Biomass (g/m^2).

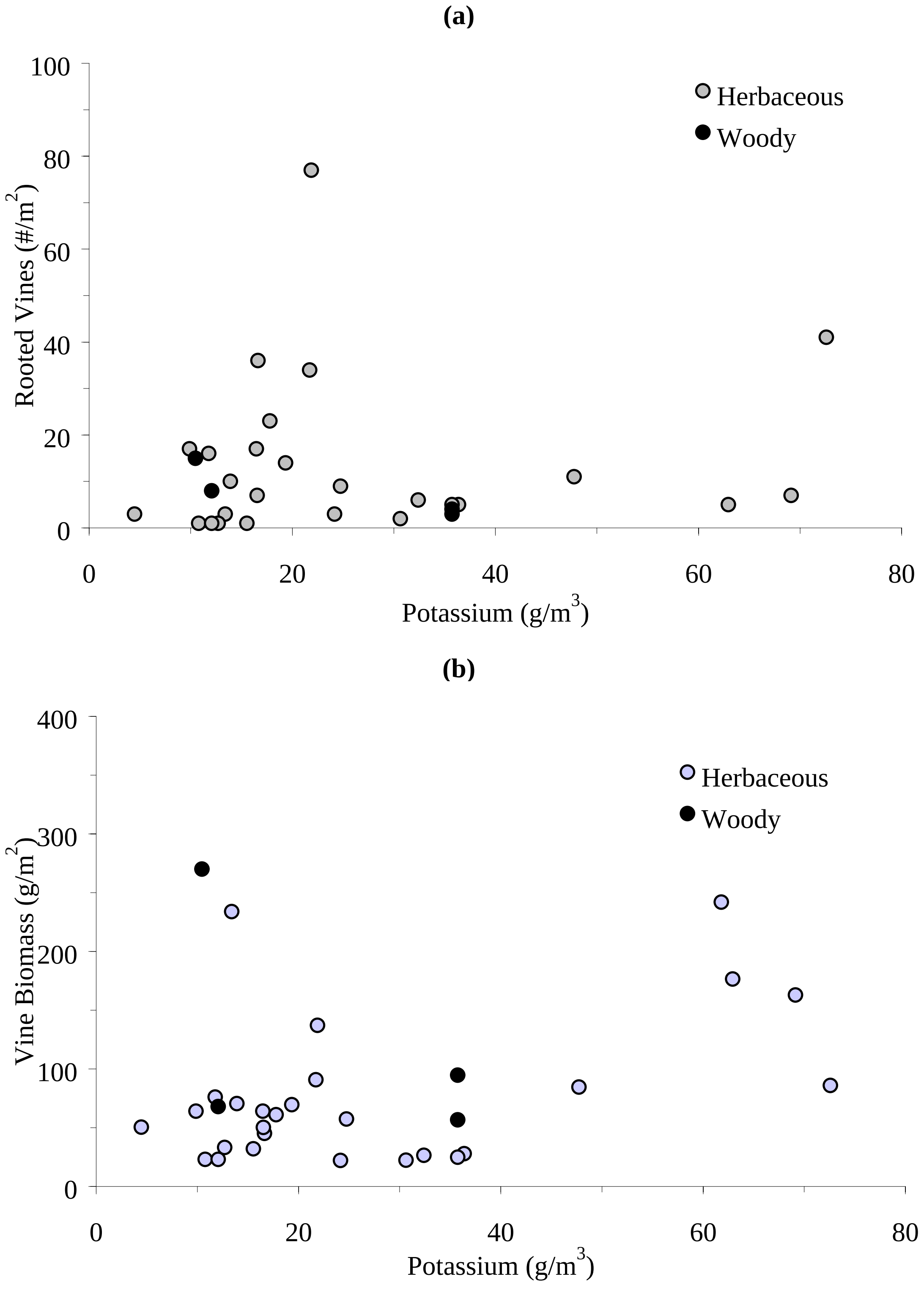


Figure 6.38. Vine Distribution in the Landscape According to the Soil Potassium Concentrations on the Intensive Sites. (a) Shows the Rooted Vines (#/m^2) and (b) the Dry Weight of Vine Biomass (g/m^2).

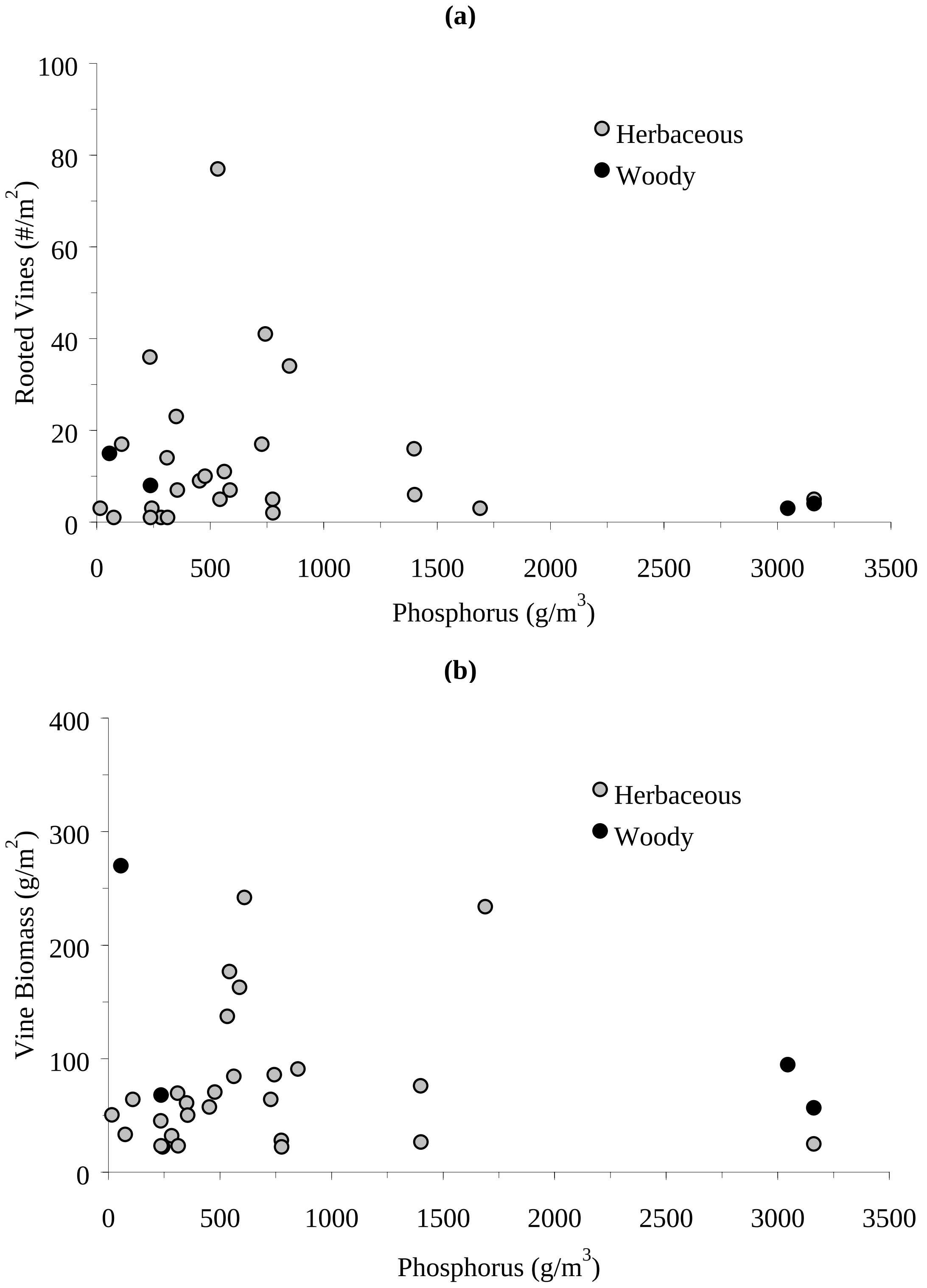


Figure 6.39. Vine Distribution in the Landscape According to the Soil Phosphorus Concentrations on the Intensive Sites. (a) Shows the Rooted Vines #/m^2) and (b) the Dry Weight of Vine Biomass (g/m^2).

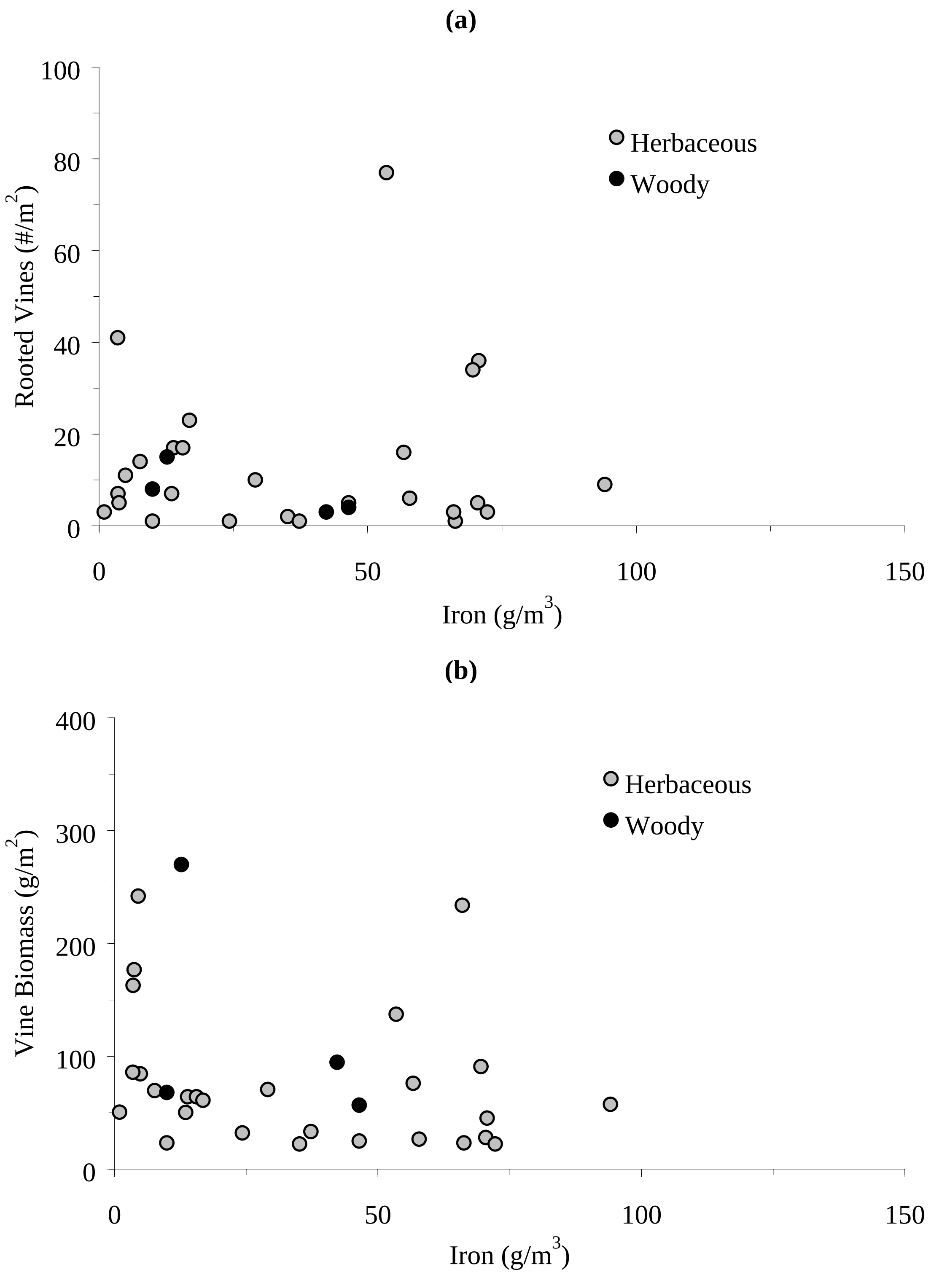


Figure 6.40. Vine Distribution in the Landscape According to the Soil Iron Concentrations on the Intensive Sites. (a) Shows the Rooted Vines (#/m^2) and (b) the Dry Weight of Vine Biomass (g/m^2).

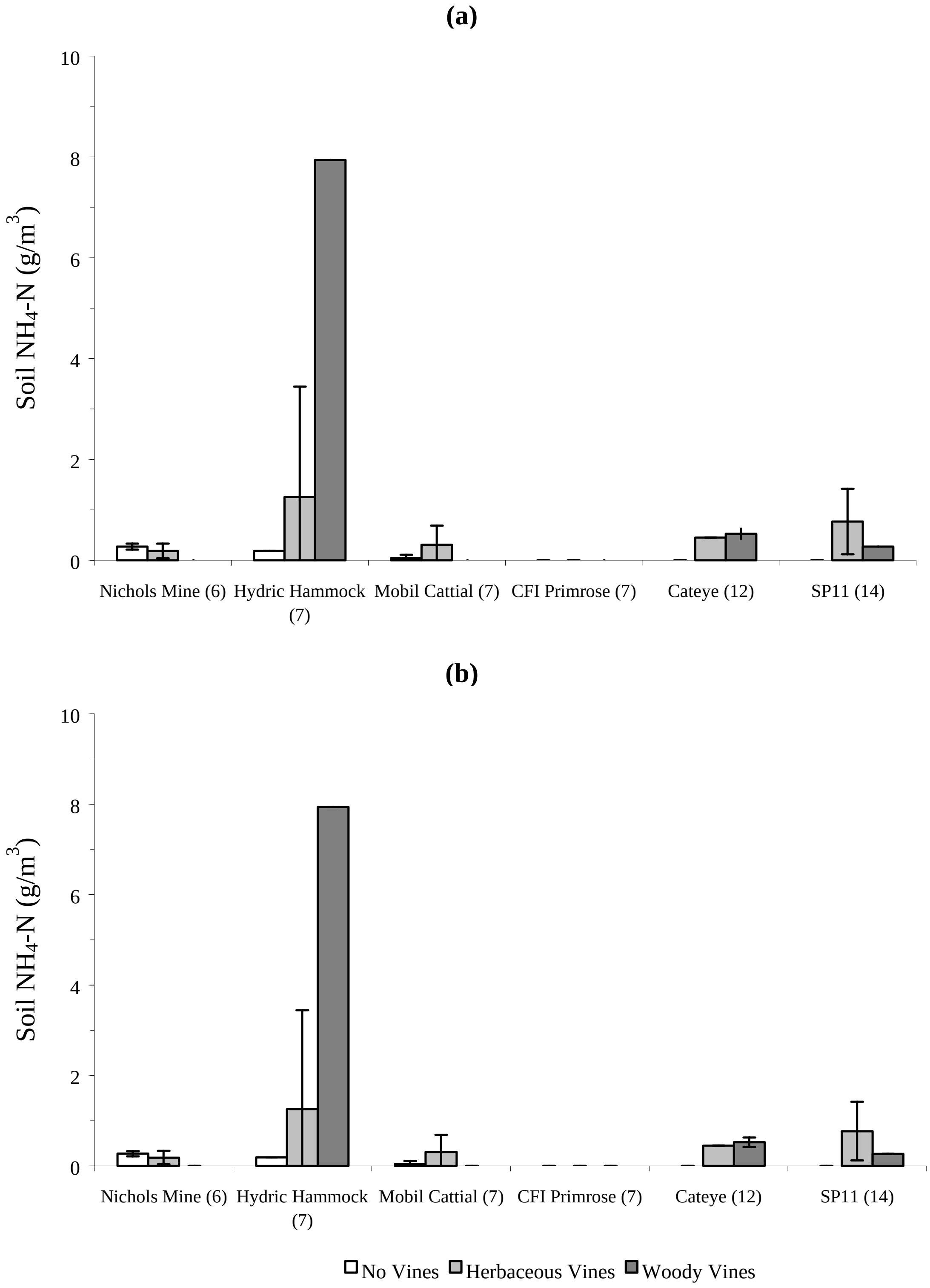


Figure 6.41. Vines Occur in Various Ranges of Soil Nitrogen (g NH_4-N/m^3) on the Intensive Sites. (a) Shows the Mean Soil Moisture in Quadrats with No Rooted Vines, Rooted Herbaceous Vines, and Rooted Woody Vines; (b) Shows the Mean Soil Moisture in Quadrats Where No Vine Biomass, Herbaceous Vine Biomass, and Woody Vine Biomass Were Harvested.

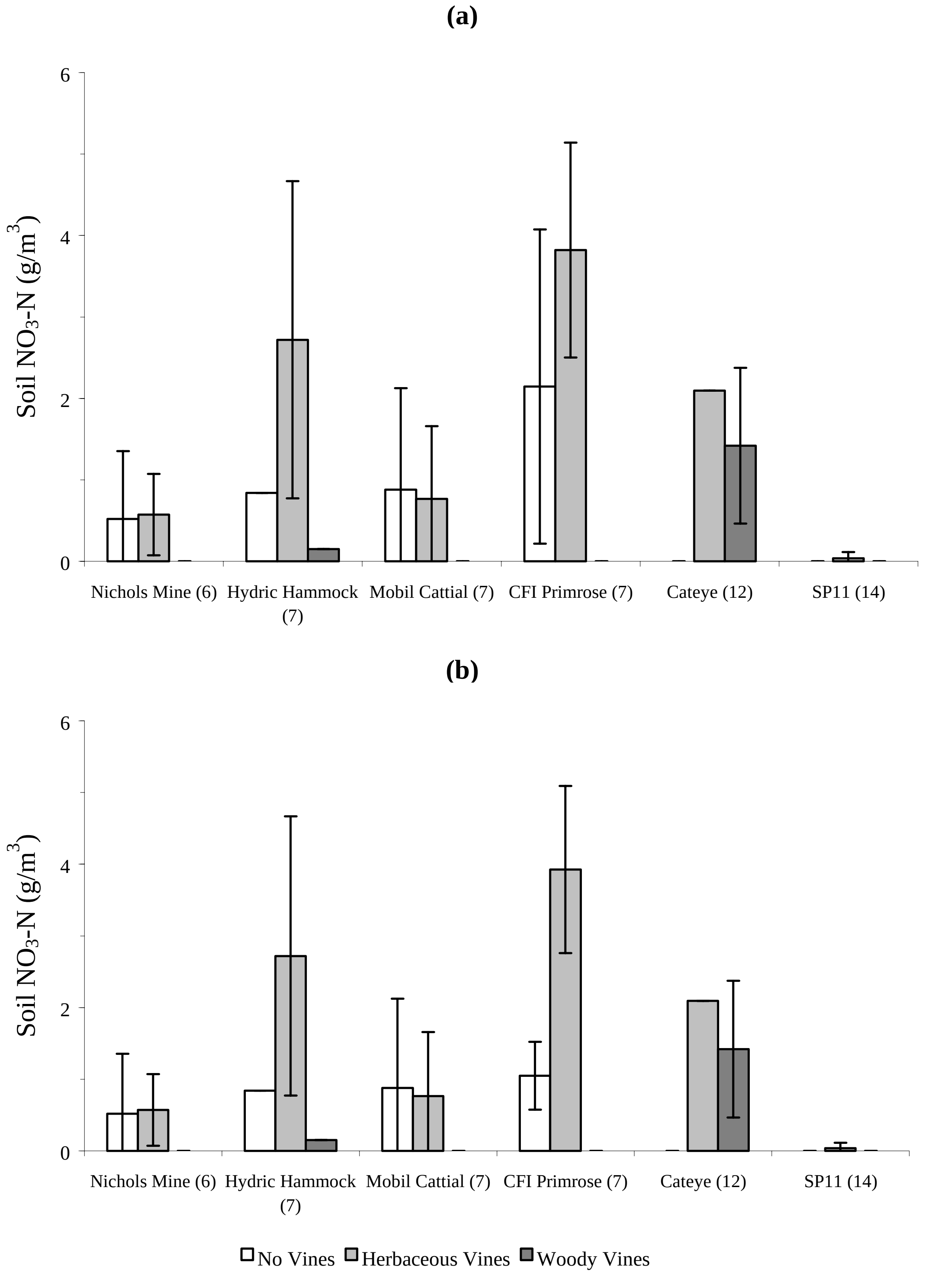


Figure 6.42. Vines Occur in Various Ranges of Soil Nitrogen (g NO_3-N/m^3) on the Intensive Sites. (a) Shows the Mean Soil Moisture in Quadrats with No Rooted Vines, Rooted Herbaceous Vines, and Rooted Woody Vines; (b) Shows the Mean Soil Moisture in Quadrats Where No Vine Biomass, Herbaceous Vine Biomass, and Woody Vine Biomass Were Harvested.

Table 6.14. Spearman Correlation Coefficient for Soil moisture (%), Soil Nitrogen as Ammonium (NH_4-N) and Nitrate (NO_3-N), and Plant Available Nutrients (Ca, Mg, K, P, and Fe).

	Rooted Vines	% Soil Moisture	Nitrogen as NH_4-N	Nitrogen as NO_3-N	Ca	Mg	K	P	Fe
% Soil Moisture	-0.377 (0.013)								
NH_4-N	0.412 (0.006)	-0.459 (0.002)							
NO_3-N	0.025 (0.874)	0.218 (0.160)	-0.388 (0.010)						
Ca	0.025 (0.874)	0.218 (0.160)	-0.388 (0.010)	1.000 *					
Mg	0.025 (0.874)	0.218 (0.160)	-0.388 (0.010)	1.000 *	1.000 *				
K	0.065 (0.680)	-0.278 (0.071)	-0.158 (0.312)	0.462 (0.002)	0.462 (0.002)	0.462 (0.002)			
P	0.043 (0.784)	-0.383 (0.011)	0.060 (0.703)	0.349 (0.022)	0.349 (0.022)	0.349 (0.022)	0.565 (0.000)		
Fe	0.108 (0.489)	-0.291 (0.059)	0.349 (0.022)	-0.339 (0.026)	-0.339 (0.026)	-0.339 (0.026)	0.011 (0.946)	0.364 (0.016)	

Cell Contents: Pearson correlation, (P-Value)

Four separate simulations were run representing forested wetland succession following site establishment, forested wetland succession in the absence of vines, forested wetland succession when vine management occurs in year 7, and forested wetland succession when vine biomass is controlled when the storage of herbaceous vine biomass equals 20%.

Figure 6.43 shows the results from the model of forested wetland succession following site establishment. Initial values for the storages of herbaceous vine biomass (5%), woody vine biomass (8.3%), tree biomass (30%), tree nutrients (6%), and organic matter (7.8%) were assigned according to the percent of the steady state storage present during site establishment. Initial vine biomass represented seeds and viable vine segments present in the applied mulched layer and as litter fall from surrounding areas in the landscape. Tree biomass and nutrients values reflected that associated with planted stock. The organic matter storage represented the mulched layer applied to the forested wetland surface during wetland establishment.

This initial run suggested that herbaceous vine biomass peaked at approximately 5-15 years, followed by a marked decline through year 25. Herbaceous vine biomass remained within the ecosystem throughout forested wetland maturity. Woody vine biomass entered the system between 5-10 years after site establishment, reached steady state at around 35 years, and remained in the system through maturity. Tree biomass reached maturity at around 100 years after site establishment. Within the first 10 years of site establishment, tree biomass grew rapidly, followed by slower growth through maturity. Soil organic matter closely followed the peak and decline of herbaceous vine biomass, with maximum organic matter storage at approximately 10-20 years. This suggests the important role vines play in the creation of organic matter.

To explore the role of vines further, a second simulation model was run, reflecting forested wetland succession, tree biomass development, and organic matter storage in the absence of vines. Initial values for tree biomass (30%), tree nutrients (6%), and organic matter (7.8%) were unchanged, while the initial storage values of herbaceous and woody vine biomass were set at zero. Figure 6.44 shows tree biomass grew slowly without reaching the steady state level within the first 200 years of forested wetland succession. Additionally, the storage of organic matter remained extremely low in the absence of the contributions from vines.

A third simulation was run to test the hypothesis that vines play an important role in forested wetland development, and that by removing vines from systems during development, the systems may be delayed in reaching maturity. For this run, the management switch representing vine removal was activated in year 7 representing herbiciding and physical removal of vine biomass from the wetland.

Figure 6.45 shows a sharp decline in the storage of herbaceous vine biomass at 7 years, followed by a peak at 10 years, and a decline in herbaceous vine biomass, with some threshold storage level remaining throughout maturity. Woody vine biomass was also knocked back in year 7, followed by a low level of woody vine biomass through year

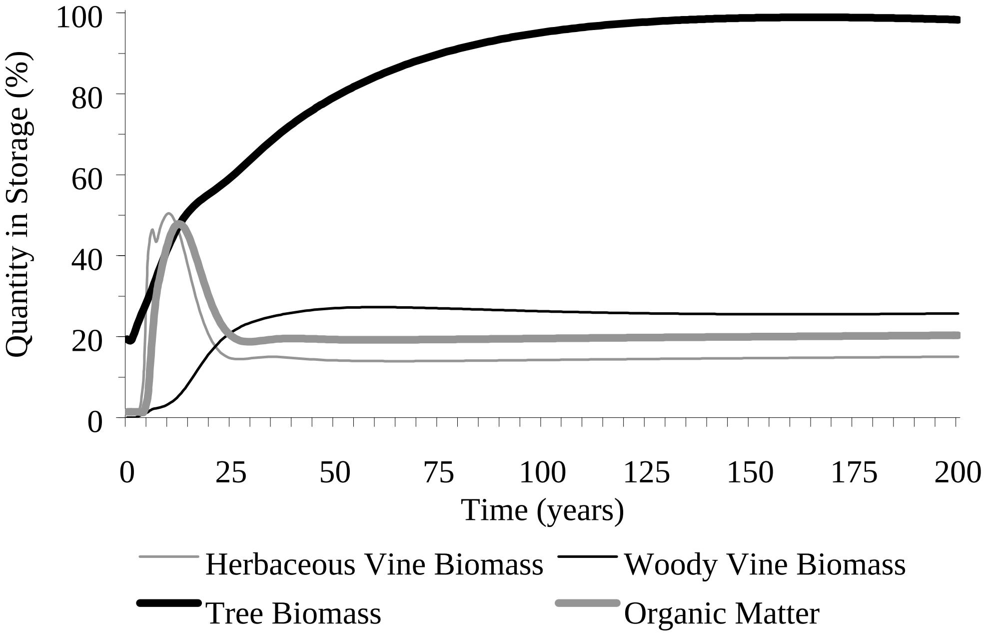


Figure 6.43. Initial Start-Up Conditions for the Computer Simulation Model of the Role of Vines in Succession.

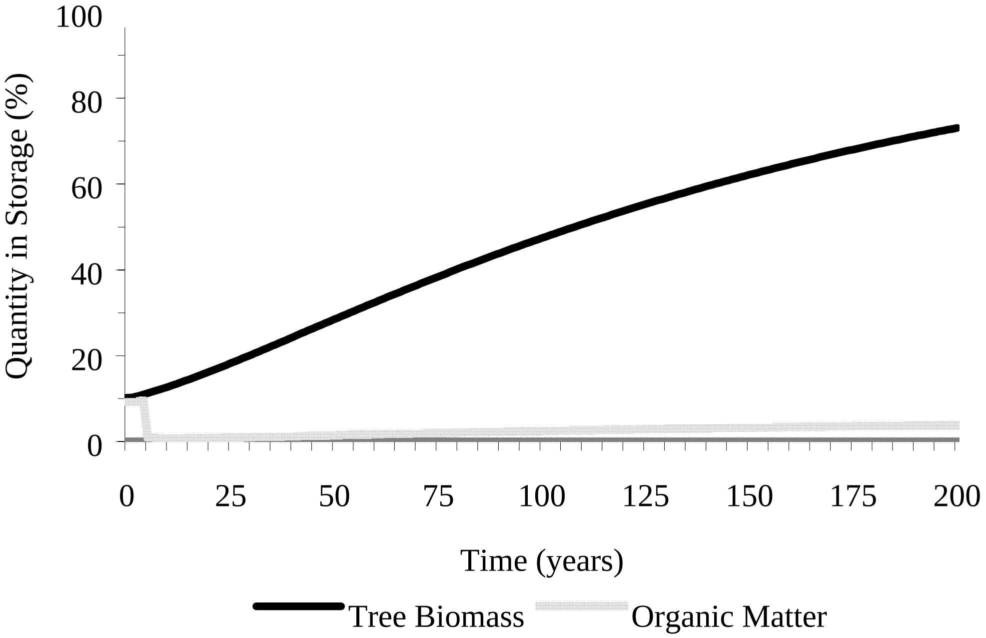


Figure 6.44. Simulation Showing Forested Wetland Succession in the Absence of Vines.

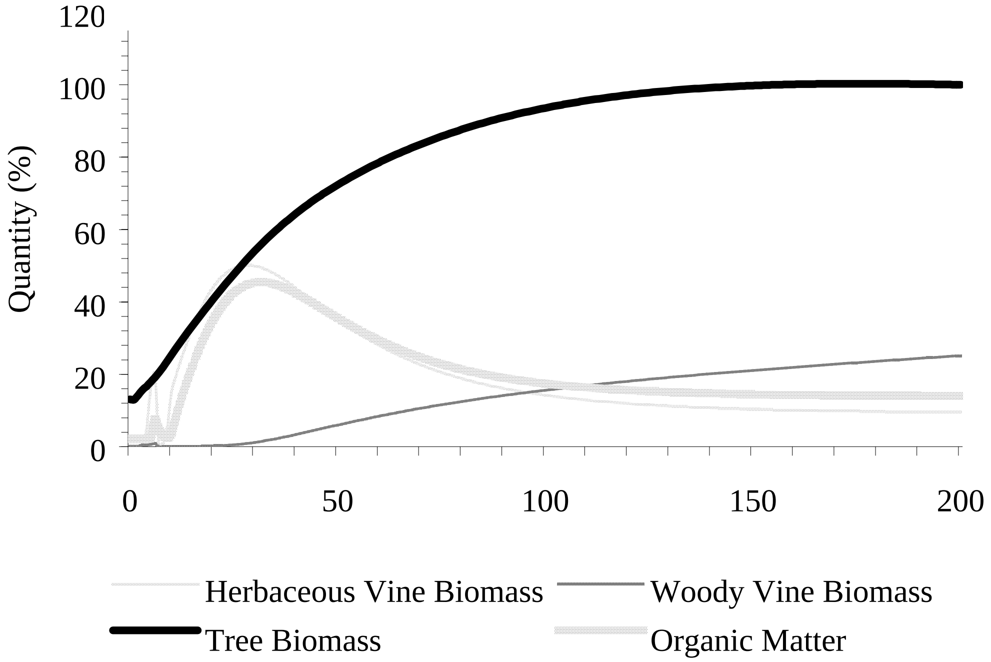


Figure 6.45. In This Simulation, Vine Management in the Form of Herbicide and Manual Removal of Vine Biomass Has Occurred in Year 7, Mimicking Common Practices by Reclamation Companies.

30 before reestablishing within the wetland system. Tree biomass reached maturity at around 150 years after site establishment. The storage of organic matter followed closely with the storage of herbaceous vine biomass. Organic matter peaked at approximately 20 years followed by a decline.

A final simulation was run to simulate the effects of the regular removal of vines when the biomass of herbaceous vines reaches 20% capacity. Often, land managers will visit reclaimed forested wetlands and determine the need for annual control of vines and other less desirable species. This run has simulated the periodic control of vines. Figure 6.46 shows the oscillating pattern of herbaceous vine biomass production and removal. The storage of organic matter closely follows the pattern of herbaceous vine biomass storage. The storage of woody vine biomass begins to accumulate in the first few years after site establishment as it did in the first start-up simulation run. However, after the first removal of vine biomass the herbaceous vines never recover. The model is constructed to show competition between herbaceous vines, woody vines, and trees for both sunlight and nutrients. This competition appears to prevent woody vine establishment. Tree biomass reaches a steady state near 200 years.

It is interesting to note that the herbaceous vine biomass grows rapidly in the first 30 years after site establishment. Then, as the storage of tree biomass increases, the accumulation of herbaceous vine biomass takes longer to reach the 20% capacity level. Herbaceous vine biomass appears to decline as the storage of tree biomass reaches steady state, with the last removal effort occurring 91 years after site establishment.

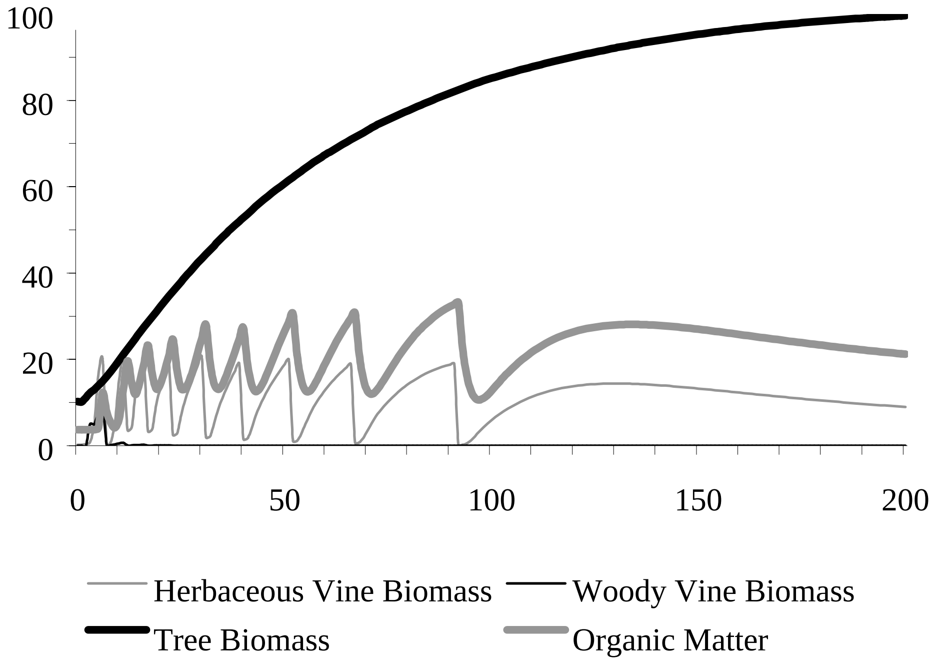


Figure 6.46. Simulation with Vine Management in the Form of Herbicide and Manual Removal of Vine Biomass Whenever the Storage of Herbaceous Vine Exceeds 20% of Storage.

DISCUSSION

This project focused on quantifying the areal extent of dominance and persistence of vines on reclaimed phosphate mined lands. The research concentrated on growth characteristics of vines, conditions favorable for their growth, their invasive nature, and their persistence over time. The systems studied were constructed forested wetlands undergoing primary succession. Of particular interest were the questions: what role vines play in succession in constructed forested wetlands; how pervasive vines are in constructed forested wetlands; how their role and areal dominance change over time; and what environmental conditions favor vine growth.

Fieldwork included collecting both abiotic and biotic data such as vine species identification, vine stem counts, vine basal diameter, above ground vine biomass, percent cover of understory vegetation, tree cover by vines, sunlight transmittance, mean water depth, and soil characteristics. A chronosequence sampling design allowed for random sampling used to determine what percent of the landscape vines occupied. An intensive sampling design of areas dominated by vines was employed to answer the question what environmental conditions favor vine growth.

Data collected in the field were incorporated into a computer model of forested wetland succession. The model included herbaceous vine biomass, woody vine biomass, and tree biomass storages competing for sunlight and nutrients. The model was used to test theories of the role of vines in successional forested wetland environments.

RESEARCH SUMMARY

This research has focused on the presence of vines and the impact they have on constructed forested wetland succession. Conclusions drawn from this research include:

1. Are vines detrimental to the development of newly constructed landscapes? Vines do not appear to be a problem in the landscape. According to above ground biomass, vines appear to account for less than 1% of the above ground biomass in the central Florida phosphate district. However, vines occupy a much larger percentage according to areal extent. In younger sites, vines occupy a very small percentage of the landscape, with the 0.5-year-old site having less than 10% herbaceous vines on an areal basis and no woody vines present. As sites mature, vines occupy a larger percentage of the landscape. In the oldest site sampled, herbaceous vines occurred in 60% of the sampled quadrats, while woody vines occurred in 95%.

2. Do vines interfere with ecological succession and community development? Vines do not appear to hinder ecological succession and forest development. Vines occurred throughout all ranges of herbaceous

understory cover and sunlight transmittance. The median dbh was not greater for trees not hosting vines versus those hosting vines (Mann-Whitney test at the 95% confidence level). In fact, vines may play an important role in contributing organic matter and cycling nutrients throughout ecological succession.

3. As ecosystems develop, do vines persist? Do vines exhibit successional trends where different species are dominant during different stages of succession? The number of rooted vines and dry weight vine biomass increased with increasing site age, suggesting that vines exist in mature forested wetland systems at some level. Only herbaceous vines occurred during the first few years after site establishment, followed by the recruitment and establishment of woody vines. As systems developed vine species richness increased, with the 0.5, 2, and 5-year-old sites having vine species richness values of zero and the 18-year-old site with a value of 3.8. Frequency of occurrence increased with site age, with the 0.5 and 2-year-old sites having 0% vine occurrence while the 18-year-old site had 100% frequency of occurrence.

4. Are there specific environmental conditions that favor vine dominance? There appears to be a zone of favorable edaphic conditions where vines thrive. The most notable condition was intermediate soil moisture, ranging from 5-40%. This zone appears as a band between the upland ecotone region and the more saturated soils of the open water region. NH_4-N (rS = 0.412, P = 0.006) appears to correlate the greatest with rooted vines, with the remaining plant-available nutrients Ca, Mg, K, P, Fe and NO_3-N not demonstrating significant correlations.

THE OCCURRENCE OF VINES

Vines within the central Florida phosphate district appear to represent less than 1% of the estimated total above ground biomass/m^2 when compared to data available from several wetlands in the southeastern United States (Appendix 6.F). Vines were found on all of the sites sampled throughout the constructed forested wetlands of the central Florida phosphate district. Even the youngest site, 0.5-year-old LP2 Phase 1, hosted vines, although they did not occur within the randomly placed sample transects (Table 6.4). The oldest site, 18-year-old Sink Branch, had the greatest heterogeneity with 12 different genera of vines recorded. All of the sites sampled had varying site histories including differences in hydrology, soils, and species planted, yet all of the sites provided adequate conditions for vine growth. In fact, most of the vines identified occurred on multiple sites (Figure 6.8), suggesting that site history may play a limited role in determining the occurrence of vines throughout the reclaimed landscape.

Through the first 18 years of reclaimed wetland development, the occurrence and variety of vines increased. Throughout succession vines appear to play an important role by adding species and structural diversity. Vine species richness increased with site age, suggesting that a greater variety of vines occur as sites age (Figure 6.8). Two previous studies have found similar results following site disturbance. Bush and others (1995) found that throughout over 100 years of sampling on three islands in Indonesia the number of vine species present increased over time. Additionally, Norman and Hawley (1995) found that the frequency of vine species increased over a 20 year period at Turtle Mound at New Smyrna Beach, Volusia County, Florida.

Ewel (1990) compiled data from many studies, and identified *Ampelopsis arborea*, *Aster carolinianus*, *Smilax* spp., *Toxicodendron radicans*, and *Vitis* spp., as vines frequently inhabiting mature bay swamps, cypress ponds and strands, hydric hammocks, mixed hardwood swamps, and river swamps in Florida. These woody vines were also common throughout the oldest sites sampled in the constructed wetlands in the central Florida phosphate district. Frequency of occurrence within sampling quadrats approached 100% with increasing site age.

Vines occur throughout much of the landscape of mature systems. Along the Savannah River, Collins and Wein (1993) found that only 8.5% of the landscape had no vines present on an areal basis, while characteristic vines such as *Smilax* spp. and *Vitis* spp. occurred throughout 30.5% and 23.2% of the landscape, respectively. Additionally, they found that two other species identified in the central Florida phosphate district, *Campsis radicans* and *Toxicodendron radicans*, occurred throughout 1.2% and 9.8% of the forested system, respectively. On the reclaimed forested wetlands studied, the four oldest sites sampled were found to host vines throughout at least of 85% of the landscape (Table 6.5).

Monk (1965) sampled 60 mixed hardwood forests and found similar results with *Campsis radicans* occurring throughout 37%, *Galactia elliotti* throughout 2%, *Gelsemium sempervirens* throughout 81%, *Parthenocissus quinquefolia* throughout 80%, *Toxicodendron radicans* throughout 75%, *Smilax bona-nox* throughout 79%, and *Vitis rotundifolia* throughout 90% of the landscape.

Vines occur throughout the landscape regardless of the percent of understory vegetative cover, and the presence of herbaceous understory vegetation seems fairly insignificant in determining the presence of vines (Figure 6.9; Figure 6.28). Similarly, vines appeared to occur throughout the ranges of tree basal area (Figure 6.14) and sunlight transmittance (Figure 6.13; Figure 6.30). As sites age and the tree canopy begins to close, it is expected that more vines will attached to tree trunks and grow into the forest canopy. Woody vines will establish as they use trees for support in climbing to the forest canopy. It follows that the total percent of trees covered by vines increased as sites aged (Figure 6.11).

The percentage of trees with vine cover varied throughout the sites, with some individual tree genera exhibiting an affinity for hosting vines (Table 6.9). At the youngest site, none of the trees within the transect boundaries hosted vines, whereas at the oldest site 100% of eight of the tree genera present hosted vines. The likelihood that a tree species will host vines is generally based on tree physiology, including branch formation, crown shape, and leaf morphology (Putz 1984). Of the tree genera found on the reclaimed forested wetlands, *Magnolia virginiana* and *Taxodium* spp. had the greatest percent of trees hosting vines (Figure 6.11). Previous research suggests that the large leaves of *Magnolia virginiana* may promote vine attachment, and the textured bark of *Taxodium* spp. may provide attachment opportunities for the tendrils and adventitious roots of vines (Hegarty 1989; Putz 1984). However, the high percentage of *Magnolia virginiana* and *Taxodium* spp. hosting vines may also be an artifact of the characteristics of where the trees are planted within the wetlands and the number of trees and basal area of the site.

Despite the negative effects vines are thought to impart to their trees hosts, there was no significant difference in the dbh of trees hosting vines or not (Figure 6.12). In fact, the mean dbh for a majority of the tree species hosting vines, including *Acer rubrum*, *Fraxinus* sp., *Liquidambar styraciflua*, *Magnolia virginiana*, *Myrica cerifera*, and *Quercus laurifolia*, appeared slightly greater than the mean dbh for trees of those same species that did not host vines.

An additional stand characteristic relating to the occurrence of vines is tree basal area. Vines occurred throughout the entire range of tree basal area (Figure 6.14). The greatest tree basal area on the reclaimed forested wetlands was 18.22 m^2/ha occurring at the 14-year-old SP11 site (Table 6.7). Mitsch and Gosselink (1993) compiled average stand statistics for riparian forested wetlands throughout the United States, and the mean basal areas recorded ranged from 17.7-42.0 m^2/ha. Basal area at the SP11 site falls within that range after only 14 years. This suggests SP11 may be the “oldest” site in terms of structural successional development having conditions that promote tree stand development or this may result from greater tree densities. However there where sites with equivalent or greater tree densities not yet supporting basal areas within this range.

As expected, there was greater sunlight transmittance in areas with smaller tree basal areas. Vines occurred throughout the entire range of tree basal area and therefore throughout the entire range of sunlight transmittance. This contradicts the widely held theory that vines are restricted to high light environments. Jones and others (1994) found that vines were the second most shade tolerant category of vegetation, second to shrubs. They found that both older and younger vines had high survival rates in the shade, with the exception of *Campsis radicans.*

Many vines are intolerant of flooding during seedling establishment, but can tolerate standing water for periods once they have become established. For example, the woody vine *Vitis* spp. is relatively intolerant of flooding in the seedling stage (Jones and others 1994). Few vine species can tolerate extended periods of inundation. *Mikania scandens* was the only vine found rooted in areas of standing water as deep as 23 cm (Figure 6.31). *Mikania scandens* was also the most frequent vine species found on reclaimed forested wetland sites, occurring on 8 of the 9 chronosequence sites sampled (Figure 6.8). *Mikania scandens* prevails over a wide range of site characteristics, and has been noted as flood tolerant. Previous studies suggest that flooding actually enhances the growth of *Mikania scandens* (Moon and others 1993).

THE ROLE OF VINES IN SUCCESSION

Vines are rapidly growing species with large surface areas that are highly adapted to early successional stages because they can actually over-grow other species (Odum and others 1997). These early successional, pioneer species are noted for their impermanent structures that permit competitive growth rates without wasting energy on persistent structure. Herbaceous vines can be considered early successional species create organic matter and store available nutrients, and prepare the system for later successional stages. Until system resources become limiting, these early successional species will dominate the system (Odum and others 1997). However, these early successional species are not expected to leave the system entirely, existing at low threshold levels as the system matures (Richardson 1988). On the other hand, woody vines put more energy into structure, in the form of woody stems and underground biomass storages, and enter the systems after herbaceous vines have become established. Woody vines use the tree species as hosts to climb to the top of the canopy, and woody vines will persist in forested systems.

In mature ecosystems, vines find their niche in high light environments such as forest gaps, canopy irregularities, and forest margins. Many previous studies have noted specifically that vines are light demanding, at least through establishment (Collins and Wein 1993; Dillenburg and others 1993b; Putz 1988; Putz 1984; Webb 1958). Therefore, most herbaceous vines cannot survive once tree canopy and subcanopy species begin to shade them out, except in high light environments. Additionally, woody vines establish themselves before canopy closure (beginning as early as 6-years-old) and continue to grow as the canopy grows, using trees for support, and calling on their energy reserves stored in their structure.

As forested wetlands experience canopy closure, shading occurs, decreasing available sunlight transmittance. Decreasing quantities of herbaceous vines and increasing quantities of woody vines coincide with the characteristics of later succession, including a decrease in herbaceous vegetation, an increase in taller woody species, an increase in the accumulation of organic matter, reduced light penetration due to canopy development, and possibly an increase in species diversity (Figure 6.7; Odum 1994). Indeed, vine species richness increased with increasing site age (Table 6.4; Figure 6.8), and vines occurred more frequently on older sites (Table 6.5).

The growth form and climbing mechanism of vines may be used to determine the stage of forest maturity (Bush and others 1995; Carter and others 1987; Putz and Chai 1987). Carter and others (1987) suggested that tendrillar vine species are better suited to climb the structures typical of closed canopy deciduous forests and that tendrillar vine species are physiologically tailored to low-light conditions over non-tendrillar vine species. Six tendrillar species occurred on the reclaimed forested wetlands sampled, including Ampelopsis arborea, *Melothria pendula*, *Momordica charantia, Passiflora incarnata*, *Smilax* spp., and *Vitis* spp. (Table 6.6). All of these vines were found growing on sites six-years or older, suggesting that there may be a direct correlation between the presence of tendrillar vine species and increased forest maturity.

At six-years, the forested wetlands studied had an approximate canopy height of 3 meters and a basal area of 4 m2/ha (Table 6.7), which correlated to approximately 50% sunlight transmittance through the canopy (Figure 6.13). Vine leaf area peaked around 6-7 years (Figure 6.29). Although forest maturity is hardly complete by age 6, the definition of forest maturity may need to be modified to stress the onset of canopy closure by early successional subcanopy species. Additionally, most of the studies on vines have been conducted in tropical systems where lianas (large woody vines) dominate the systems. These tropical systems have greater turnover times, taller canopies, and greater structure.

The initial run of the computer simulation model reflects these successional conditions with increasing tree biomass and a peak of herbaceous vine biomass between 5-10 years after site establishment (Figure 6.43). The wetlands sampled in the chronosequence design do not reflect forested wetlands at maturity, but rather forested systems progressing through succession. According to the model, the herbaceous vine biomass levels off at by year 20, whereas the oldest site sampled was 18-years-old. Tree biomass reaches a steady state level at approximately 100 years after site establishment, with well over 80% of the steady state biomass achieved by 50 years. Woody vines enter the system at approximately 5 years after establishment, and reach a steady state level by approximately 25 years.

The second run of the model demonstrates forested wetland succession and tree biomass development in the absence of vines (Figure 6.44). In this simulation, tree biomass at maturity is greatly reduced without the storage of organic matter created by vines. Vines may in fact make important contributions to organic matter accumulation and therefore the successional development of tree biomass (Bush and others 1995; Castellanos 1992; Putz and Mooney 1989).

Vines may be important to forested wetland development, and vine removal may be unnecessary and possibly even detrimental to timely system self-organization of developing forested wetlands (Figure 6.45; Figure 6.46). To discover the effects of management by means of biomass removal of vines two simulations were run mimicking management in the form of herbiciding and removal of vine biomass. These simulations showed delayed accumulation of organic matter following closely with the delayed peak of herbaceous vine biomass. The lack of organic matter and therefore vine biomass may contribute directly to the natural succession of forested wetland systems. It appears that by removing vine biomass throughout succession organic matter accumulation in the system is reduced.

Competition between herbaceous vines, woody vines, and trees for available sunlight and nutrients is also visible when woody vines do not recover after initial biomass removal (Figure 6.45; Figure 6.46). Herbaceous vines grab available nutrients by rooting at multiple nodes and translocating nutrients and water throughout their stems. However, woody vines and trees rarely have the ability to root throughout the landscape. Therefore, herbaceous vines have a competitive advantage of receiving nutrients and moisture. On the other hand, herbaceous vines are easily shaded out as canopies begin to close. Woody vines have a competitive advantage; they are adapted to climbing the structures of a closed canopy forest (Carter and others 1987). However, woody vines rely on their host canopies for support, and they grow up with the established trees. In the simple simulation model, woody vines compete directly with trees for sunlight and nutrients, and so the structure intensive growth form of the trees wins out over time, grabbing all of the available sunlight and nutrients.

ENVIRONMENTAL CONDITIONS FAVORABLE TO VINE GROWTH

Reclaimed wetlands host a wide range of values for soil parameters, most likely as a result of the materials used in reclamation and the long time span necessary for wetland soil development. Natural wetland soils have a long site history; however, reclaimed wetlands are recent in origin. The soils used in wetland construction have been mined, slurried, settled, hauled back to the sites, and left to dry out before recontouring even begins. Additionally, the surface mulched layer is often hauled in from other wetlands or from composted yard waste (Rosemarie Garcia, personal communication). These constructed wetlands lack well-defined hydric soil profiles. These soils may resemble natural wetland soil profiles; however, in the first few decades after establishment, these soils exhibit great heterogeneity.

Despite these diverse initial soil conditions, there appears to be a specific zone with favorable conditions for supporting vine growth. In wetlands surrounding streams or lakes, this zone appears to exist between the upland-transitional zone and the deeper waters of the stream or lake. In depressional and seepage forested wetland systems, this zone may extend from the upland-transitional ecotone through the wetland and to the upland-transitional ecotone on the far side. If these wetlands have permanent standing water, this zone will most likely encircle the wetland, with the exception of *Mikania scandens*. However, depressional and seepage wetlands may not exhibit such an apparent zone of vines if there is microtopographic relief and shallow or no standing surface water throughout the middle of the wetland.

Too much or too little soil moisture limits vine growth and distribution in forested wetlands throughout the southeast. Vine density is generally greatest in areas of intermediate soil moisture, with few vine species tolerating areas of exceptionally high soil moisture or flooding. Both vine and potential understory competitors flourish in areas of intermediate soil moisture, suggesting that the microenvironment may be the greatest influence on vine distribution (Collins and Wein 1993).

Intermediate soil moisture has been used as an indicator of this zone of vines, with most vines occurring at soil moisture levels ranging from 5-40% soil moisture

(Figure 6.15). The specific ranges varied at each wetland due to other factors, yet there was a general range of intermediate soil moisture apparent. At Hydric Hammock areas with soil moisture levels less than 10% had the lowest number of rooted vines, but in areas with soil moisture levels greater than 25% there were more rooted vines, often with 25 rooted vines per square meter (Figure 6.16). While most of the vines were rooted in this 5-40% soil moisture range, there were also areas within this range that did not host vines (Figure 6.32).

The same appears true for ranges of soil bulk density (Figure 6.33). Typical mineral soils have bulk densities between 1.25-1.45 g/cm^3, while typical highly organic histosols have bulk densities between 0.20-0.30 g/cm^3 (Brady 1990). On the reclaimed forested wetlands sampled, threshold levels of dry soil bulk density ranged from 0.5-1.5 g/cm^3 for rooted herbaceous vines, and from 1.0-1.5 g/cm^3 for rooted woody vines (Figure 6.18). Yet, areas with no rooted vines were also recorded throughout the 0.5-1.5 g/cm^3 range.

Many factors will affect soil organic matter content including water flow, oxidation, and hydroperiod. The lower range of values for herbaceous vines may be a relic of *Mikania scandens* taking root in standing water where organic matter breaks down more slowly than in dry, aerobic environments, lowering the soil bulk density. Accordingly, herbaceous vines occurred predominantly in areas with a greater soil organic matter range, from 5-15%, whereas the majority of the woody vines occur in the range of 0-10% soil organic matter (Figure 6.19).

Soil organic matter content may also suggest other site characteristics such as the degree of anoxic conditions and the hydroperiod. Permanently flooded sites have higher soil organic matter contents, whereas sites not flooded have lower soil organic matter contents (Jones and others 1994; Ewel 1990). Faulkner and Richardson (1989) found that the amount of organic matter in wetlands ranges from 15-75%, and Mitsch and Gosselink (1993) define mineral soils as those with less than <20-35% organic matter. By those standards, the reclaimed wetlands studied have mineral soils, with soil organic matter contents ranging from 5-20% (Figure 6.19). This may be attributed to the recent establishment of these sites. However, in a study along the Savannah River, Jones and others (1994) found that unflooded sites adjacent to a large and small river had soil organic matter contents of 4.6% and 11.4%, respectively. Additionally, soils from the flooded site within the large river streambed had 3.8% soil organic matter. Nessel and Bayley (1984) also found ranges of soil organic matter from 8-49% in wetlands.

There may also be a correlation between rooted vine presence and the concentrations of soil NH_4-N and Fe (Table 6.14). However, vines occurred throughout the full ranges of plant available nutrients, such as: 0-9,000 g calcium/m^3 (Figure 6.20; Figure 6.36), 0-600 g magnesium/m^3 (Figure 6.21; Figure 6.37), 0-70 g potassium/m^3 (Figure 6.22; Figure 6.38), 0-3,000 g phosphorus/m^3 (Figure 6.23; Figure 6.39), 0-100 g iron/m^3 (Figure 6.24; Figure 6.40), and 0-7 g nitrate-nitrogen/m^3 (Figure 6.26; Figure 6.42). Norman and Hawley (1995) also found wide ranges of nutrients within the upper layer of soils at Turtle Mound with values such as: 5559-6487 ppm calcium, 47-691 ppm magnesium, 15-1231 ppm phosphorus, and 13-107 ppm potassium. Nessel and Bayley (1984) and Monk (1966) found similar broad ranges for cypress swamps and mixed swamps, respectively.

LIMITATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Chronosequence Field Design

The greatest limitation for this field design was the small sample size, considering the large degree of intra- and inter-specific site variability. Only 9 wetlands were sampled, ranging in age from 0.5-18 years. There is a large gap in the data between ages 6 and 12, where ideally more sites should be sampled. Also, acceptable sample sites were limited based on ease of accessibility and availability of site history. It has been difficult to find specifics concerning many of the sites characteristics such as construction date, soil type used in recontouring, and species planted.

As a general note, 17-year-old Morrow Swamp is an exception to most trends concerning herbaceous and woody vines. This is probably due to many factors, with the most dominant reasons being the wide plantation-like spacing of the trees within this wetlands and a mean water depth of 5 cm. This site was created for an earlier hydrology study, and is thought to be an anomaly versus average 17-year-old sites.

Intensive Field Design

Only 6 intensive sites were sampled, leaving many gaps in the temporal span of the sites. Also, 2 of these sites (Nichols Mine and Mobil Cattail) had mean standing water levels of 9 and 21 cm, respectively. This poses a problem because only the herbaceous vine *Mikania scandens* was sampled in quadrats with standing water. The intention of the intensive sites was to target where vines grow specifically and under which conditions they flourish. Also, the CFI Primrose site was never planted with tree canopy species, so it had a significantly different structure than sites of equal age. This fact was discovered after sampling occurred.

Further Research

Many possible future research studies can be developed from the ideas presented in this study. First is the question of the management of vines. What is the acceptable or threshold level for vines at each successional stage? Is there some level of areal occurrence or biomass at which vines contribute to arrested succession? And is that a larger scale issue concerning site hydrology or some other physical characteristic?

Herbicide applications are common practice in the control of “nuisance species” when in fact such applications deplete species richness and may delay successional development. Future research could focus on the extent herbicide applications delay site development, not to mention the effects on “desirable species” and wildlife. In the long run, the simulation model shows a negative effect for vine removal. Is this an accurate prediction for real forested wetlands over a period of decades?

Also, what are the levels of vines in natural forested wetlands in the central Florida phosphate district? Are levels similar for reclaimed wetlands? If not, why, and how can reclamation managers create conditions that support natural levels?

CONCLUSIONS

Succession occurs in systems when disturbance leads to conditions that favor development of early pioneer species followed by recruitment of later successional species. The goal of wetland reclamation is to assist nature in succession by establishing appropriate wetland vegetation, soils, and hydrology, while preventing arrested succession in which the forested system never reaches maturity. Related research on phosphate mined lands has looked at the contributions of *Ludwigia peruviana* (primrose willow) and *Typha* spp. (cattail), both species are considered as early successional nuisance species by phosphate reclamation standards (Carstenn 2000; Richardson 1988). Both studies found that as canopy closure occurs these species play less of a role in the overall organization of the forested wetland. In other words, these species are restricted to early successional roles, and inhabit older sites only in disturbed environments at low threshold levels, much like vines.

This research has focused on the role of vines and conditions favoring vine domination. While initial dominance by vines may appear detrimental to trees, the evidence indicates that vines are important in the development of forested wetland and mesic systems. In fact, these early successional herbaceous vines may be crucial to the timely and successful development of reclaimed forested wetlands.

This research can be summarized with four main points. First, vines do not appear to be detrimental to the development of constructed landscapes. Second, vines do not appear to hinder ecological succession and forest development. Third, vines exhibit successional trends where different species are dominant during different stages of succession. Vines do in fact persist throughout forest maturity with increasing species richness and frequency of occurrence increasing with increasing site age. Fourth, there appears to be a zone of favorable edaphic conditions where vines thrive. In conclusion, the role of vines appears important throughout forested wetland succession.

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APPENDIX 6-A

LITERATURE REVIEW PERTAINING TO WETLAND CONSTRUCTION

RECLAMATION AND RESTORATION

Phosphate mining reclamation offers the unique opportunity to study primary succession and to see the effects of recontouring, revegetating, and managing wetland ecosystems. Each reclaimed wetland has a unique combination of site characteristics, including but not limited to hydrology, soils, mulching materials, distance to seed source, and species planted. Forested wetland ecosystems are constantly changing, and predictions of regeneration and plant succession are difficult due to high species richness and the influence of variable environmental factors such as flooding, disease, herbivory, root competition, shade, frost, and drought (Jones and others 1994; Streng and others 1989; Walker and others 1986). This makes assessing wetland reclamation success difficult when assigning simple criteria necessary for success.

Phosphate mining affects both the structure and function of natural systems at the landscape scale, and mining covers expansive areas of the central Florida landscape. The complete process of phosphate mining from initial land clearing through site reclamation affects the environmental integrity of central Florida. Schnoes and Humphrey (1980) note that some landscape effects of phosphate mining are the disruption of regional hydrology, lowering of surface water quality, creation of new landforms, and destruction of native habitat.

Marion (1986) describes reclamation as the recontouring of mined lands with sand tailings capping overburden fill or the development of the surface layer of dried clay settling areas. Reclaimed lands are frequently restored to open pasture, agricultural lands, temporary non-forested wetlands, forested wetlands, and open water habitats. The phosphate industry constructs a considerable portion of all wetlands built in Florida (Marion 1986). Requirements for successful reclamation of forested wetlands have traditionally focused on the vegetative community structure, assuming that by creating a forested wetland with similar vegetative composition found in the wetland destroyed, the constructed wetland ecosystem will function as the natural system did. To date, no overall analysis of the general success or failure of these reclaimed wetland systems on phosphate lands has been completed (Best and others 1997).

Reclamation efforts for forested wetlands often focus on planting the proper mix of late successional species and preventing establishment and dominance by nuisance species. Reclaimed forested wetlands are generally planted as mixed hardwood swamps. Vince and others (1989) define mixed hardwoods swamps as both bottomland hardwoods, which occur along creek and river basins, and hydric hammocks, which are more isolated swamps occurring as sloughs or depressions in the landscape. Native mixed hardwood swamps are dominated by broad-leaved deciduous species (Ewel 1990). Typical canopy species of mixed hardwood swamps include *Acer rubrum* L. (red maple), *Quercus nigra* L. (water oak), *Fraxinus caroliniana* Mill. (Carolina ash), *Nyssa sylvatica* Marsh. (water tupelo), *Liquidambar styraciflua* L. (sweet gum), *Taxodium distichum* (L.) Rich. (bald-cypress), and *Taxodium ascendens* (L.) Brongn. (pond-cypress). Native mixed hardwood swamps often have woody mid- and under-stories of *Ilex cassine* L.

(dahoon holly) and *Cephalanthus occidentalis* L. (common buttonbush) (Ewel 1990). Vines naturally occur within these systems (Norman and Hawley 1995; Jones and others 1994; Collins and Wein 1993; Beckwith 1968; and Monk 1965).

PERTINENT LEGISLATION

The presence of “nuisance species,” which include several vine species, is of special concern on reclaimed phosphate mined lands due to permitting requirements. The Florida Department of Environmental Protection, Bureau of Mine Reclamation, requires that nuisance species make up less than 10% of the total vegetative cover of reclaimed forested wetlands as described in the Florida Administrative Code Chapter 17-312 (FAC 1999).

One concern for regulating the percent vine cover is that permitting agencies require the control and elimination of these species, yet little research has been done on the extent of area dominated or impacts, both positive and negative, due to the presence of vine species. Because of the lack of information on vine species in reclaimed forested wetland systems, it is important to understand their role and interactions within the developing ecological community.

Until the 1970’s, no restrictions had been placed on the phosphate industry addressing voluntary or required reclamation of phosphate mined lands. Abandoning mined sites was common practice after surface mining was complete. However, in 1971 Chapter 211 (Part II) of the Florida Statutes was enacted, which required severance taxes to be paid on phosphate mined in Florida (Florida Statutes 2001). This severance tax applied to the extraction of the solid phosphate minerals intended for use outside of Florida, with the primary purpose of encouraging the voluntary reclamation of post-mine lands by giving tax refunds for the economic costs connected with land reclamation (Zellars-Williams and others 1980).

The following year, the Clean Water Act of 1972 (CWA) was passed. The CWA is federal legislation that, among other things, protects and regulates wetlands. Its main objective is to maintain the chemical, physical, and biological integrity of the waters of the United States. Section 404 authorizes the United States Army Corps of Engineers (USACE), with supervision by the United States Environmental Protection Agency (USEPA), to regulate the discharge of dredged or fill material into United States waters, which includes wetlands (USACE 1995; Mitsch and Gosselink 1993).

In 1978, Chapter 211 of the Florida Statutes (Part II, Section 16C-6) was modified, requiring the reclamation of all lands mined in Florida after July 1, 1975 (Florida Statutes 2001). This included the replacement of mined wetlands with constructed wetlands (Best and others 1997; Marion and King 1988). Marion and King (1988) summarized these new regulations as:

1. Encouraging conservation and preservation of the natural resources present after phosphate mining,
2. Considering the original drainage conditions on site,
3. Protecting endangered plant and animal species,
4. Establishing native trees and understory vegetation,
5. Identifying wildlife losses,
6. Planting a minimum of 10% of the upland area in a variety of indigenous hardwoods and conifers, and
7. Designating "wildlife areas" where the slope and erosion controls on nonreclaimed lands can be waived or modified in order to benefit and protect wildlife production.

However, these political attempts to establish useful guidelines for reclamation have poorly understood consequences for the successional development of these reclaimed systems (Schnoes and Humphrey 1980). Additional legislation governing mined lands includes Florida Statutes Chapter 378, which deals specifically with reclamation and requires the Department of Natural Resources to develop criteria and standards for mandatory reclamation (Florida Statutes 2001). These criteria are included in 62 C-16 of the Florida Administrative Code (FAC 1999).

Additionally, the Warren S. Henderson Wetlands Protection Act of 1984 is the principal regulatory legislation governing Florida wetlands. The Henderson Act adopted a vegetative index for successful restoration and increased the Department of Environmental Protection's (DEP's) jurisdiction over wetlands. Additionally, it expanded the DEP's permit review to include consideration of fish and wildlife values and the public's interest. It has also acknowledged the need for wetland mitigation and provided for consideration of growing impacts to wetlands**.**

PHOSPHATE MINING

The phosphatic rocks found in Florida were deposited during the Miocene epoch in the Tertiary period of geologic history when the state was inundated, and phosphorus was laid down as a consequence of oceanic deposits. Polk, Hillsborough, and the surrounding counties of central Florida host the highest concentration and best quality of phosphorus deposits in Florida. These deposits form the Bone Valley Formation, which is composed of phosphate rich boulders, pebbles, and sandy clay (Brown and others 1990; Schnoes and Humphrey 1980).

Mining activities for phosphorus extraction began about 1900 in Florida (Zellars-Williams and others 1980). Schnoes and Humphrey (1980) estimated that 5,180 km^2 in the central Florida district have large phosphate ore reserves accessible by surface mining. Phosphate is mined by open pit method, where overburden is moved to the side by a large mechanical dragline. Soil matrix, rich in phosphorus, is then removed and mixed into a slurry of insoluble materials with high-pressure water jets that break-up clays. The slurries are then piped up to several kilometers to industrial beneficiation plants that separate the extracted clay soil matrix through a process of washing and settling of the sands and silts. This process separates the slurry into phosphate product, sand tailings, and phosphatic clay slimes. The byproducts are then disposed of throughout the mined landscape.

The three main environments receiving beneficiation byproducts are clay settling ponds, overburden soil pits, and sand tailings. Clay settling ponds occupy 60-70% of the mined landscape (Rushton 1988), forming expansive wetlands and open water areas surrounded by earthen dams. The typical size of a clay settling pond is 2.5 km^2. However, clay settling ponds are an impermanent system designed to dry out waterlogged clays. The water content remains high in the clays for years, drying out gradually through pan evaporation and transpiration (Zellars-Williams and others 1980). Without human intervention, this drying process may take 10-20 years (Maehr 1984). For a more complete study of wetland succession on abandoned clay settling ponds see Rushton (1983).

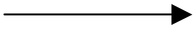
Overburden soil pits make up approximately 10-25% of the total land holdings and are a direct consequence of digging by draglines (FDE 1984). These areas are characterized by narrow, steep upland mounds surrounded by water bodies commonly filled with effluent from the industrial beneficiation of the mined phosphate. This water often comes in direct contact with ground water.

The remaining byproducts are the sand tailings, which are settled out in the industrial beneficiation process. After beneficiation, sand tailings are left nutrient poor. Because of low nutrient levels, sand tailings are difficult to vegetate (Zellars-Williams and others 1980) and are often used as reclamation fill or simply stacked in large piles on the mined landscape.

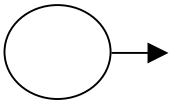
APPENDIX 6-B

SYSTEMS ECOLOGY SYMBOLS

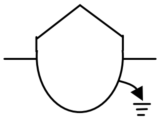
SYSTEMS ECOLOGY SYMBOLS



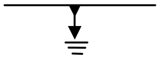
Energy circuit. A pathway whose flow is proportional to the quantity in the storage or source upstream.



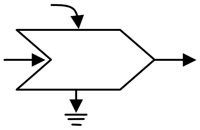
Source. Outside source of energy delivering forces according to a program controlled from the outside; a forcing function.



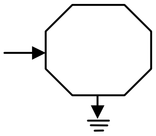
Tank. A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.



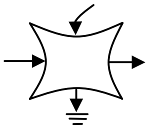
Heat sink. Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system.



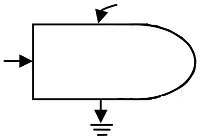
Interaction. Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; control action of one flow on another; limiting factor action; work gate.



Consumer. Unit that transforms energy quality, stores it, and feed it back autocatalytically to improve inflow.



Switching action. A symbol that indicates one or more switching actions.



Producer. Unit that collects and transforms low-quality energy under control interactions of high-quality flows.

Figure 6B-1. Symbols Used in Energy Systems Language (Odum 1994).

APPENDIX 6-C

KRUSKAL-WALLIS TEST FOR VINES BASAL DIAMETER

VINE BASAL DIAMETER FOR HERBACEOUS VINES ON THE CHRONO-SEQUENCE SITES

HN: The median vine basal diameter is the same between site ages.

HA: The median vine basal diameter is not the same for all site ages.

Kruskal-Wallis Test: Response versus Factor

Factor	N	Median	Average Rank	Z
Nichols Mine (a)	6	0.1700	19.1	0.43
Hydric Hammock (b)	8	0.1100	12.6	-1.58
Cateye (c)	2	0.1400	12.5	-0.73
Guy Branch (d)	3	0.1500	17.5	0.00
Morrow Swamp (e)	7	0.1900	22.9	1.60
Sink Branch (f)	8	0.1500	17.8	0.08
Overall	34		17.5	

$H = 4.60$ $DF = 5$ $P = 0.466$

$H = 4.65$ $DF = 5$ $P = 0.460$ (adjusted for ties)

$$Q = \frac{R_A - R_B}{SE}$$

Q = test statistic
R_A and R_B denote the mean ranks of the two treatments being compared
SE is the standard error, the calculation given by:

$$SE = \sqrt{\left[\frac{N(N+1)}{12} - \frac{\varphi t}{12(N-1)}\right] * \left[\frac{1}{n_A} + \frac{1}{n_B}\right]}$$

$Q_{AB} = +1.209$ $Q_{AC} = +0.812$ $Q_{AD} = +0.227$
$Q_{AE} = -1.815$ $Q_{AF} = +0.242$ $Q_{BC} = +0.013$
$Q_{BD} = -0.727$ $Q_{BE} = -1.998$ $Q_{BF} = -1.044$
$Q_{CD} = -0.550$ $Q_{CE} = -1.303$ $Q_{CF} = -0.673$
$Q_{DE} = -0.786$ $Q_{DF} = -0.445$ $Q_{EF} = +0.990$

VINE BASAL DIAMETER FOR WOODY VINES ON THE CHRONO-SEQUENCE SITES

Kruskal-Wallis Test: Response2 versus Factor2

Factor2	N	Median	Ave Rank	Z
Cateye (a)	2	0.4400	18.0	1.31
SP11 (b)	6	0.2050	11.8	-0.07
Guy Branch (‘c)	2	0.1950	11.0	-0.22
Sink Branch (d)	13	0.1900	11.3	-0.56
Overall	23		12.0	

H = 1.75 DF = 3 P = 0.626
H = 1.75 DF = 3 P = 0.625 (adjusted for ties)

$Q_{AB} =$ +1.12 $Q_{AC} =$ +1.032 $Q_{AD} =$ +1.301
$Q_{BC} =$ +0.409 $Q_{BD} =$ +0.061 $Q_{CD} =$ -0.058

APPENDIX 6-D

MANN-WHITNEY TEST RESULTS FOR DBH OF TREES NOT HOSTING AND HOSTING VINES

H_N: The median dbh of trees not hosting vines is greater than the median dbh for trees not hosting vines.

H_A: The median dbh of trees not hosting vines is less than or equal to the that for trees hosting vines.

SUPER HUMMOCK

***Acer rubrum:* Mann-Whitney Test and CI: Acru, VAcru**

```
Acru       N =  15     Median =      0.8000
VAcru      N =   2     Median =      0.6500
Point estimate for ETA1-ETA2 is      0.2000
95.6 Percent CI for ETA1-ETA2 is (-0.4000,1.0999)
W = 140.5
Test of ETA1 = ETA2  vs  ETA1 > ETA2 is significant at 0.2280
The test is significant at 0.2266 (adjusted for ties)
Cannot reject at alpha = 0.05
```

HYDRIC HAMMOCK

***Acer rubrum*: Mann-Whitney Test and CI: Acru, VAcru**

```
Acru       N =  13     Median =       3.200
VAcru      N =  25     Median =       4.300
Point estimate for ETA1-ETA2 is      -0.900
95.1 Percent CI for ETA1-ETA2 is (-2.300,0.500)
W = 203.5
Test of ETA1 = ETA2  vs  ETA1 > ETA2
Cannot reject since W is < 253.5
```

***Liquidambar styraciflua:* Mann-Whitney Test and CI: List, VList**

```
List       N =   8     Median =       5.400
VList      N =  10     Median =       9.750
Point estimate for ETA1-ETA2 is      -3.150
95.4 Percent CI for ETA1-ETA2 is (-7.999,3.198)
W = 65.0
Test of ETA1 = ETA2  vs  ETA1 > ETA2
Cannot reject since W is < 76.0
```

***Magnolia virginiana*: Mann-Whitney Test and CI: Mavi, VMavi**

```
Mavi       N =   8     Median =      0.5500
VMavi      N =   6     Median =      0.8500
Point estimate for ETA1-ETA2 is     -0.2500
95.5 Percent CI for ETA1-ETA2 is (-0.4998,0.2002)
W = 51.5
Test of ETA1 = ETA2  vs  ETA1 > ETA2
Cannot reject since W is < 60.0
```

GUY BRANCH

***Acer rubrum*: Mann-Whitney Test and CI: Acru, VAcru**

```
Acru       N =  41     Median =       2.800
VAcru      N =  10     Median =       8.450
Point estimate for ETA1-ETA2 is      -4.350
95.2 Percent CI for ETA1-ETA2 is (-10.198,-1.200)
W = 955.0
Test of ETA1 = ETA2  vs  ETA1 > ETA2
Cannot reject since W is < 1066.0
```

***Taxodium distichum:* Mann-Whitney Test and CI: Tadi, VTadi**

```
Tadi       N =  11     Median =       10.80
VTadi      N =   4     Median =       13.75
Point estimate for ETA1-ETA2 is       -3.15
95.7 Percent CI for ETA1-ETA2 is (-8.60,7.70)
W = 84.0
Test of ETA1 = ETA2  vs  ETA1 > ETA2
Cannot reject since W is < 88.0
```

MORROW SWAMP

***Taxodium distichum*: Mann-Whitney Test and CI: Tadi, VTadi**

```
Tadi       N =  16     Median =      12.350
VTadi      N =  35     Median =       9.100
Point estimate for ETA1-ETA2 is       1.800
95.2 Percent CI for ETA1-ETA2 is (-0.401,4.000)
W = 499.5
Test of ETA1 = ETA2  vs  ETA1 > ETA2 is significant at 0.0460
The test is significant at 0.0459 (adjusted for ties)
```

SINK BRANCH

***Myrica cerifera*: Mann-Whitney Test and CI: Myce, VMyce**

```
Myce       N =   5     Median =       3.400
VMyce      N =  44     Median =       6.100
Point estimate for ETA1-ETA2 is      -2.900
95.1 Percent CI for ETA1-ETA2 is (-4.200,0.001)
W = 62.5
Test of ETA1 = ETA2  vs  ETA1 > ETA2
Cannot reject since W is < 125.0
```

***Quercus laurifolia*: Mann-Whitney Test and CI: Qula, VQula**

```
Qula       N =  19     Median =       1.200
VQula      N =   3     Median =       0.300
Point estimate for ETA1-ETA2 is       0.700
95.5 Percent CI for ETA1-ETA2 is (-1.500,8.700)
W = 233.5
Test of ETA1 = ETA2  vs  ETA1 > ETA2 is significant at 0.0827
The test is significant at 0.0824 (adjusted for ties)
Cannot reject at alpha = 0.05
```

***Salix caroliniana*: Mann-Whitney Test and CI: Saca, VSaca**

```
Saca       N =  27     Median =      10.000
VSaca      N =   2     Median =      15.150
Point estimate for ETA1-ETA2 is      -5.350
95.7 Percent CI for ETA1-ETA2 is (-12.802,1.501)
W = 386.0
Test of ETA1 = ETA2  vs  ETA1 > ETA2
Cannot reject since W is < 405.
```

APPENDIX 6-E

SOIL MOISTURE GRADIENTS ALONG WETLAND TRANSECTS

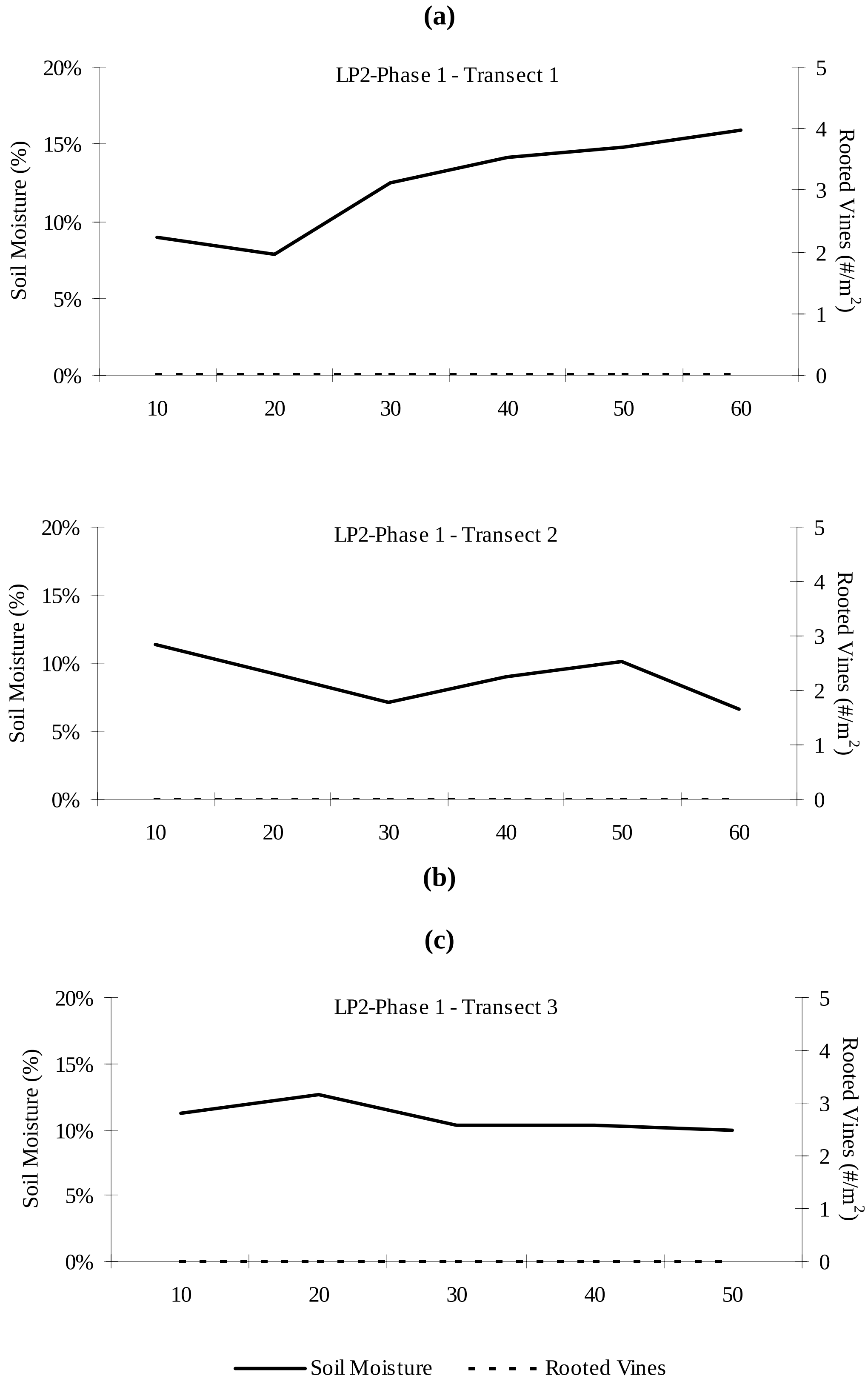


Figure 6E-1. **The Number of Rooted Vines Relating to Soil Moisture on Gradients at LP2-Phase 1. LP2-Phase 1 is a Fringing Wetland. Transects Began in the Upland/Wetland Ecotone and Towards the Lake, Although Never Reaching Standing Water. (a) Shows the 60 Meter Long Transect 1; (b) Shows the 60 Meter Long Transect 2; (c) Shows the**

50 Meter Long Transect 3.

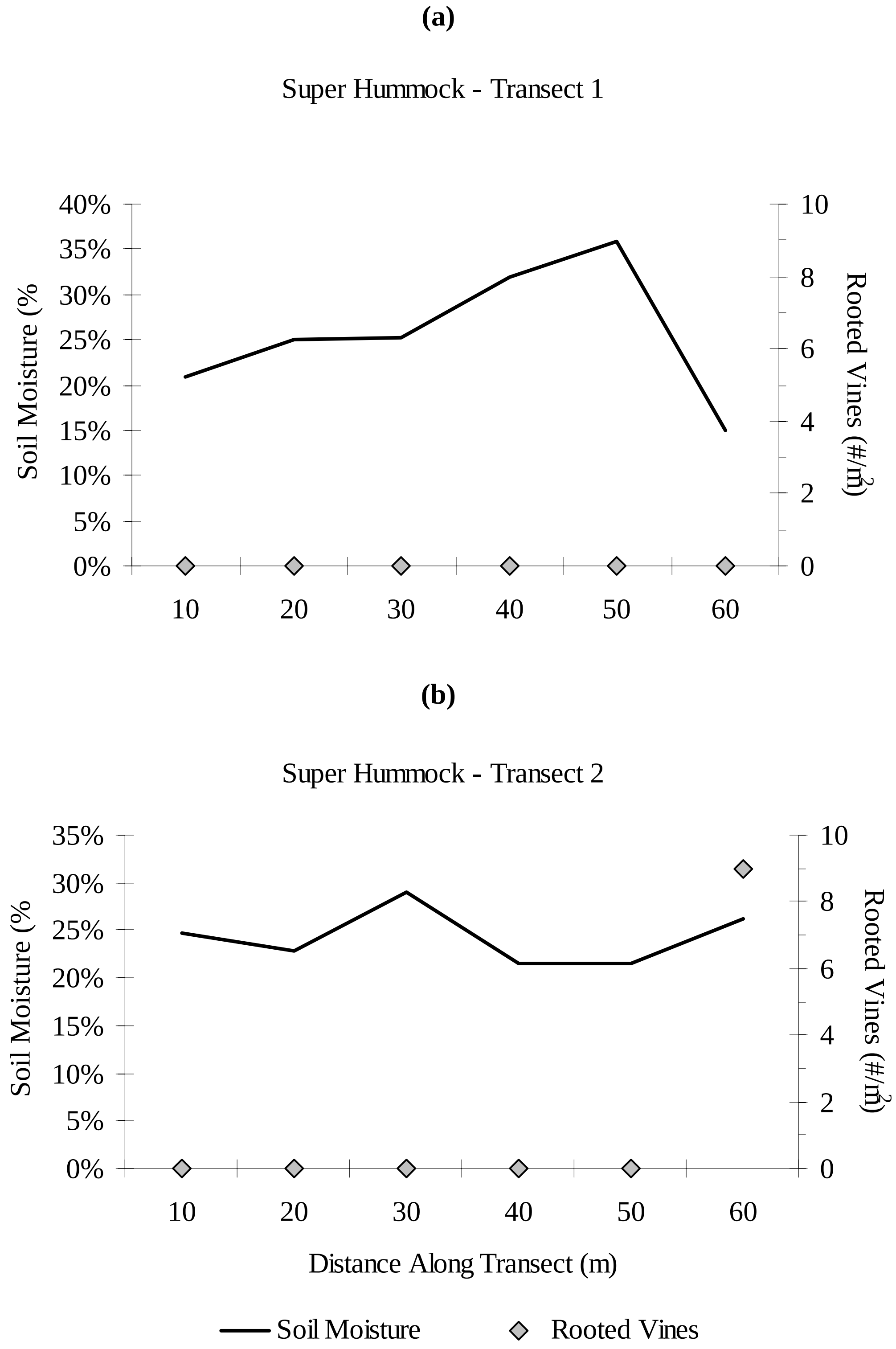
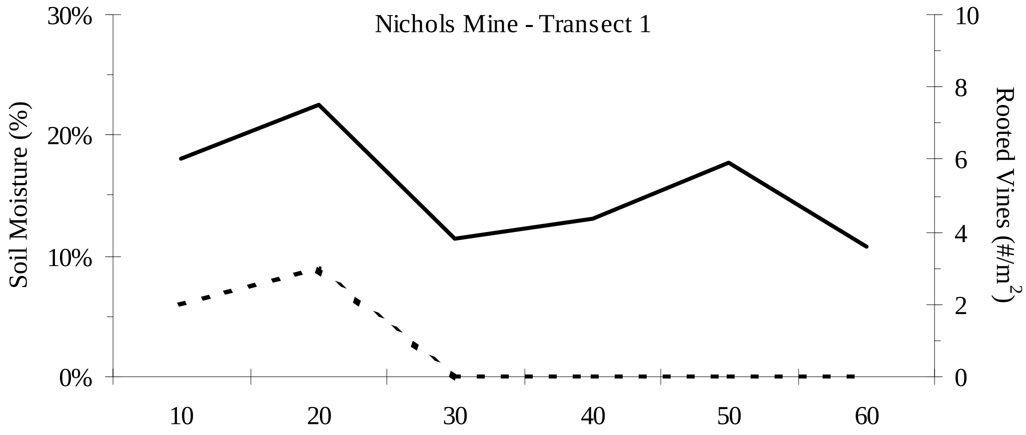
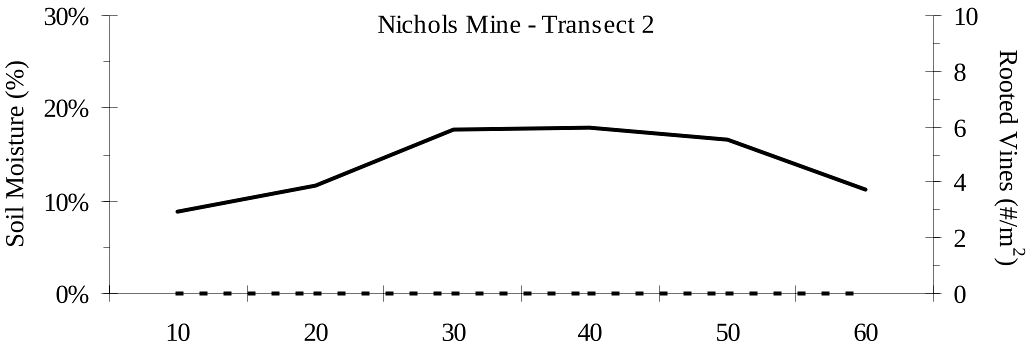


Figure 6E-2. The Number of Rooted Vines Relating to Soil Moisture on Gradients at Super Hummock. Super Hummock is a Depressional Wetland. Transects Began Along the Upland/Wetland Ecotone and Ran Towards the Center. This Wetland Shows Varying Soil Moistures Along the Transect Due to the Large Hummocks Placed Throughout the Wetland. (a) Shows the 60 Meter Long Transect 1; (b) Shows the 60 Meter Transect 2.



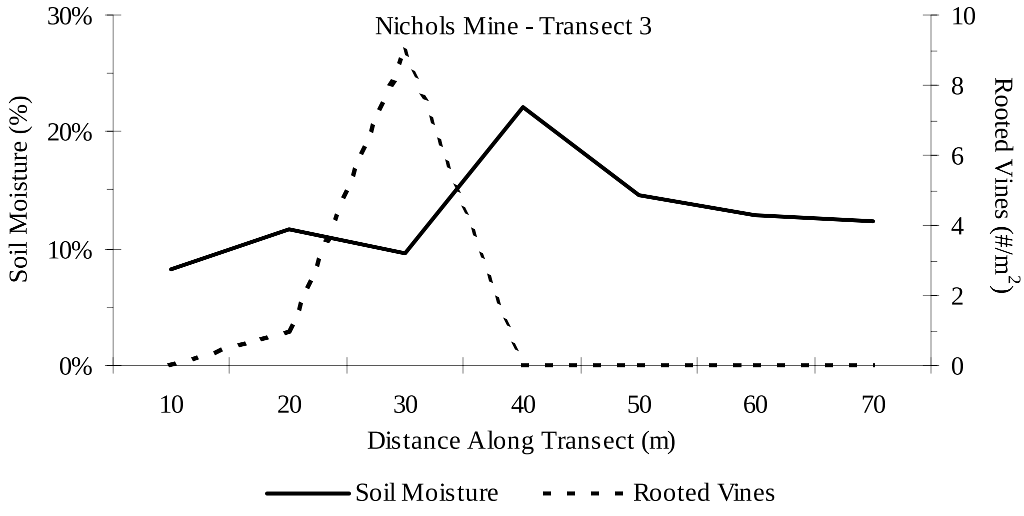
(a)



(b)

(c)

Figure 6E-3. The Number of Rooted Vines Relating to Soil Moisture on Gradients at Nichols Mine. Nichols Mine is a Seepage Wetland. Transects Began in the Upland/Wetland Ecotone and Continued through the Wetland, Although Never Reaching the Upland/Wetland Ecotone Region on the Far Side. (a) Shows the 60 Meter Long Transect 1; (b) Shows the 60 Meter Long Transect 2; (c) Shows the 70 Meter Long Transect 3.



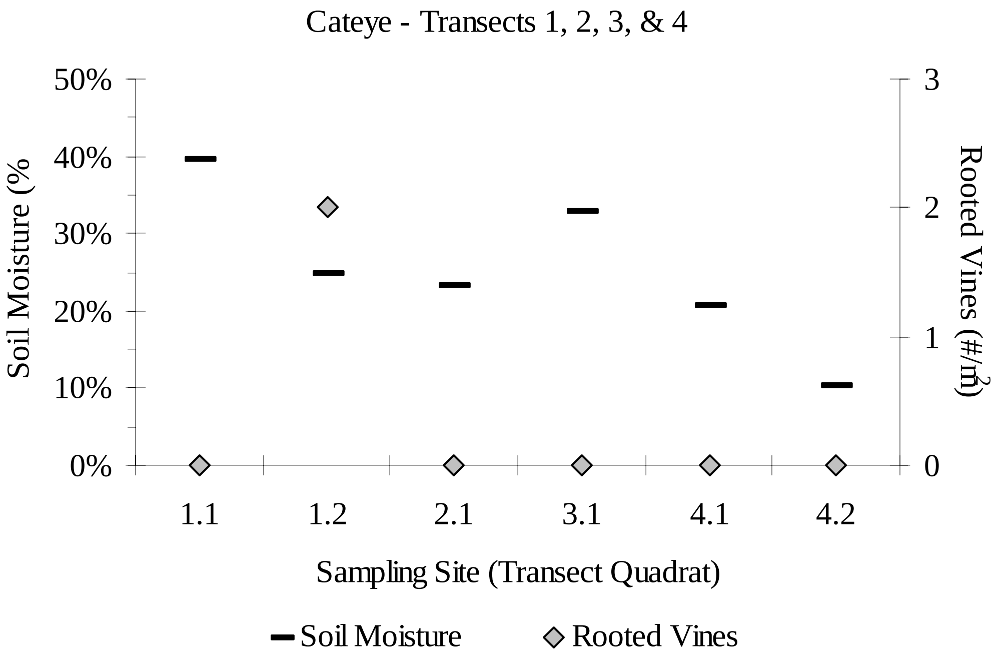


Figure 6E-4. **The Number of Rooted Vines Relating to Soil Moisture on Gradients at Cateye. Cateye is a Narrow Fringing Wetland, Which Has a Depressional Area Running Perpendicular to the Lake. Transects Ran Perpendicular to the Hydrologic Gradient, Thus Intersecting the Depressional Area. Maximum Transect Length Was 20 Meters Due to the Small Size of This Wetland.**

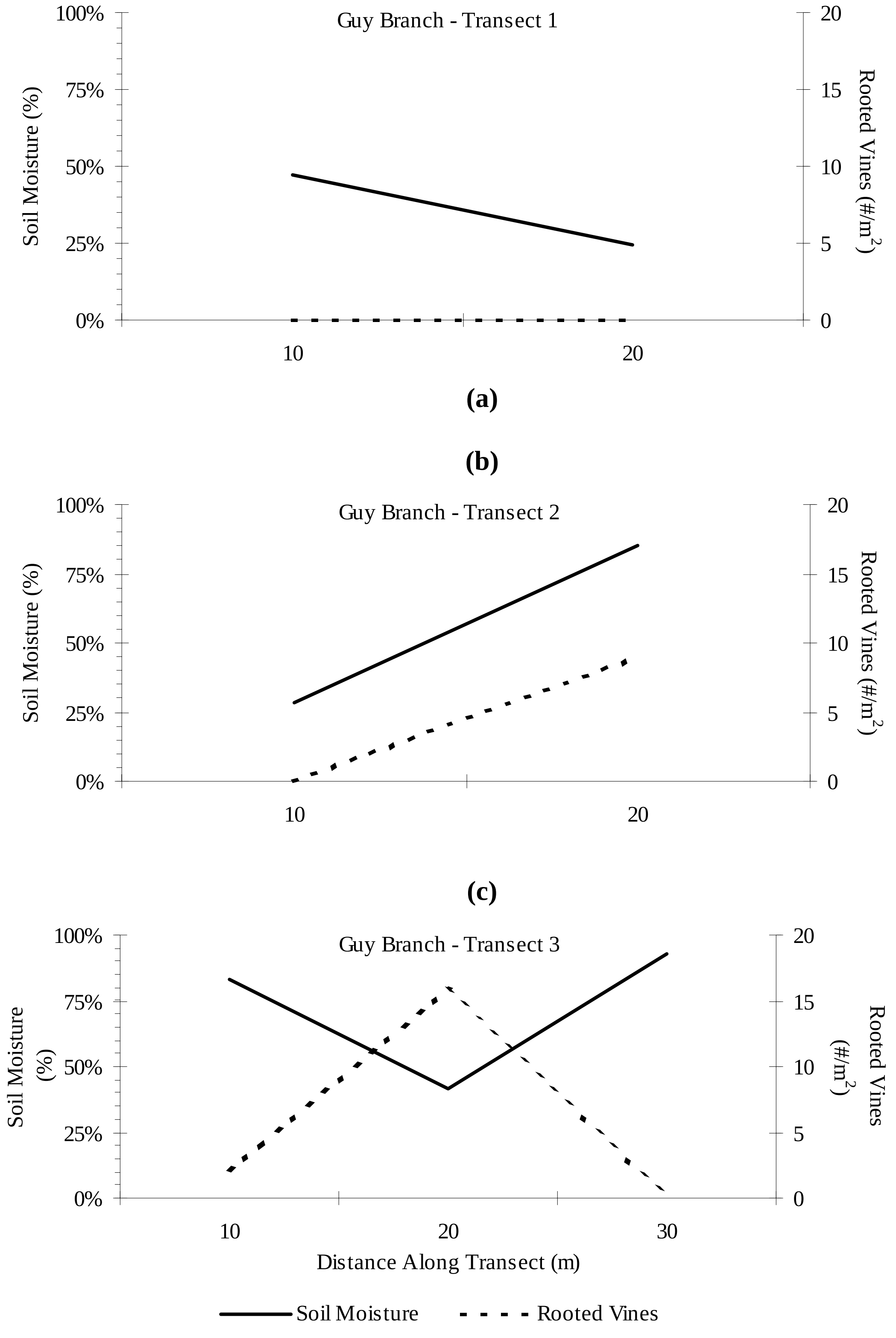


Figure 6E-5. The Number of Rooted Vines Relating to Soil Moisture on Gradients at Guy Branch. Guy Branch Borders a Stream Channel. Transects Ran Perpendicular to the Hydrologic Gradient Intersecting the Stream Channel. (a) Shows the 20 Meter Long Transect 1; (b) Shows the 20 Meter Long Transect 2; (c) Shows the 30 Meter Long Transect 3.

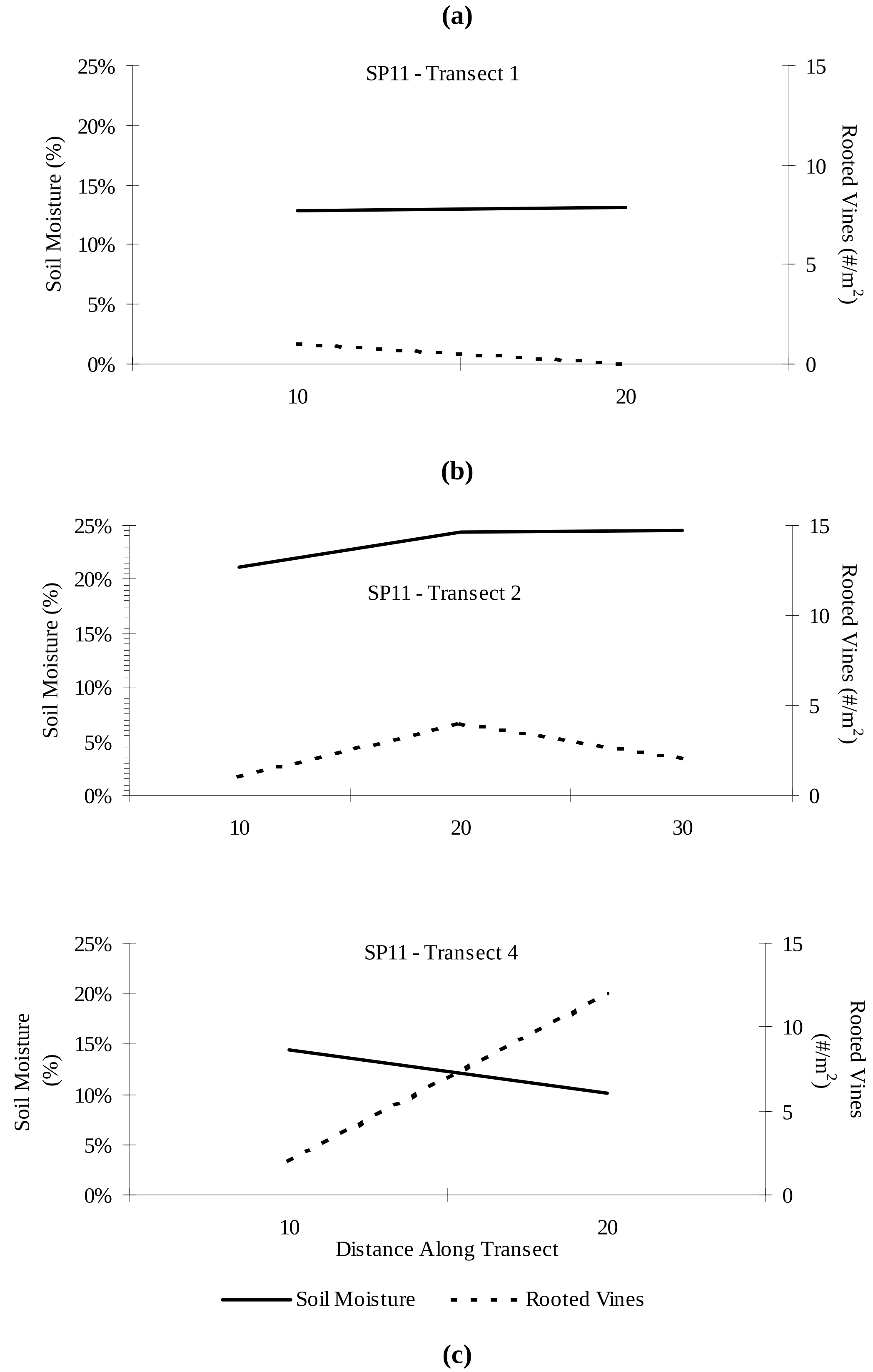
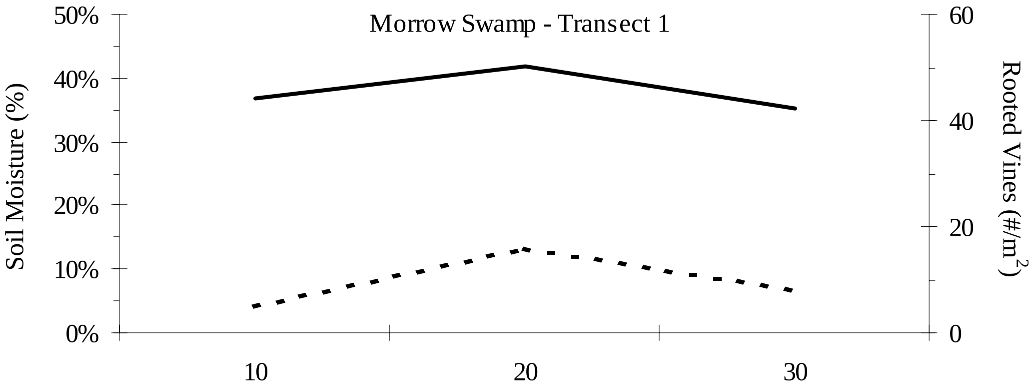


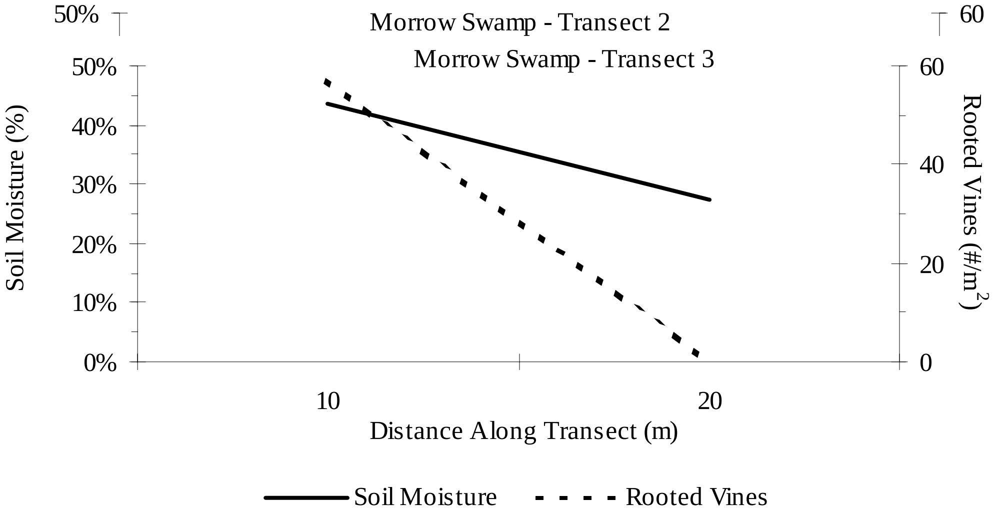
Figure 6E-6. The Number of Rooted Vines Relating to Soil Moisture on Gradients at SP11. SP11 is a Fringing Wetland. Transects Began in the Upland/ Wetland Ecotone and Towards the Lake, Although Never Reaching Standing Water. (a) Shows the 20 Meter Long Transect 1; (b) Shows the 30 Meter Long Transect 2; (c) Shows the 20 Meter Long Transect 4.

Transect 3 is Not Shown.



(a)
(b)
(c)

Figure 6E-7. The Number of Rooted Vines Relating to Soil Moisture on Gradients at Morrow Swamp. Morrow Swamp is a Depressional Wetland Designed for a Previous Hydrology Experiment. Transects Ran within the Wetland Boundaries, with No Overlap into the Upland/Wetland Ecotone Regions. (a) Shows the 30 Meter Long Transect 1; (b) Shows the 30 Meter Long Transect 2; (c) Shows the 20 Meter Long Transect 3.



APPENDIX 6-F

ABOVE-GROUND VINE BIOMASS IN THE LANDSCAPE

Table 6F-1. Above-Ground Vine Biomass at Each Research Site and Percentage of Total Above-Ground Biomass Represented by Vines. Total Above-Ground Biomass Based on Four Estimates Found in the Literature.

Site	LP2 Phase 1	Super Hummock	Nichols Mine	Hydric Hammock	Cateye	SP11	Guy Branch	Morrow Swamp	Sink Branch
Age (years)	0.5	2	5	6	12	14	15	17	18
Above Ground Vine Biomass (g/m^2)									
Herbaceous	0	11.64	1.25	31.19	10.35	2.68	25.11	60.81	- -
Woody	0	0	0	34.57	0	38.12	10.14	0	- -
Total	0	11.64	1.25	65.76	10.35	40.8	35.25	60.81	- -
[1]Lousiana riparian forested wetland (16.5 kg/m^2)									
Herbaceous	0	0.07%	0.01%	0.19%	0.06%	0.02%	0.15%	0.37%	- -
Woody	0	0%	0%	0.21%	0	0.23%	0.06%	0	- -
Total	0	0.07%	0.01%	0.40%	0.06%	0.25%	0.21%	0.37%	- -
[2]Florida scrub cypress ecosystem, natural control (3.79 kg/m^2)									
Herbaceous	0	0.31%	0.03%	0.82%	0.27%	0.07%	0.66%	1.60%	- -
Woody	0	0	0	0.91%	0	1.01%	0.27%	0	- -
Total	0	0.31%	0.03%	1.74%	0.27%	1.08%	0.93%	1.60%	- -
[2]Florida scrub cypress ecosystem, unnaturally flooded (10.99 kg/m^2)									
Herbaceous	0	0.11%	0.01%	0.28%	0.09%	0.02%	0.23%	0.55%	- -
Woody	0	0	0	0.31%	0	0.35%	0.09%	0	- -
Total	0	0.11%	0.01%	0.60%	0.09%	0.37%	0.32%	0.55%	- -
[3]Fakahatchee strand of South Florida (19.18 kg/m^2)									
Herbaceous	0	0.06%	0.01%	0.16%	0.05%	0.01%	0.13%	0.32%	- -
Woody	0	0	0	0.18%	0	0.20%	0.05%	0	- -
Total	0	0.06%	0.01%	0.34%	0.05%	0.21%	0.18%	0.32%	- -

[1] Connor and Day (1976), value for the total above ground biomass in a Louisiana riparian forested wetland = 16.5 kg/m^2.

[2] Brown et al. (1984), values for the total above ground biomass in two scrub cypress ecosystems in Florida. The first is a natural, control site = 3.79 kg/m^2. The second is a site that has been unnaturally flooded = 10.99 kg/m^2.

[3] Burns (1984), value for the total above ground biomass in the Fakahatchee strand of South Florida = 19.18 kg/m^2.

CHAPTER 7

SELF-ORGANIZATION AND SUCCESSIONAL TRAJECTORIES OF CONSTRUCTED FORESTED WETLANDS

S.M. Carstenn

INTRODUCTION

STATEMENT OF PROBLEM

With increasing emphasis on restoration ecology and the construction of ecosystems as a means of reestablishing productive ecological communities on degraded or drastically altered lands, there is a renewed importance to understanding ecological succession. While much is known about forest succession, sometimes called “old field succession,” little is understood about the process in wetland environments, especially successional processes in “constructed” wetlands. As the demand for replacing wetland functions within the landscape increases, there is a greater need for better methods of constructing and managing developing ecosystems. Yet, the gap in knowledge related to wetland succession may be a significant hindrance to developing effective wetland construction, restoration and management techniques.

Ecosystem succession is driven by available resources and is the orderly replacement of plant and animal species through time, beginning with relatively simple community organization (composed of a few species) and ending in more complex organization with higher diversity. Sometimes referred to as ecosystem development (Odum 1969), the process results in changes in community structure, composition and organization. Generally, the trajectory of change is toward increasing production, diversity, complexity and organization. Living components increase in size and longevity. Live biomass, organic matter and nutrients accumulate, and food webs become more complex.

When conceived as a system level response to conditions that favor increased productivity, succession is described as a perfect example of self-organization (Odum 1989), where components of a system benefit individually, but interact in such a way as to reinforce all others. Components of a system and their pathways of interaction are self-organizing, in that appropriate and successful organization results in increased productivity that in turn reinforces those components and pathways that stimulated the productivity in the first place. From the perspective of self-organization, patterns that result in increased energy and resource flows are successful and therefore selected for over time.

In this dissertation, self-organization of constructed forested wetlands was studied by measuring numerous parameters related to vegetation and soil constituents and by constructing successional trajectories (pathways of development in biotic and abiotic parameters over time) with the data. Successional theory describes distinct, directional changes in ecosystems with time, often moving toward an asymptotic maximum. If these changes occur across systems and are measurable, changes should be apparent by measuring the changing parameters across a chronosequence of successional stages.

Table 7.1 lists the descriptive parameters measured for eventual trajectory development. Figure 7.1 represents a hypothetical successional trajectory of a parameter. The actual value for a parameter over time, although unknown, is represented by the dotted line. The solid black represents a best estimate of the value of the parameter derived from field data. A 95% confidence interval around the measured values of the parameter provides an acceptable range of values for that parameter at any given time. Regions lying above the acceptable range may represent unrealistic expectations for the value of the parameter, while the region below the acceptable region may indicate a need for concern. Values of the parameter falling in the area of concern may indicate the parameter is progressing in the desired direction and that expected self-organization processes are not occurring.

There is not a single trajectory, but as many trajectories as there are components and processes that change with succession. Therefore the real question is, “Are there one or more trajectories that could be used to aid in construction, management and assessment of forested wetland systems?”

REVIEW OF LITERATURE

Successional Theory as a Basis for Ecosystem Construction and Management

Historically, a unifying theory of ecological succession has been elusive. Varying approaches to the study of ecological succession have resulted in opposing conceptualizations, many of which can be resolved by identifying the scale of reference. The concept of steady state or successional climax, although apparent at a landscape scale, is questioned by those approaching an understanding of succession at a smaller scale. A small-scale approach leads to a view of a dynamic and constantly changing environment driven by stochastic events.

If succession is an orderly progression through a sequence of developmental stages, defining the underlying mechanism of this change becomes the focus of research. Early efforts directed toward a unified successional theory focused on the biotic component, primarily vegetation, since the changing plant community is the most easily observable change through time. Connell and Slayter (1977) summarize three mechanistic models for explaining change in plant species composition with time.

Table 7.1. Individual Parameters and Emerging Properties Established for Vegetation Structural Categories and Soils.

Individual Parameters

Canopy Trees
- Height
- Diameter at breast height
- Dbh size class distribution
- Community basal area
- Canopy cover
- Stem density
- Species richness
- Species diversity
- Light transmittance

Subcanopy Trees and Shrubs
- Stem density
- Diameter at breast height
- Species richness
- Species diversity

Herbaceous Species
- Species richness
- Species diversity
- Cover abundance

Total ground cover
- Canopy and subcanopy seedling richness and frequency of occurrence
- Vine species richness and frequency of occurrence
- Nuisance species frequency of occurrence

Soils
- Plant available nutrients (Ca, Ma, K, P, Fe, NO_3-N, NH_4-N)
- Soil moisture
- Bulk density
- Organic matter content

Emerging Properties
- Hierarchical size class frequency distributions of tree diameter
- Increasing organic matter associated with increases soil-water content
- Decreasing bulk density associated with increases in soil organic matter
- Changes in frequency of vegetational structural categories with age

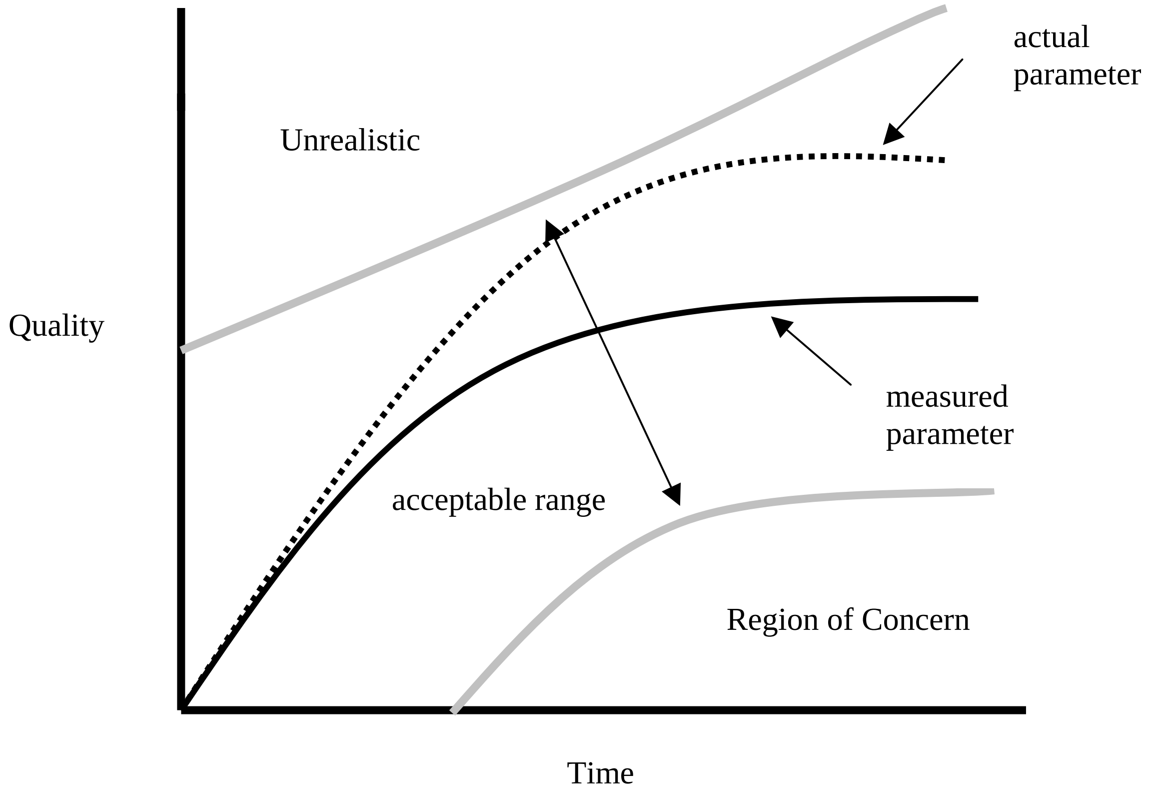


Figure 7.1. A Successional Trajectory. Dotted Line Represents the Actual Parameter of Interest, Could It Be Known. The Solid Black Line Represents the Parameter as Measured in the Field. The Area Between the Two Gray Lines Represents an Acceptable Range of Variation Around the Measured Parameter. Above and Below This Area Represents a Region of Unrealistic Expectations and a Region of Concern, Respectively.

The first model, referred to as “facilitation”, suggests that early successional species modify the environment (Clements 1917; Egler 1954). The resulting environmental modifications facilitate the recruitment and establishment of later successional species. According to the “tolerance” model, the sequence of species is determined solely by the species’ life history characteristics. Later successional species are considered to arrive at the site later or to have arrived at the same time as early successional species but to grow more slowly. This model suggests that the eventual dominance of later successional species is not influenced by the presence of early successional species. The third, “inhibition” model holds that early successional species inhibit the invasion and establishment of later successional species; and for successional processes to move forward, early successional species must die. Later successional species eventually replace early successional species since the longevity of early successional species is shorter than that of later successional species. Because of differential longevity, early successional species will be replaced more often than later successional ones. If seeds of later successional species are available, they have an equal probability of replacing early successional species, and because of their longevity they will accumulate in the system.

As increasing efforts are focused on constructing ecosystems, the following philosophical questions arise, and their answers are the foundation of management and regulation.

- Can succession be accelerated?
- Is it possible or desirable to omit successional stages?
- Can succession be short-circuited by omitting or shortening stages?

The answers to these questions vary with successional paradigm. The “Facilitation Model” suggests that jump-starting, shortening or omitting various stages in the successional processes may be met with limited success. The success of any subsequent successional stage is dependent on environmental modifications provided by earlier stages. The “Tolerance Model” lends support to the probable success of accelerating succession by virtue of ensuring the presence of late successional species to a system early in the developmental process. The “Inhibition Model” supports accelerating succession by the removal of individual species or groups of species. This model suggests that herbiciding or manual removal of early successional species will enhance the development of late successional species and ultimately a mature ecosystem.

Competing Views of Ecological Succession

Clements viewed succession as a highly ordered and predictable process in which vegetation change within a plant community represented life stages corresponding to growth stages of an individual organism. Communities were believed to converge through succession, regardless of initial conditions, toward a climax vegetation that was characteristic of a regional climate.

Clements (1904, 1917) developed a scheme of processes that drive succession: 1) initial causes that produce new or denuded soil on which invasion is possible, 2) ecesic processes resulting in migration (arrival at the site) include ecesis (germination, growth, and reproduction), aggregation (grouping of offspring about the parent plant), competition (interaction of organisms at the site), invasion (movement of plant from one area to another) and reaction (the modification of the site by the organisms); and 3) stabilization which results in the development of a stable climax (Weaver and Clements 1929). Clements emphasized the importance in succession of autogenic processes, processes controlled from within a system. He viewed reaction, creating environmental conditions less favorable to early colonists and more favorable to late seral or climax species, as the main driving force of succession.

Gleason (1927) stressed the unique individualistic behavior of plant species and the role of stochastic events in the successional process. He believed successional stages resulted from the response of individual species with different environmental tolerances to a constantly changing suite of environmental forces. Tansley (1935) criticized Clements' assumption that all vegetation change in a particular region would converge toward the same type of climax driven primarily by the regional climate. Tansley argued that rock type and topographic position may result in a climax that differs from that associated with a regional climate. Tansley's terminology (1935) included the term "autogenic" succession, referring to controlling processes originating from within the biological components of the system, and "allogenic" succession referring to controlling influences from the physicochemical components of the system.

Egler (1954) concluded that the initial floristic composition of a site may largely determine the subsequent vegetation. The "initial floristics" model of succession suggests that the initial composition of species migrating to and establishing at the site determined the direction of later species replacements.

Margalef (1958, 1963) suggested that the linkages among trophic levels and populations represented information and that succession represents a natural trend toward the accumulation of greater information in an ecosystem. Odum (1969) believed that successional trends and ecosystem properties result from the tendency of ecosystems to develop toward greater homeostasis. Within limits set by the physical environment, succession proceeds toward an ecosystem of maximum biomass and diversity.

Walker and Chapin (1987) suggest that the major factors influencing importance of successional processes are (1) stage of succession; (2) type of succession (primary, secondary, or regeneration after disturbance); (3) availability of environmental resources (particularly water and nutrients;) and (4) type, frequency and intensity of disturbance.

Since the mid-1970's two major conceptual trends have appeared (1) a shift away from holistic explanations of successional phenomena postulated by Clements, Odum and Margalef, toward mechanistic approaches emphasizing proximate causes of vegetative change; and (2) a shift away from equilibrium paradigms. However, in the shifting-mosaic steady-state model of succession (Borman and Likens 1979) the forest as a whole is a dynamic mosaic, ever-changing at a small scale, yet remaining much the same at a larger scale of reference. This suggests that the existence of equilibrium is scale-dependent. Holling (1992) supports this claim by suggesting that “Ecosystem models can be legitimately criticized for presuming ever-increasing detail improves predication.”

The view of succession as primarily a species replacement process driven by reaction or plant controlled environmental modification has been rejected by many. It has been followed by several overlapping hypotheses that may all apply to varying degrees to any one successional sequence: succession as (1) a gradient in time or resource availability (Pickett 1976); (2) the consequence of differential longevity and other population processes (Egler 1954); (3) the result of differences in life history characteristics (Grime 1974); or (4) as a stochastic process. Common to all these hypotheses is a reductionist perspective emphasizing life histories and competitive interactions of the component species rather than emergent properties of communities.

Systems Perspective of Succession

The terms, succession and self-organization, are often used interchangeably. However, succession is purely a descriptive term and has, as yet, not provided a mechanism by which this process proceeds. Systems ecology provides the integrating principal of ecosystem development, the maximum power principle (Lotka 1922).

> System designs organize so as to bring in energy as fast as
> possible and use it most efficiently (Odum 1998).

Ecosystem succession is the result of self-organization and the maximum power principle. Ecosystems respond to the surrounding environment; those responses contributing to the efficient use of resources are reinforced. During self-organization, systems are guided by the maximum power principle. Systems will continue to organize toward maximum power and efficiency unless disturbed by external forces (stochastic events) that reset the successional clock.

Wetlands Succession

The assumption can be made that the same processes influencing terrestrial succession are at work in wetland systems. Clements’ concept of succession holds that within a region, the same final or climax stage results whether succession begins on solid rock or in open water.

A successional sequence beginning in open water, termed a hydrarch, will progress through a sequence of stages termed hydrosere. The first stage of a hydrosere includes establishment of submerged vegetation. A floating stage, reed-swamp stage, sedge-meadow stage, and a woodland stage follow this stage. Clements suggests that the vegetation occurring in each of these stages influences the system by producing shade and lowering the water table, ultimately resulting in conditions that support a climax forest.

Little evidence exists to support the supposition that a wetland will become an upland because of the influence of vegetation on hydrology, but succession within a forested wetland may be directional. Clements acknowledges that stochastic events or other environmental factors can block the pathway of succession and can result in the maintenance of a subclimax community. Van der Valk (1981) considered that allogenic processes dominate in wetlands. Through interactions with the life history characteristics of wetland vegetation allogenic processes can predict successional change in wetlands. His qualitative model of wetland succession predicted either progression toward a climax-forested wetland or maintenance of a subclimax community based on relatively few parameters including vegetation life history (species life-span, propagule longevity, establishment requirements) and wetland environment condition (flooded or drawdown). This model assumes that interactions among species, such as competition and allelopathy, and would not result in the loss of any species from the wetland.

Soil Succession

Studies of successional processes in soil formation support the concept of directional change in many soil parameters. If these changes are dependable, repeatable and measurable within a reasonable time frame, they may lend themselves to the development of predictive trajectories for soil succession.

Jenny (1941) identified five soil-forming factors including climate, organisms, parent material, relief and time. Vegetation strongly influences initial soil development (Salisbury 1925; Jenny and others 1969; Olsen 1958; Dickson and Crocker 1953; Crocker and Major 1955). Yaalon (1975) emphasized the importance of parent material in determining the properties and genesis of young soils. Organic carbon, total nitrogen, pH and bulk density changed rapidly during initial soil development and were influenced strongly by vegetation (Dickson and Crocker 1953).

Sithe and others (1971) studied soil genesis in iron-mine spoils in West Virginia. Spoils had deeper rooting, higher cation exchange capacity, and higher exchangeable nutrients than natural soils. Natural soils had lower bulk density, higher porosity, greater soil structure, and higher nitrogen and organic carbon contents. Wali and Freeman (1973) studied species composition and soil characteristics of North Dakota mine spoils compared to adjacent undisturbed areas. Spoils had higher pH, electrical conductivity, exchangeable magnesium, exchangeable sodium, total phosphorus, sulfur and silt and clay content. Unmined sites had greater organic carbon; exchangeable potassium, species diversity, species abundance, and species density. Caspall (1975) found that organic matter content increases rapidly with time in the top few centimeters of Illinois' mine soils. Organic matter increases more slowly below about 5 cm. After only 14 years, organic matter in the upper 12 cm of mine soils was about 60 percent of equilibrium.

Graetz and Reddy (1997) studied soils in reclaimed wetlands on phosphate mined lands in central Florida. They found decreasing bulk density, C:N ratio and pH, while organic matter, total nitrogen and cation exchange capacity increased with age. Native wetlands generally had greater organic matter accumulation in the litter and on the soil. The results of Anderson (1977), and Schaffer and others (1979) indicate that soil development processes occurring in natural soils are active in mine soils. They conclude that mine soils should become more like natural soils with increasing age since the same processes that occurred in the development of natural soils are active in mine soils.

Vitousek and Farrington (1997) investigated the nature of nitrogen and phosphorus limitation on a chronosequence of soil of volcanic origin in Hawaii using a fertilization experiment, and found younger sites to be nitrogen limited, while older sites were phosphorus limited. Earlier investigations by Crew and others (1995) on the same Hawaiian chronosequence suggest a general pattern of decreasing nitrogen limitation as soil fertility increases early, followed by increasing phosphorus limitation as soil fertility declines late. They believe this trend is a function of "1) the biogeochemical controls on net inputs and outputs of these two elements at different stages of ecosystem development and 2) a possible decomposition feedback that intensifies the fertility or infertility of the different ages." The decomposition feedback results from the apparent greater decomposability and more rapid nutrient release from litter in high-fertility conditions.

A model of phosphorus transformation during terrestrial soil development proposed by Walker and Syers (1976) suggests that all soil phosphorus is in the form of calcium apatite minerals at the beginning of soil development. With time, the mineral – P slowly dissolves and is either taken up by organisms thus entering the organic phosphorus pool, or is sorbed onto secondary mineral surfaces. Crew and others (1995) tested this model on the soil chronosequence in Hawaii. Several predications made by the Walker and Syer model were supported by the results of Crew and others, including "1) decreases and exhaustion of calcium phosphates early in soil development, 2) the increase and eventual dominance of the occluded-P fraction later in soil development, and 3) increases in organic phosphorus until calcium phosphates were exhausted followed by a decline in organic phosphorus. In contrast to the Walker and Syer model, Crew and others found that the inorganic phosphorus pool persisted throughout the chronosequence as a significant fraction."

Robertson and Vitousek (1981) investigated several physico-chemical properties of soils in primary and secondary succession. In primary succession, they found that bulk density decreased and water-holding capacity increased. Exchangeable NH_4-N increased through the vegetated sites, and acid-soluble P followed a similar trend. Calcium and magnesium increased, then decreased, and were strikingly low in the oldest sites. Trends in NO_3-N and potassium concentrations were not apparent, although the highest concentrations of nitrate were found in the older site. The pH decreased, while both organic carbon and total nitrogen increased with soil age. C:N ratio decreased throughout succession, since percent nitrogen rose more sharply than did organic carbon.

In secondary succession, calcium, magnesium and pH decreased with succession. Organic carbon increased with succession. The C:N ratio increased with succession. NO_3-N, NH_4-N, K and acid soluble PO_4-P showed no consistent trends.

PLAN OF STUDY

To answer the question, “Do self-organizational processes of forested wetland communities result in measurable trajectories?” field measurements of vegetation and soils on a chronosequence of sites in the central Florida phosphate-mining district were collected. The selection of a chronosequence of research sites ranging in age from 0.5 to 19 years old facilitated the detection of changes in parameters with time. Trajectories were developed for each of the vegetation structural categories and soil parameters identified in Table 1.

METHODS

SITE SELECTION AND DESCRIPTION

The central Florida phosphate-mining district encompasses much of Hillsborough, Polk, Manatee, Hardee and Desoto Counties. Research sites were located in the heart of this district, the southwest corner of Polk County (Figure 7.2).

More than 30 potential research sites were selected by reviewing Florida Institute of Phosphate Research reports and mining company monitoring reports. Research sites were selected by touring reclamation sites with reclamation specialists from several phosphate-mining companies. Those sites for which repeated access was easily obtained and documentation of site preparation and history readily available selected. The list of eligible sites was blocked by age (0-1 year, 2-3 years, 4-5 years….) Table 7.2 lists the fourteen sites selected and sampled. Figure 7.2 shows the location of each site.

The physical characteristics and history of each site were documented from research and monitoring reports and site visitation. Table 7.2 provides information including site soil preparation (overburden, sand tailing, mulching), generalized wetland hydrology (fringing wetland, depressional, seepage, riparian), date of completion, and cattail and primrose willow management histories. Descriptions of each site follow.

CF Industries - SP1

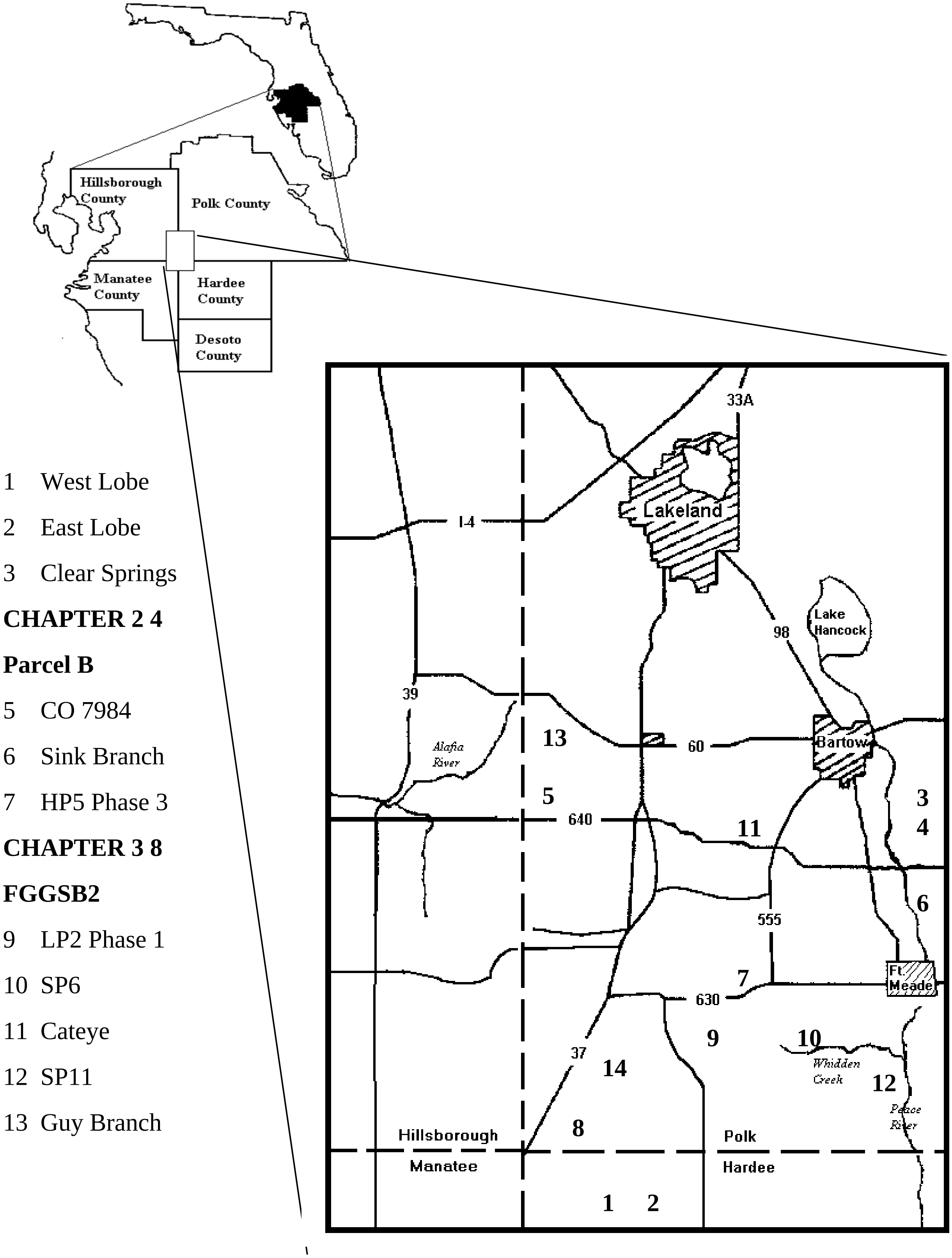
SP1 consists of two separate depressional wetlands, East Lobe and West Lobe, reclaimed from clay settling ponds. Both sites were backfilled with a sand-clay mix, and the sites were not mulched. The original reclamation plan did not include planting understory vegetation. However, *Cephalanthus occidentalis*, an understory species, was planted in 1997.

IMC-Agrico Clear Springs

Clear Springs Seep is located at the IMC-Agrico Clear Springs Mine south of Bartow, Florida. It is a seepage wetland.

IMC-Agrico Parcel B

Parcel B is primarily a depressional wetland located immediately adjacent to the Peace River floodplain. A dike separates the restored wetland hydrologically from the floodplain. Transects in Parcel B varied in wetland hydrology; transect one could be described as a fringing wetland, while transect 2 and 4 were depressional.



1 West Lobe

2 East Lobe

3 Clear Springs

CHAPTER 2 4

Parcel B

5 CO 7984

6 Sink Branch

7 HP5 Phase 3

CHAPTER 3 8

FGGSB2

9 LP2 Phase 1

10 SP6

11 Cateye

12 SP11

13 Guy Branch

Figure 7.2. Research Sites for the Investigation of Successional Trajectories of Constructed Forested Wetlands.

Table 7.2. Summary of Research Sites.

Project Number	Project Name	Company	Mine	Sampling Date	Age at Sampling	Year Revegetated	Supplemental Planting
LP2	Phase 1	Cargill	Fort Meade	Jul-98	0.5	1998	****
FGGSB2	****	IMC - Agrico	Fort Green	Jul-98	2.0	1996	****
CO7984	****	Agrifos	Nichols	Jun-98	5.0	1993	****
HP5	Phase 3	Cargill	Hooker's Prairie	Jul-98	6.0	1992	1992
****	Clear Springs Seep	IMC - Agrico	Clear Springs	Aug-97	8.0	1990	****
SP - 1	East Lobe	CF Industries	Hardee Phosphate Complex	Jul-97	10.0	1987	1997
SP - 1	West Lobe	CF Industries	Hardee Phosphate Complex	Jul-97	10.0	1987	1997
****	Cateye	IMC - Agrico	Phosphoria	Jul-99	12.0	1987	****
SP11	****	Cargill	Fort Meade	Jul-99	14.0	1985	****
NPS1	Guy Branch	Agrifos	Nichols	Aug-99	15.0	1984	****
SP6	Gardinier	Cargill	Fort Meade	Aug-98	16.0	1982	****
FG13	Morrow Swamp	IMC - Agrico	Fort Green	Aug-99	17.0	1982	****
****	Sink Branch	Mobil	Fort Meade	Jun-98	18.0	1980	****
****	Parcel B	IMC - Agrico	Clear Springs	Aug-97	19.0	1978	****

Table 7.2 (Cont.) Summary of Research Sites.

Project Number	Project Name	Acreage (acres)	Mulched	Understory Planted	Nuisance Control	Cattails Present	Primrose Present	Hydrology	Wetland History	Soils
LP2	Phase 1	****	Y	N	N	N	Y	fringing	reclaimed	sand tailings
FGGSB2	****	38.50	Y	N	1998	Y	Y	depressional	reclaimed	sand tailings
CO7984	****	0.76	Y	Y	1997	Y	Y	seep	reclaimed	overburden
HP5	Phase 3	2.00	Y	N	1992	N	Y	fringing	reclaimed	
****	Clear Springs Seep	****	****	N	****	N	Y	seep	reclaimed	sand tailings
SP - 1	East Lobe	****	N	N	Y	Y	Y	depressional	clay settling pond	clay
SP - 1	West Lobe	****	N	N	Y	N	Y	depressional	clay settling pond	clay
****	Cateye	****	****	****	****	N	Y	stream	reclaimed	
SP11	****	****	****	****	****	N	Y	fringing	reclaimed	
NPS1	Guy Branch	****	****	****	****	Y	Y	stream	reclaimed	
SP6	Gardinier	1.80	Y	N	****	N	Y	depressional	reclaimed	
FG13	Morrow Swamp	150.00	Y	Y	Y	Y	Y	depressional	reclaimed	
****	Sink Branch	****	Y	****	N	N	Y	stream	reclaimed	sand/clay
****	Parcel B	50.00	N	Y	****	N	Y	depressional	reclaimed	sand/clay

After mining, Parcel B was backfilled with overburden to create approximately 4 ha of wetlands within the 20 ha site. The site was not mulched but was revegetated with both a variety of tree species and five herbaceous species.

Agrifos Consent Order 7984

This site is a seepage wetland located at Agrifos Nichols Mine. CO7984 was designed as a seepage wetland. However, transects for this study ran through an area more accurately described as depressional. CO 7984 is a 0.31 ha forested wetland adjacent to the 25-year flood plain of Thirty-mile creek, a tributary of the North Prong of the Alafia River. *Nyssa sylvatica* and *Taxodium distichum* were planted as the dominant canopy trees. Subdominant trees included *Fraxinus caroliniana*, *Magnolia virginiana*, *Ilex cassine*, *Persea palustris*, *Acer rubrum* and *Myrica cerifera*. Shrub species planted included: *Cephalanthus occidentalis*, *Itea virginica* and *Lyonia lucida*. Major water source is rainfall with surface inflow from the surrounding uplands, some amount of groundwater inflow contributes to the total water budget. Clayey overburden base was used to simulate a hardpan; evapotranspiration was intended to be the major outflow, with overland flow across a grassy swale occurring when the water reaches maximum elevation.

Mobil Sink Branch

Located on Mobil Fort Meade Mine, the Sink Branch site is a reclaimed stream where the original stream channel was rerouted into a reclaimed channel. At the time of sampling for this project, there were two distinct channels, the area between the channels varied from upland to wetland. Trees planted included: *Quercus laevis, Quercus virginiana, Quercus laurifolia, Pinus elliottii, Liquidambar styraciflua, Acer rubrum, Fraxinus caroliniana, Magnolia virginiana, Acer rubrum,* and *Taxodium distichum.* Four soil treatments were used in separate areas of Sink Branch. The four treatments included various combinations of overburden, sand tailings and mulch. *Pontedaria cordata, Panicum distichum* and *Sagitaria* sp. were being considered for planting; it is not clear if these were actually planted. Although a variety of wetland species were observed in 1998, none of these species were included.

Cargill HP5 Phase 3

This site is located on Cargill's Hooker's Prairie Mine. It is a hydric hammock fringing a sawgrass marsh. This young forested wetland was originally planted with *Liquidambar styraciflua, Magnolia virginiana, Gordonia lasiathus, Ilex cassine, Persea palustris, Quercus laurifolia, Quercus nigra* and *Acer rubrum. Cephalanthus occidentalis* was the only shrub planted. In 1992, supplemental planting of *Magnolia virginiana* occurred because of low survival of the original specimens of this species.

IMC-Agrico FGGSB 2

This 15.58 ha site located at the Fort Green Mine is a depressional system designed with large hummocks created from wetland muck. Transects in this site covered both hummocks and depressional areas between hummocks. This site is located immediately adjacent to a tributary of the Alafia River. *Acer sp.*, *Fraxinus sp., Liquidambar styraciflua, Magnolia grandiflora, Magnolia virginiana, Taxodium distichum, Carya aquatica, Catalpa bignoniodes, Gordonia lasianthus,* and *Nyssa sylvatica* were planted. In addition, one shrub species, *Cephalanthus occidentalis*, was planted. The site was mulched, and no herbaceous species were planted. At the time of sampling, the herbaceous component of the wetland was diverse most likely as a result of the rich seedbank in the mulch. This site was herbicided to control primrose willow in 1998 after sampling.

Cargill LP2 Phase 1

This site is located at Fort Meade Mine. It is a fringing forested wetland. Transects were placed in that part of the wetland south of open water. The northern edge was planted primarily with cypress, while planting on the southern edge included a wider variety of wetland tree species, including several subcanopy species.

Cargill SP6

This site is a perched depressional wetland located at Fort Meade Mine. This created wetland system was sixteen years old at the time of sampling. Included in the design of SP6 were two perched depressional wetlands and a lake fringing wetland. Perched wetland 1, as identified in Brown and others (1992), was sampled for this study. The site is located immediately adjacent to unmined Whidden Creek. *Magnolia grandiflora*, *Magnolia virginiana*, *Liquidambar styraciflua*, *Fraxinus sp.*, *Acer rubrum*, *Taxodium distichum*, *Carya aquatica*, *Catalpa bignoniodes*, *Gordonia lasianthus*, *Nyssa sylvatica* were planted. *Cephalanthus occidentalis* was present at the time of sampling in August 1998, but none were reported surviving as early as 1992 by Brown and others, making unclear whether *C. occidentalis* should be considered planted or recruited.

IMC-Agrico Cateye

On the east, Cateye begins as a forested wetland fringing open water. It follows an intermittent stream that runs from west to east. The wetland ranges from 20 to 50 meters in width.

Cargill SP11

SP11 is a fringing wetland located at Cargill's Fort Meade Mine. The forested wetland consists of an approximately 30 m wide band along the south and east side of open water.

Guy Branch

Located on the Agrifos Nichol's Mine, Guy Branch is a stream. The forested wetland runs along both sides of the stream ranging in width from 40 to 60 meters.

IMC-Agrico Morrow Swamp

Morrow Swamp is a fringing wetland located at IMC-Agrico's Fort Green Mine. The site is located adjacent to the western boundary of the floodplain of Payne Creek. The 60.71 ha experimental wetland was designed to include freshwater marsh and hardwood swamp. The principal wetland species planted were *Taxodium distichum, Platanus occidentalis*, *Acer rubrum*, *Liquidambar styraciflua*, *Gordonia lasianthus, Nyssa sylvatica*, *Fraxinus caroliniana*, and *Ulmus americana.* A few oaks (*Quercus laurifolia* and *Q. virginiana*), *Ilex cassine*, *Pinus elliottii* and other miscellaneous hardwoods were also planted.

Transects, for this study, were located in an area dominated by *Taxodium distichum.* Herbicide applications for cattail control are documented in several monitoring reports.

DATA COLLECTION

Vegetation

Multiple line transects were established within each wetland. Line transects were used to facilitate sampling across the environmental gradient from upland to wetland. Planted canopy and subcanopy trees were evaluated in a belt transect extending 3 meters to each side of the line transect and extending the entire length of the transect. Figure 7.3a illustrates the layout of the belt transect along a 10 m segment of a line transect. Shrubs and multi-stemmed subcanopy trees (e.g. *Myrica cerifera* and *Salix caroliniana*) were evaluated in 9 m^2 (3m X 3m) quadrats established randomly along each 10 meter segment of transect. All species less than 1 meter in height were evaluated in a 1 m^2 (1m X 1m) quadrat nested within a 9 m^2 quadrat along each 10 meter segment of transect. Figure 7.3b illustrates the placement of a 9 m^2 quadrat and a 1 m^2 quadrat associated with each 10 m segment of transect. In each 1m^2 quadrat, light transmittance was measured, and a canopy photograph and soil sample were taken. Figure 7.3c shows where light and soil were sampled and the camera placement for canopy photographs.

Prior to field-data collection, all wetland plant species found in central Florida were divided into structural categories. Structural categories were based on those in *Florida Wetland Plants* (Tobe and others 1998). Those species identified as large trees (> 30 m) were classified as canopy trees, while medium and small trees (10 m-30 m) were classified as subcanopy. Shrubs included multi-stemmed, woody species, while herbs are non-woody plants. Understory refers to vegetation in all structural categories less than one meter in height.

Subcanopy and shrub species were further designated as either early successional or late successional species. Those species deemed undesirable by regulatory agencies in Florida and limited in allowable percent cover by permit were considered early successional. *Myrica cerifera and Salix caroliniana* are both considered early successional subcanopy species. *Ludwigia peruviana*, *Baccharis halimifolia*, and *Sambucus canadensis* were classified as early successional shrubs. *Typha latifolia* was the only herbaceous species to warrant early successional classification by these criteria. Those species not meeting these criteria were designated as late successional.

The following exceptions to placement in structural categories should be noted. *Myrica cerifera* and *Salix caroliniana* were considered shrubs for field data collection because they are multi-stemmed but were analyzed as subcanopy species because of their size. *Rhus copelina* was considered a shrub for data collection but analyzed as a subcanopy species. Although it is single stemmed, its abundance in the site at which it was first encounter necessitated its sampling as a shrub. *Rubus sp*. and *Aster caroliniana* were sampled as herbaceous species, although they are considered by some to be a shrub or vine.

All canopy and subcanopy tree species (other than *Myrica* sp. and *Salix caroliniana*) reaching breast height were identified to species, and diameter at breast height was measured. Forest height was estimated at the top of the canopy above a point on the transect using a clinometer. Hemispherical photos were taken to estimate canopy cover.

Diameter at breast height and stem density of *Myrica cerifera, Salix caroliniana* and all shrub species except *Rubus* sp. and *Aster caroliniana* were recorded within a 3m X 3m quadrat placed randomly along each 10m segment of transect. Because of the growth architecture of *Myrica cerifera*, *Salix caroliniana*, and most shrubs, which results in multiple stems emerging from a single root system, diameter at breast height was measured for each stem reaching breast height regardless of origin of the stem. *Rubus* sp,. because of thorns, and *Aster caroliniana,* because of vine-like growth structure, did not lend themselves to this sampling procedure and were instead sampled as understory.

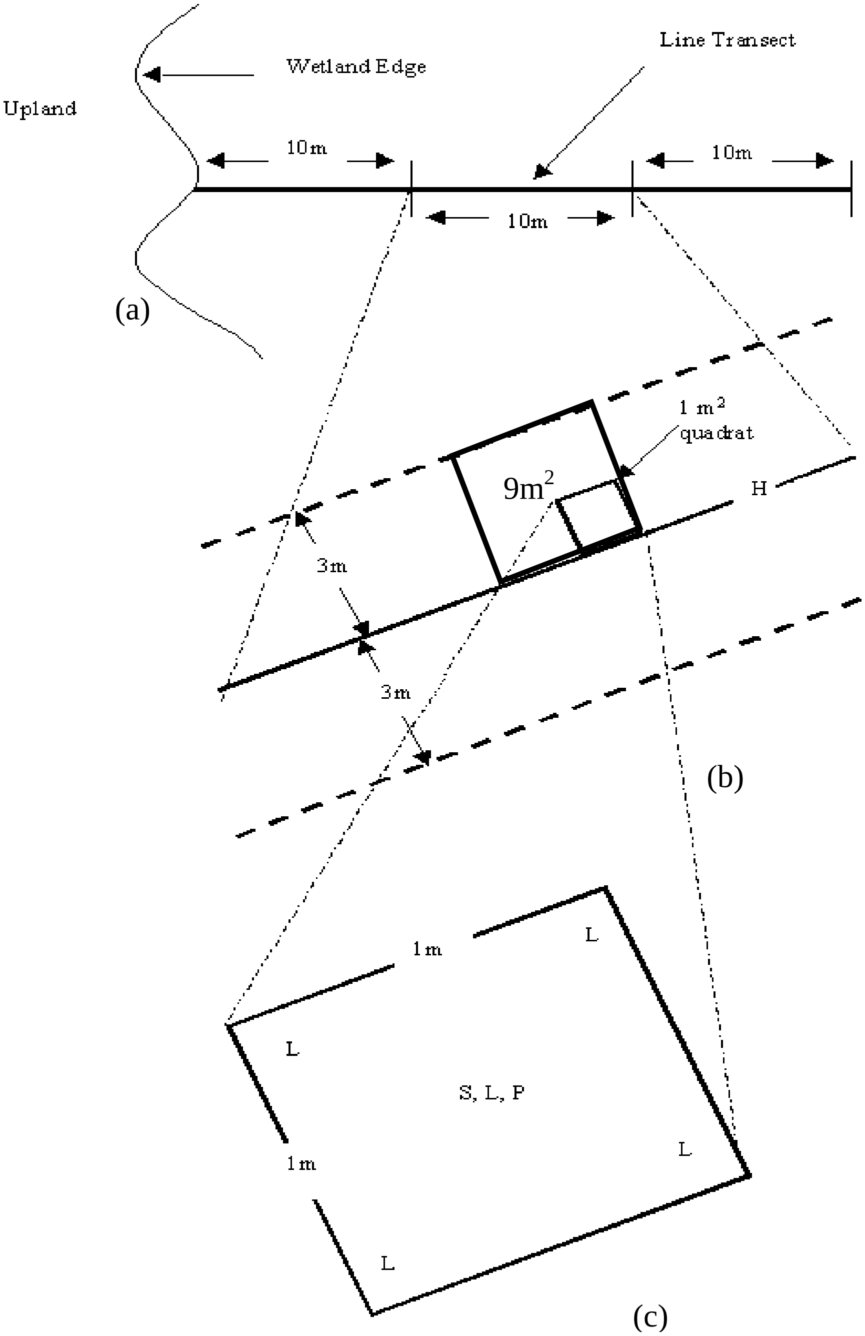


Figure 7.3. Wetland Transects of Varying Length (a) Were Established in Constructed Wetlands Beginning at the Wetland Edge and Extending Downslope. Transects Were Divided into 10 Meter Segments (b). Canopy and Subcanopy Trees Were Sampled Within 3 Meters of Each Side of the Transect. Canopy Height Was Estimated at One Random Point (H). A Nested 9 m^2 Quadrat and a 1 m^2 Quadrat Were Randomly Located Within Each 10 m Segment (c) for Identifying Shrubs and Herbaceous Vegetation, Respectively. Location of Canopy Photos (P), Light Measurements (L) and Soil Samples (S) Are as Indicated Within Each Quadrat.

All vegetation less than one meter in height within a 1m^2 quadrat was identified to species. Percent vegetative cover of the quadrat (cover abundance) of all vegetation less than one meter was estimated and assigned a number based upon the following scale.

Cover Abundance Scale

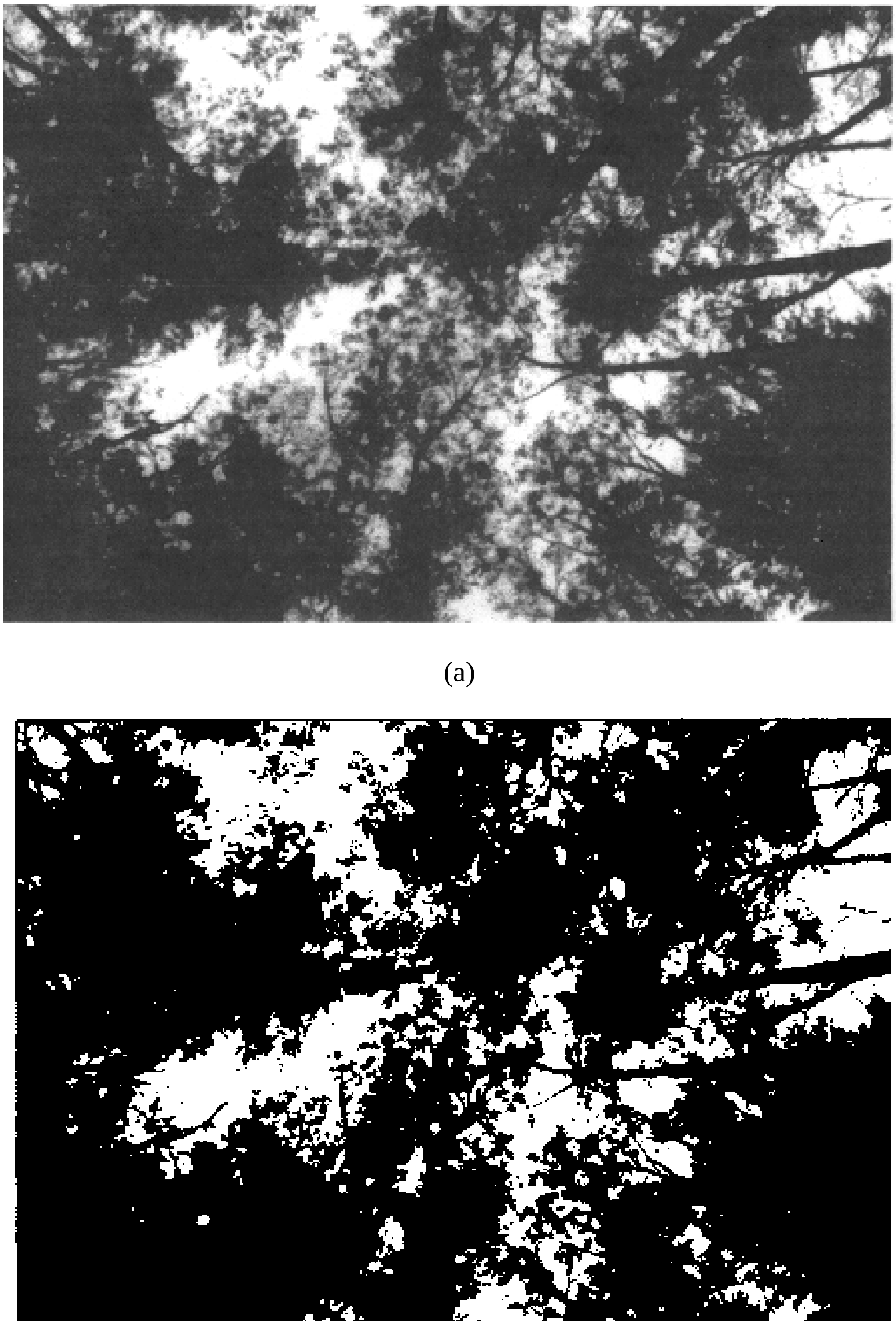
5	76% to 100% cover
4	51% to 75% cover
3	6% to 50 % cover
2	10% to 25% cover
1	< 10% cover

Above-ground biomass of primrose willow and cattail present within the 1m^2 quadrats was harvested, dried, and weighed to determine standing crop (grams dry weight/square meter). Frequency of occurrence of primrose willow and cattail in the understory was calculated by dividing the number of 1m^2 quadrats in which each occurred by the total number of quadrats sampled. Since relatively few samples of primrose willow and cattail resulted from sampling the chronosequence, data were supplemented with three to five quadrats selected from sites dominated by primrose willow and cattails.

Canopy Photographs

Hemispherical photographs for canopy cover analysis were taken using a Nikon 35mm camera, a Nikon 16mm lens and Kodak Tri X black and white film. The camera was placed on a tripod approximately 50 cm above the ground or slightly above the surface of the water, whichever was higher. The camera was leveled with the lens pointing up and top of the camera facing north. A photographic light meter was used to determine the appropriate aperture and shutter speed. Three photographs were taken at each point bracketing the aperture and shutter speed recommended by the light meter. Dawn and dusk photographic outings allowed all photographs to be taken while avoiding direct radiation from the sun.

After developing and printing photographic images, the image with highest contrast was selected and scanned using a flatbed scanner. Each computer image, which included pixels of all shades of gray, was then converted to a high contrast black and white image. Gray pixels were eliminated by grouping all gray pixels as either black or white. Once the black and white image was completed, percent canopy cover was assessed to be the percent of the total image pixels that were black. Figure 7.4 shows a sample photo image (Figure 7.4a) and the computer-enhanced high-contrast black and white image (Figure 7.4b).



(a)

(b)

Figure 7.4. Canopy Cover Analysis (a) Canopy Photograph and (b) High-Contrast Black and White Image After Computer Enhancement. This is an Example of 75% Cover.

Light Transmittance

Light (400-700 nm) transmitted through the canopy to 50 cm above the forest floor was measured at five points within the 1m^2 quadrat and averaged to determine the mean for the quadrat. A LiCor 185b quantum/radiometer/photometer with a quantum sensor was used to determine available photosynthetically active radiation at 50 cm. A measurement was also taken in full sun immediately prior to those taken on the forest floor. Shrubs were removed to determine the light being intercepted by the canopy and subcanopy only.

% transmittance = radiation @ 50 cm / radiation in full sun [7.1]

Soil

At the center of each 1m^2 quadrat (Figure 7.3c), a 20 cm soil core was collected using 3.7 cm diameter coring tube. Cores were placed in a plastic bag, stored on ice, and wet weight of the core was recorded within 24 hours of collection. Each core was thoroughly homogenized by thoroughly hand mixing, and a 25g subsample was placed in a drying oven at 70° C until constant weight was achieved. A dry/wet conversion (dry weight/wet weight) factor was established from each subsample and multiplied by the wet weight of the entire core to estimate the dry weight of the entire core. The following formula was used to calculate percent moisture.

(Core wet weight – Core dry weight) / Core wet weight = % moisture [7.2]

Bulk density for each core was determined by dividing the core dry weight by the total volume of soil contained in each sample. Soil sample volume was estimated by calculating the volume of the coring device (1.85 cm * 1.85 cm * 3.14 * 20 cm = 214.9 cm^3). Dried samples were then ground with a mortar and pestle and stored in an airtight container.

One gram of dried soil from each core was ashed in a muffle furnace for 6 hours at 500° C. This relatively low temperature was used to drive off the organic matter while leaving inorganic carbon ($CaCO_3$), which volatizes at approximately 540° C. The loss from ignition was reported as a rough estimate of organic matter. This method can over estimate organic carbon because inorganics can lose mass after heating. Specifically, clays can lose water bound within their chemical structure.

Available nutrients were estimated using the Mehlich I extractant (Mehlich 1978) for Ca, Mg, K, P, and Fe. Twenty ml of Mehlich I extractant (0.05 M HCl in 0.025 N H_2SO_4) was added to 5 g of dried soil. The soil and extractant were shaken for five minutes using a reciprocating shaker and then filtered. Elements were analyzed by Inductively Coupled Argon Plasma (ICAP) Spectroscopy at the IFAS Analytical Research Laboratory at the University of Florida. Results are presented as mg nutrient kg^{-1} soil and g nutrient m^{-2} to a depth of 20 cm.

A KCl extractant (Bremner 1965; Kenney and Nelson 1982) was used to estimate available NO_3-N and NH_4-N. Fifty milliliters of 1 M KCl was added to 5 g of fresh soil, shaken for 30 minutes and filtered. Nitrogen was analyzed at the IFAS Analytical Research Laboratory at the University of Florida. Because of the low concentrations of nitrogen in all soil samples, KCl extraction methods were modified for sites sampled during the second year of data collection (10 grams of soil and 25 ml of 2 M KCl were used.) Fresh soil was used to reduce the likelihood of conversion of NH_4-N to NO_3-N. A wet-dry conversion was used to report results in mg NH_4-N or NO_3-N kg^{-1} dry soil.

$$\text{mg N/g dry soil} = (\text{mg N/l} * \text{l extractant}) / \text{g (dry wt.) soil} \qquad [7.3]$$

Because of drastic differences in bulk density associated with wetland soils, available nutrients were also reported on an areal basis (grams of nutrient per square meter to a depth of 20 cm. The following formula was used to calculate nutrient availability on an areal basis,

$$N_{ia} = N_{im} * \text{bulk density (g cm}^{-3}) * \text{volume (200000 cm}^{3}) \qquad [7.4]$$

where N_{ia} is the soil nutrient *i* per square meter to 20 cm depth and N_{im} is soil nutrient *i* expressed in milligrams of nutrient per gram of soil.

DATA ANALYSIS

Vegetation

Species richness was recorded for all structural categories by noting the number of species encountered during sampling. Species occurring outside of sampling areas were not included in species richness but were noted. A Shannon-Weaver diversity index was calculated for canopy, subcanopy, and shrub species using the following formula:

$$H' = - \Sigma\, p_i * \log (p_i) \qquad [7.8]$$

where H' is the Shannon-Weaver diversity, and p_i, the probability of sampling an individual species and i is the i^{th} of N species found in the sample. Each p_i value is determined by the number of times a species is sampled out of the total number of individuals sampled ($p_i = n_i/n$, where n_i is the number of individuals of species i, and n is the total number of individuals).

Understory vegetation was sampled by presence or absence and not by individual, since many wetland herbaceous species are clonal, and definition of an individual is problematic. However, p_i was determined by weighting each species by its frequency of occurrence. First, the frequency of occurrence is calculated (number of times a species is sampled divided by the total number of sampling efforts). The frequency of occurrence of each species is then scaled to 1 by dividing the frequency of an individual species by the total frequencies of all species.

Species evenness for all structural categories was calculated using the following formula:

$$\text{Evenness} = H'/ H'_{max} \qquad [7.9]$$

where H'_{max} is the maximum possible Shannon-Weaver diversity for the given number of species. H'_{max} is calculated using the following formula:

$$H'_{max} = \text{Log } S \qquad [7.10]$$

where S is the number of species.

Frequency of occurrence of canopy, subcanopy, shrub seedlings, and vines in the understory was calculated by dividing the number of $1m^2$ quadrats in which each occurred by the total number of quadrats sampled.

Plant species were designated as obligate, facultative wetland, facultative, facultative upland or upland (Reed 1988). The Florida Delineation Handbook's vegetative index (Gilbert and others 1995) provided the status for many facultative, facultative wetland and obligate species. For species not found in The Florida Delineation Handbook (Gilbert and others 1995), plant status was provided by the National List of Plant Species that Occur in Wetlands (Reed 1988). Status for those species not found on either list were classified by consensus of a group of five botanists.

Plant community status of the understory of constructed wetlands was calculated by determining the quadrat frequency of occurrence of each species. The frequencies were then scaled to 1 by dividing the quadrat frequency of each species by the total over all species. The scaled species frequencies, for each wetland plant status, were summed. The summed frequencies were weighted using the following scale and summed again to obtain the "understory community status" index:

Obligate	1
Facultative wetland	2
Facultative	3
Facultative upland	4
Upland	5

The quadrat frequency of species of unknown status is provided but is not used in final calculation.

Successional Trajectories of Wetlands

Site means for each descriptive variable measured (Table 7.1) were calculated for determining each trajectory. In EXCEL, a trend analysis, the least squares fit for a line, represented by one of the following equations was determined.

Linear $y = mx + b$ [7.11]

where m is the slope and b is the intercept.

Polynomial $y = b + c_1x + c_2x^2 + c_3x^3 + \ldots + c_6x^6$ [7.12]

where b and $c_1 \ldots\ldots c_6$ are constants.

Logarithmic $y = c \ln x + b$ [7.13]

where c and b are constants, and ln is the natural logarithm function.

Exponential $y = ce^{bx}$ [7.14]

where c and b are constants, and e is the base of the natural logarithm

Power $y = cx^b$ [7.15]

where c and b are constants.

The equations resulting in the best fit were used to transform data to perform a linear regression analysis.

RESULTS

CHRONOSEQUENCE OF WETLANDS

Lists of plant species sampled in a chronosequence of wetlands and their frequency of occurrence are provided in three separate tables: (i) canopy, subcanopy and shrub species greater than 1 meter in height (Table 7.2), (ii) canopy, subcanopy and shrub species less than one meter in height found in the understory regardless of structural category (Table 7.7) and (iii) herbaceous species (Table 7.8). Data describing canopy, subcanopy, shrub and understory components of the developing ecosystems are presented separately in tabular form (Tables 7.3-7.6 and Tables 7.9-7.10).

Canopy Tree Species

Table 7.3 summarizes canopy tree species found at each research site. All tree species in all sites are classified as either facultative wet or obligate except for three upland tree species. *Pinus elliotti* was sampled at the edge of Clear Springs Seep and SP11. *Prunus* sp. and *Quercus virginiana* were sampled at the edge of Sink Branch. *Acer* sp. was the most common wetland tree species, while *Plantanus occidentalis* and *Populus deltoides* were the least common.

Table 7.4 provides average canopy tree data at each site. Canopy height was greatest at Sink Branch (10.8 m) and Parcel B (10.48 m), the oldest sites, followed by SP11 (8.37 m) and Clear Springs Seep (7.82 m). The only other sites with canopy trees over 7 meters in height were Cateye (12 years) and Morrow Swamp (17 years). Mean DBH was greatest at Morrow Swamp (10.77 cm) followed by Clear Springs Seep (9.29 cm), an eight-year-old site, and SP11 (9.14 cm), a fourteen-year-old site. Sink Branch had the greatest canopy closure at 88%, while the other sites ranged in canopy closure between 0% to 83%.

Canopy tree density (including all size classes) was greatest at Parcel B (1792 trees ha^{-1}) and second at SP11 (1685 trees ha^{-1}). When considering only trees with diameter at breast height greater than 5 cm, tree density is much less 982 trees ha^{-1} at Parcel B and 1102 trees ha^{-1} at SP11. The highest sapling densities (tress with dbh < 5 cm) were at three of the youngest (<5 years) sites, where 100% of the trees were in the < 5 cm size class. The greatest density of saplings in sites older than 5 years was at Parcel B and HP5 Phase 3. The lowest density of tree saplings was found at Morrow Swamp with only 20 trees ha^{-1}.

Figure 7.5 shows the frequency distributions of the diameter at breast height of trees at each of the sites sampled. Those sites five years old or less have 100% of trees in the < 5 cm size class. After five years, the portion of trees in the < 5 cm size class begins to decline, while the proportion of trees in larger size classes increases. In sites 12 years or older, trees in size classes greater than 25 cm in diameter consistently occurred. Size

Table 7.3. Frequency of Occurrence of Canopy, Subcanopy and Shrub Species Found in Constructed Forested Wetlands.

		Site Age													
Species Name	wetland status	0.5	2	5	6	8	10	10	12	14	15	16	17	18	19
Canopy															
Acer sp.	facultative wet	0.18	0.21	0.04	0.54	0.04	0.06	0.43	0.05	0.18	0.84	0.65		0.20	
Fraxinus caroliniana	obligate		0.55	0.20		0.23	0.84	0.27	0.42			0.05		0.01	0.12
Liquidambar styraciflua	facultative wet	0.24		0.03	0.23					0.31		0.03		0.24	0.15
Magnolia virginiana	obligate			0.01	0.19							0.03			
Nyssa sp.	obligate	0.01		0.14		0.07									
Persea palustris	obligate	0.02	0.07	0.02											
Pinus elliottii	upland			0.02		0.01				0.28					
Plantanus occidentalis	facultative wet														0.01
Populus deltoides	facultative wet														0.01
Prunus sp.	upland													0.08	
Quercus laurifolia	facultative wet	0.22	0.07	0.02	0.03			0.11		0.04				0.35	0.13
Quercus nigra	facultative wet	0.04		0.02	0.01			0.05						0.04	0.03
Quercus virginiana	upland													0.01	
Taxodium sp.	obligate			0.47		0.63	0.08			0.18	0.16	0.21	1.00	0.04	0.27
Ulmus americana	facultative wet	0.30	0.08	0.04				0.13				0.03		0.03	0.10

** Species observed at the site but not sampled.

X Species considered shrubs but sampled as understory.

Table 7.3 (Cont.) Frequency of Occurrence of Canopy, Subcanopy and Shrub Species Found in Constructed Forested Wetlands.

		Site Number													
Species Name	wetland status	0.5	2	5	6	8	10	10	12	14	15	16	17	18	19
Subcanopy															
Celtis laevigata	facultative wetland	0.19													0.19
Cornus foemina	facultative wetland													0.22	
Ilex cassine	obligate	0.81	0.14		0.03				0.06						
Myrica sp.	facultative				0.03	0.03		0.19	0.94	0.93	0.58	0.81	0.60	0.64	0.62
Rhus copallinum	upland				0.89										
Salix caroliniana	obligate		0.86	1.00		0.17	1.00	0.81		0.07	0.42	0.19	0.40	0.15	0.20
Sapium sebiferum	facultative														0.01
Shrub															
Aster carolininus	obligate					X					X		X		
Baccharis sp.	facultative		0.71	0.07	0.46	0.38		0.22			0.03		1.00		
Cephalanthus occidentalis	obligate		0.02	0.03	0.02				0.18			0.11		0.01	0.36
Itea virginica	obligate											0.81	**		
Ludwigia octovalvis	obligate			0.86											
Ludwigia peruviana	obligate		0.27	0.03	0.51	0.08	0.13	0.05	0.04	1.00	0.68	0.07	**	0.07	0.21
Rubus sp.	facultative				X	X			X	X					
Sambucus canadensis	facultative wetland					0.52	0.87	0.76	0.78		0.27			0.95	0.04
Schinus terebinithifolius	facultative														0.39
Vaccinium corymbosum	facultative wetland			**											

** Species observed at the site but not sampled.

X Species considered shrubs but sampled as understory.

Table 7.4. Canopy Tree Data Collected from a Chronosequence of Constructed Forested Wetlands.

PROJECT NAME OR NUMBER	*AGE (YEARS)*	*CANOPY HEIGHT (m)*	*TREE DENSITY (TREES/HECTARE)*	*SAPLING DENSITY (TREES/HECTARE)*	*MEAN DBH(cm)*	*% CANOPY COVER*	*SPECIES RICHNESS*	*SPECIES DIVERSITY*	*SPECIES EVENNESS*	*% TRANSMITTANCE OF PAR*
LP2 Phase 1	0.5	0.7	1060	1057	0.76	0	7	0.69	0.81	***
FGGSB - 2	2	1.0	999	998	1.22	***	5	0.54	0.77	***
CO7984	5	1.9	1166	1166	1.69	***	12	0.75	0.70	64%
HP5 Phase 3	6	5.2	1166	766	4.51	57	5	0.50	0.72	41%
Clear Springs	8	7.8	1600	506	9.29	74	5	0.43	0.62	***
East Lobe	10	5.4	437	207	6.54	73	3	0.22	0.47	***
West Lobe	10	7.0	667	469	4.14	73	5	0.70	0.85	***
Cateye	12	7.1	1598	748	6.23	73	6	0.62	0.79	17%
SP11	14	8.4	1685	583	9.14	83	5	0.64	0.91	6%
Guy Branch	15	7.6	1466	714	6.22	***	2	0.19	0.64	***
SP6	16	7.4	616	499	4.57	83	6	0.46	0.59	9%
Morrow Swamp	17	7.8	1062	20	10.77	57	1	0.00	U	38%
Sink Branch	18	10.8	951	477	8.70	88	10	0.75	0.75	3%
Parcel B	19	10.5	1792	810	9.10	81	10	0.85	0.85	***

*** Data not collected due to inclement weather.

U - undefined

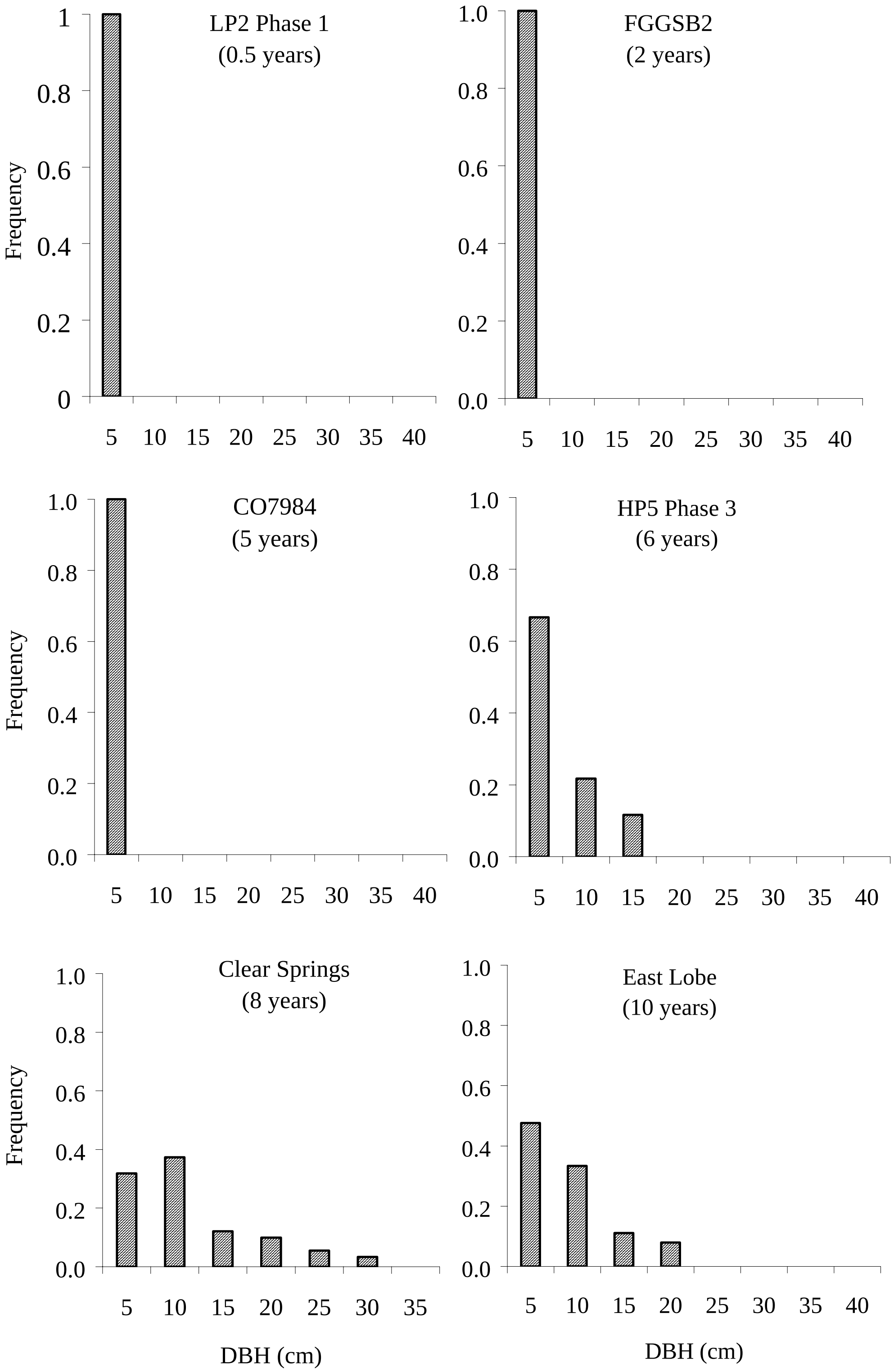


Figure 7.5. Frequency Distribution of Tree Diameter at Breast Height from the Chrono-Sequence of Constructed Forested Wetlands. (Size Class Bins: 0-5 cm, 5.1-10 cm, 10.1-15 cm, 15.1-20 cm, 20.1-25 cm…) Sites Appear in Chronological Order.

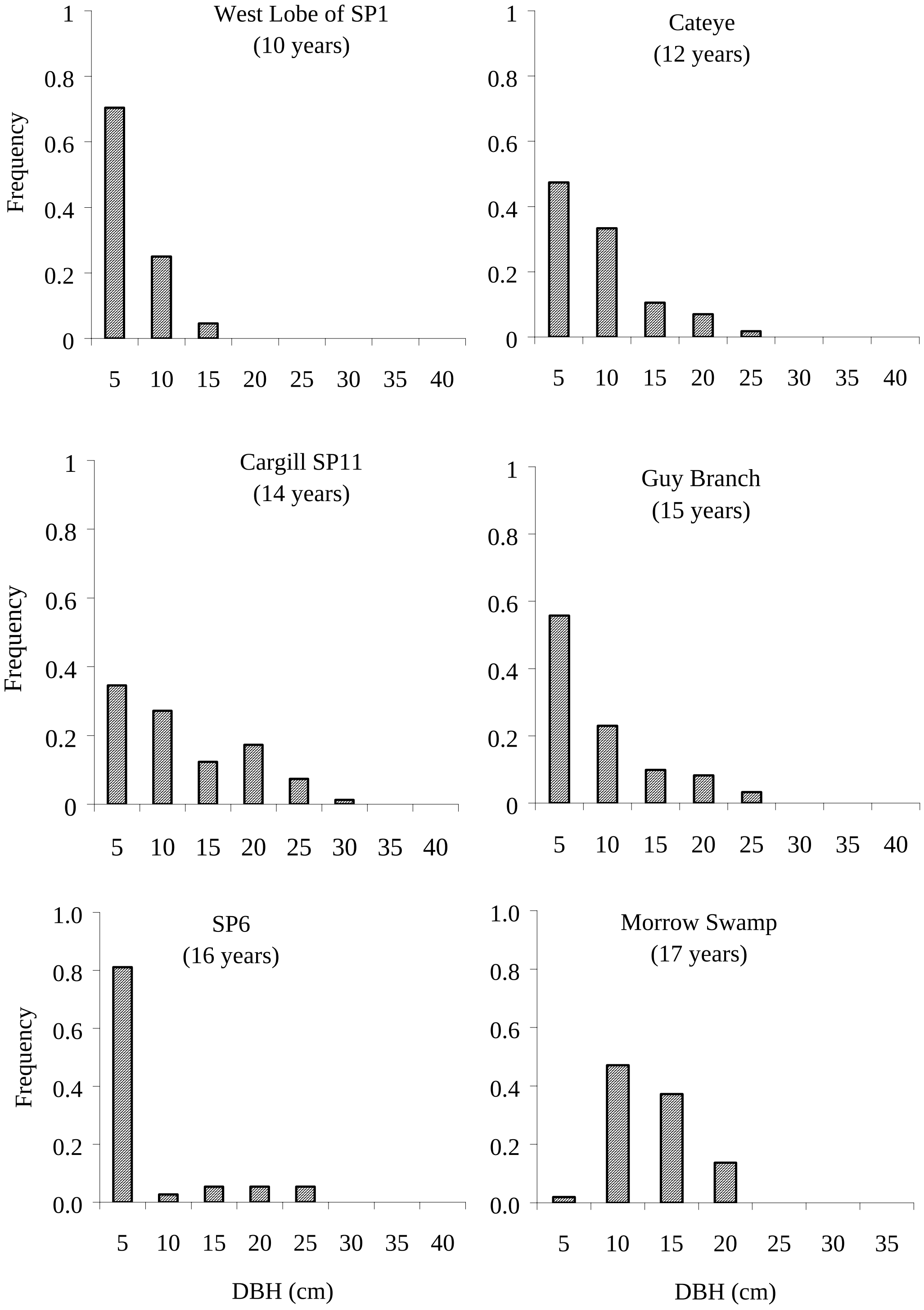


Figure 7.5 (Cont.) Frequency Distribution of Tree Diameter at Breast Height from the Chrono-Sequence of Constructed Forested Wetlands. (Size Class Bins: 0-5 cm, 5.1-10 cm, 10.1-15 cm, 15.1-20 cm, 20.1-25 cm…) Sites Appear in Chronological Order.

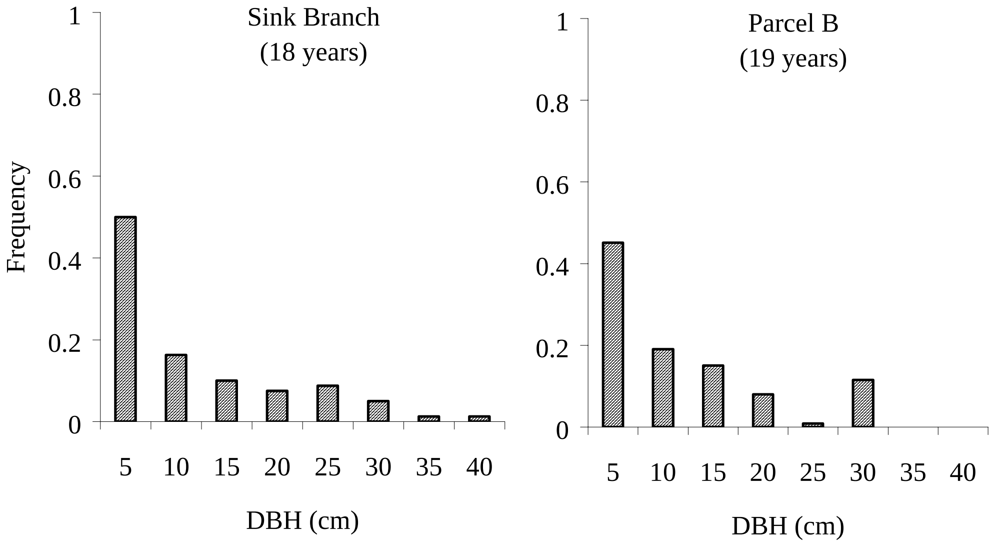


Figure 7.5 (Cont.) Frequency Distribution of Tree Diameter at Breast Height from the Chrono-Sequence of Constructed Forested Wetlands. (Size Class Bins: 0-5 cm, 5.1-10 cm, 10.1-15 cm, 15.1-20 cm, 20.1-25 cm…) Sites Appear in Chronological Order.

distribution patterns in Morrow Swamp and SP6 are strikingly different from those of the other sites. Only a small percentage of trees sampled in Morrow Swamp fall into the <5 cm size class. Only one other site, Clear Springs Seep, had fewer trees in the <5 cm size class than were found in larger size classes. SP6 displays a unique pattern of size class distribution for an older site, with over 80% of trees in the <5 cm size class. In sites 18 and 19 years old, a small fraction of all trees sampled were in the >30 cm size class. There were no trees in these size classes prior to 18 years.

While a hierarchical distribution of size classes is apparent when tree species is not taken into account, that individual tree species do not always fit this distribution (Figure 7.6). *Acer* sp. shows a hierarchical distribution in four of the seven sites where it occurs. In the other three sites, all *Acer* sp. specimens occur in the smallest size class. *Fraxinus* sp. exhibits a hierarchical distribution in two of three sites. In the third site, the greatest percent of the specimens are in the 0-5 and 5-10 cm size classes, while the least is in the smallest size class. *Taxodium* sp. does not show a hierarchical distribution in any of the sites where it occurs.

Canopy tree species richness was greatest at CO7984 (12 species) and second at Sink Branch and Parcel B (10 species). From three to seven species were found at the

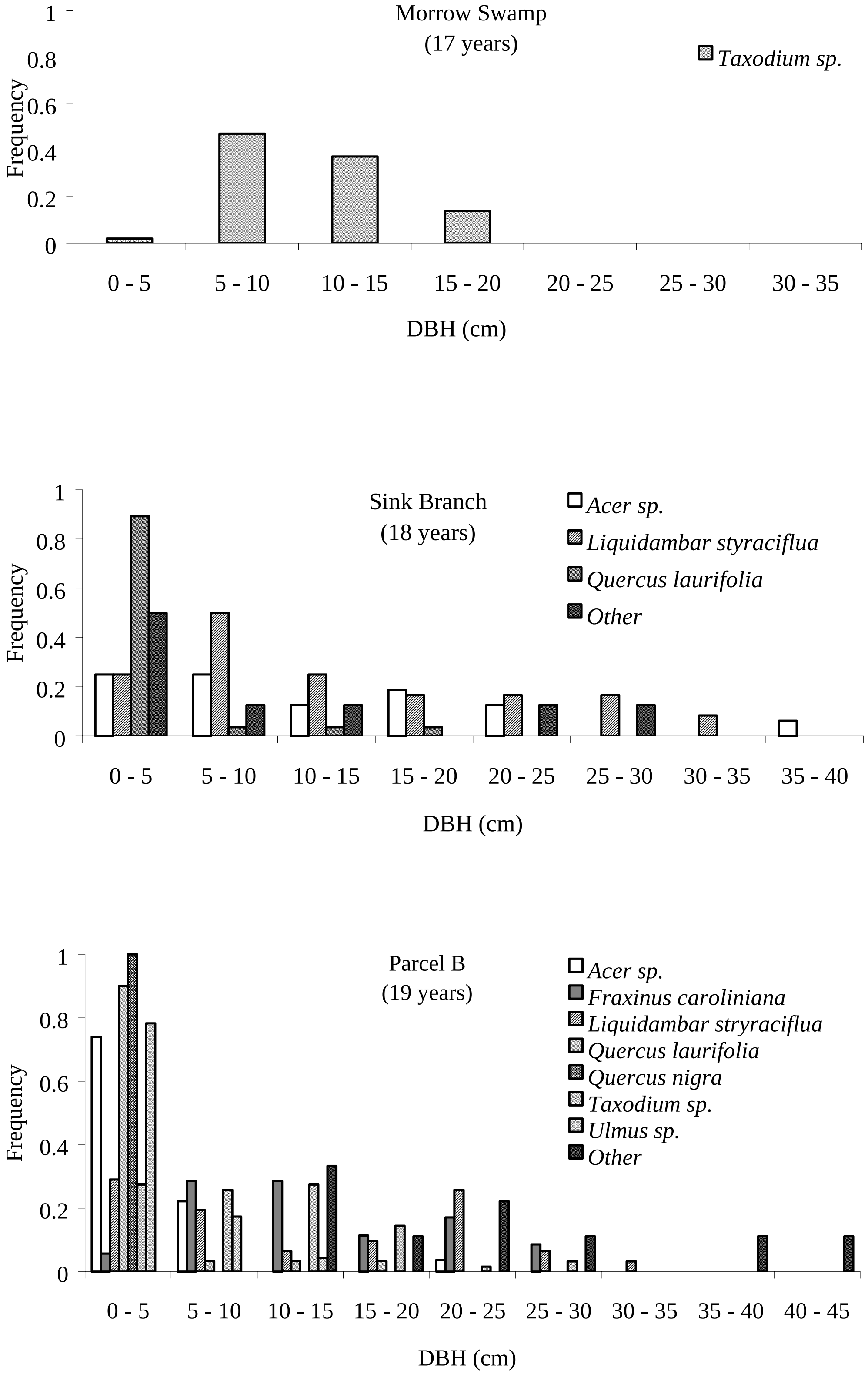
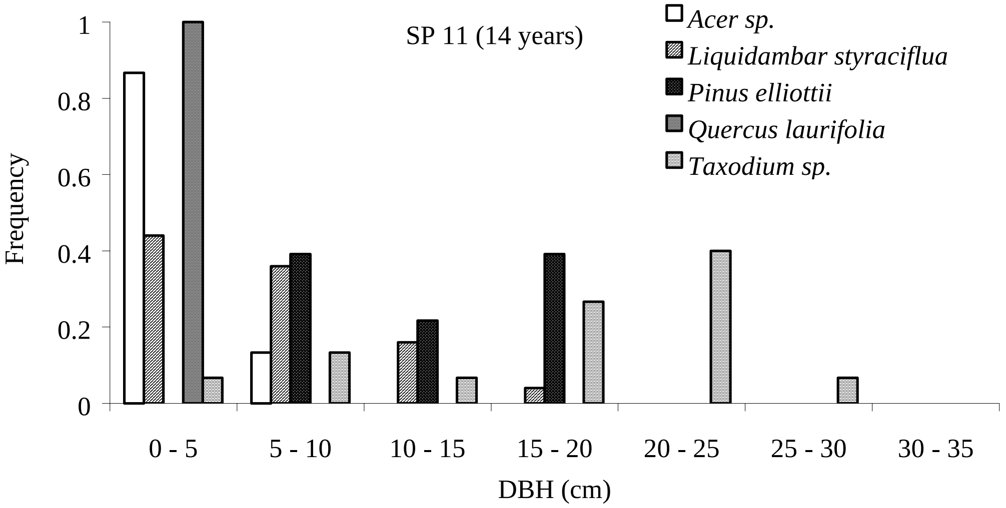


Figure 7.6. Diameter at Breast Height Size Class Frequency Distributions by Species.



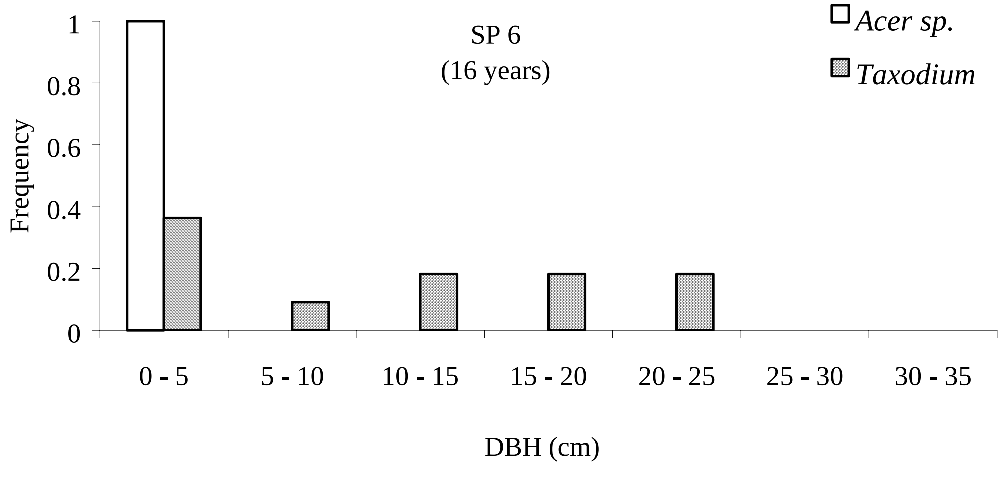


Figure 7.6 (Cont.) Diameter at Breast Height Size Class Frequency Distributions by Species.

other sites. Species diversity was greatest at Parcel B followed by CO7984 and Sink Branch. Species evenness was greatest at SP11.

Subcanopy Tree Species

Table 7.5 summarizes subcanopy tree species found at each research site. Species found in all sites were classified as facultative, facultative wet or obligate except for *Rhus copallinum*, which is designated as an upland species.

Density of early successional subcanopy species was highest at SP6 (15 years) followed by CO7984. Densities of less than 1500 trees ha^{-1} occurred at sites throughout the age range. Fewer than one half of the sites sampled had late successional subcanopy species present. The highest density of late successional subcanopy species was found at Parcel B (19 years) and Sink Branch (18 years), the two oldest sites. Sites between 5 and 17 years old were lacking a late successional subcanopy component with two exceptions, HP5 Phase 3 and Cateye, where several subcanopy species were planted during construction.

Subcanopy tree species richness was highest at Parcel B, with 4 species, and lowest at East Lobe and CO7984, with one species. *Salix caroliniana* was present at ten of fourteen sites. *Myrica spp.* was present at nine of fourteen sites. Less than one half of the sites had species other than *Myrica spp.* and *Salix caroliniana* present. *Celtis laevigata*, *Ilex cassine* and *Cornus foemina* were the only late successional subcanopy species occurring. *Sapium seribiferum* (Chinese Talo) was present at one site but is considered an invasive exotic. *Rhus copallinum* was also present at one site; it is not considered a wetland species.

Species diversity was greatest at Parcel B (0.42) and Sink Branch (0.39). Diversity of all other sites ranged from 0.0 to 0.30. East Lobe and CO7984, each with only one subcanopy species, had a species diversity of 0. Species evenness was undefined at SP1 East Lobe and CO7984; this in artifact of the occurrence of only one species. Sites with more than one subcanopy species present had evenness values ranging from 0.32 - 0.98.

Mean DBH of all subcanopy species (Table 7.5) ranged from 0.60-7.7 cm and was greatest at SP1 East Lobe. Early successional species DBH ranged from 0.5-7.7 cm, while DBH of late successional species ranged from 0.7-8.6 cm. Only in sites where late successional species were planted was the DBH of late successional species greater than early successional species.

Shrub Species

Shrub stem density ranged from 0 to greater than 20000 stems acre^{-1} (Table 7.6). This count includes all stems originating from an individual shrub, but does not reflect

Table 7.5. Subcanopy Tree Data Collected in a Chronosequence of Constructed Forested Wetlands.

PROJECT NAME OR NUMBER	*AGE (years)*	*DENSITY (trees/hectare)*	*DENSITY OF EARLY SUCCESSIONAL SPECIES*	*DENSITY OF LATER SUCCESSIONAL SPECIES*	*MEAN DBH (cm)*	*STEM DIAMTER OF EARLY SUCCESSIONAL SPECIES (cm)*	*STEM DIAMETEROF LATER SUCCESSIONAL SPECIES (cm)*	*EARLY SUCCESSIONAL SPECIES RICHNESS*	*LATE SUCCESSIONAL SPECIES RICHNESS*	*SPECIES DIVERSTIY*	*SPECIES EVENNESS*
LP2 Phase 1	0.5	108	0	108	0.7	0.0	0.7	0	2	0.21	0.68
FGGSB - 2	2	1296	1112	185	0.6	0.5	1.1	1	1	0.18	0.59
CO7984	5	9408	9408	0	1.4	1.4	0.0	1	0	0.00	1.00
HP5 Phase 3	6	4108	3996	111	1.4	1.3	5.2	2	1	0.18	0.37
Clear Springs	8	420	420	0	5.2	5.2	0.0	2	0	0.20	0.30
East Lobe	10	3969	3969	0	7.7	7.7	0.0	1	0	0.00	1.00
West Lobe	10	667	667	0	5.5	5.5	0.0	2	0	0.21	0.71
Cateye	12	3176	2991	185	3.9	3.6	8.6	1	1	0.09	0.32
SP11	14	6279	6279	0	2.6	2.6	0.0	2	0	0.30	0.35
Guy Branch	15	5041	5041	0	2.3	2.3	0.0	2	0	0.30	0.98
SP6	16	17100	17100	0	3.8	3.8	0.0	2	0	0.21	0.70
Morrow Swamp	17	2803	2803	0	0.7	0.7	0.0	2	0	0.29	0.97
Sink Branch	18	6980	5474	1507	5.7	6.5	2.8	2	1	0.39	0.82
Parcel B	19	1403	1119	284	3.6	4.1	1.4	3	1	0.42	0.69

Table 7.6. Shrub Data Collected from a Chronosequence of Constructed Forested Wetlands.

PROJECT NAME OR NUMBER	*AGE (years)*	*DENSITY(stems/hectare)*	*DENSITY OF EARLY SUCCESSIONAL SPECIES*	*DENSITY OF LATER SUCCESSIONAL SPECIES*	*STEM DIAMETER (cm)*	*STEM DIAMETER OF EARLY SUCCESSIONAL SPECIES (cm)*	*STEM DIAMETER OF LATE SUCCESSIONAL SPECIES (cm)*	*EARLY SUCCESSIONAL SPECIES RICHNESS*	*LATE SUCCESSIONAL SPECIES RICHNESS*	*SPECIES DIVERSTIY*	*SPECIES EVENNESS*
LP2 Phase 1	0.5	0	0	0	0	0	0	0	0	0	U
FGGSB - 2	2	58018	57988	30	0.6	0.6	0.4	2	1	0.29	0.61
CO7984	5	3389	3273	116	0.7	0.7	3.4	3	1	0.59	0.99
HP5 Phase 3	6	15768	15435	333	0.8	0.8	1.1	3	1	0.34	0.71
Clear Springs	8	842	842	0	2.7	2.7	0	3	0	0.40	0.83
East Lobe	10	111	111	0	3.0	3.0	0	2	0	0.16	0.54
West Lobe	10	538	538	0	2.6	2.6	0	3	0	0.23	0.78
Cateye	12	20543	16840	3703	1.6	1.7	1.5	2	1	0.27	0.56
SP11	14	279.1	113	0	0.3	0.3	0	1	0	0	U
Guy Branch	15	10310	10310	0	0.9	0.9	0	3	0	0.34	0.57
SP6	16	2999	222	2776	0.7	0.5	0.7	1	2	0.27	0.56
Morrow Swamp	17	1526	1526	0	0.4	0.4	0	1	0	0	U
Sink Branch	18	8727	8566	158	1.5	1.6	0.3	2	1	0.13	0.21
Parcel B	19	222	143	79	2.5	2.0	3.4	4	1	0.51	0.85

U - undefined

the number of individuals. Mean shrub density of late successional species was lower than that of early successional species in all sites except SP6. Mean shrub stem diameter ranged from 0.3-3.0 cm. Greatest stem diameters were found in the intermediate age sites (8-10 years) and in the two oldest sites (18 and 19 years). Early successional species stem-diameter ranged from 0.3-3.0 cm. Late successional species stem-diameter ranged from 0.3-3.4 cm.

Shrub species richness ranged from 0 to 5 species per site. *Sambucus canadensis, Baccharis halimifolia* and *Cephalanthus occidentalis* were present in 57%, 57% and 50% of the sites, respectively. *Ludwigia peruviana* was present in 100% of the sites (Sink Branch and Morrow Swamp had primrose willow present, but it was not within a sampling quadrat). *Itea virginica* was present at both Morrow Swamp and SP6 but was sampled at only one site, SP6. *Schinus terebinthifolius*, an invasive exotic, was present at Parcel B and was observed but not sampled at SP6. *Ludwigia octovalis* was found in one site.

Species diversity ranged from 0.0 to 0.59. Species diversity was greatest at CO7984 (5 years) followed by Parcel B (19 years). Species diversity was least at SP11 and Morrow Swamp where only one shrub species was sampled. Species evenness was lowest at Sink Branch (0.32). At all other sites, species evenness ranged from 0.52 to 1.0.

Understory Species

All species occurring in the research are listed in Tables 7.7 and 7.8 along with their frequency of occurrence. Herbaceous species richness ranged from 7 to 32 species (Table 7.9). Species richness of all vegetation included in the understory category ranged from 13 to 41 and was greatest at CO7984 and East Lobe. Of canopy species, *Acer* sp., the most common species, was found in all sites where seedlings occurred. *Quercus laurifolia* was the next most common species and was found in thirty-six percent of the sites. Ten of the fourteen sites had seedlings or saplings of subcanopy species present; however, no site had more than 2 species occurring. Shrub seedlings or sapling occurred in all sites sampled except LP2 Phase 1, the youngest site. Vines occurred in all but the two youngest sites. The greatest number of vine species (11) occurred in Sink Branch (18 years).

Species diversity in the understory ranged from 1.08 to 1.57. Species evenness neared unity for all sites (0.90 to 1.0) and was less than 0.90 in only one site (0.86 at SP6).

The understory community status is provided in Table 7.10. Those sites with the lowest "Understory Community Wetland Status" contain a greater probability of sampling wetland species and perhaps a greater probability of being a wetland. Figure 7.7 is a graphical representation of community wetland status. The horizontal line in Figure 7.7 represents the average "Understory Community Wetland Status" of all sites sampled. Six of the research sites have a lower than average status suggesting that they

Table 7.7. Frequency of Occurrence (No. of Quadrats Present/Total No. of Quadrats Sampled) of Canopy, Subcanopy, Shrub and Vine Species (< 1 m in Height) Found in the Understory of Constructed Forested Wetlands.

		Site Age													
Species Name	Wetland Status	0.5	2	5	6	8	10	10	12	14	15	16	17	18	19
Canopy															
Acer rubrum	facultative wetland		0.17	0.11				0.23		0.25	0.42	0.50	0.13	0.36	0.10
Fraxinus caroliniana	obligate						0.04								
Liquidambar styraciflua	facultative wetland													0.21	
Prunus sp.	upland													0.07	
Quercus laurifolia	facultative wetland							0.05		0.13	0.29			0.29	0.19
Ulmus sp.	facultative wetland														0.14
Taxodium sp.	obligate											0.10			
Subcanopy Species															
Celtis laevigata	facultative wetland														0.14
Citrus aurantium	facultative upland													0.07	
Cornus foemina	facultative wetland													0.14	
Myrica sp.	facultative/fac wet					0.30	0.08	0.14	0.33	0.75	0.29	0.10			
Rhus copallinum	upland				0.40										
Salix caroliniana	obligate		0.17	0.05			0.21	0.09					0.13		
Shrub Species															
Baccharis sp.	facultative		0.25	0.11	0.60	0.10	0.04	0.32		0.38	0.14		0.25	0.07	0.24
Cephalanthus occidentalis	obligate		0.33		0.10		0.08		0.17					0.07	
Itea virginica	obligate											0.20			
Ludwigia octovalvis	obligate			0.32											
Ludwigia peruviana	obligate		0.42	0.47	0.50	0.60	0.13	0.09	0.50	0.13	0.43	0.10	**	**	0.14
Rubus sp.	facultative				0.60	0.10			0.17	0.13				0.50	0.43
Sambucus canadensis	facultative wetland				0.10	0.20	0.25	0.18	0.17		0.29			0.57	
Schinus terebinthifolius	facultative														0.10

** Species observed at the site but was not sampled.

Table 7.7 (Cont.) Frequency of Occurrence (No. of Quadrats Present/Total No. of Quadrats Sampled) of Canopy, Subcanopy, Shrub and Vine Species (< 1 m in Height) Found in the Understory of Constructed Forested Wetlands.

		Site Age													
Species Name	Wetland Status	0.5	2	5	6	8	10	10	12	14	15	16	17	18	19
Vines															
Ampelopsis arborea	facultative						0.04				0.29			0.50	0.48
Apios americana	facultative wetland				0.50	0.50						0.10		0.36	
Campsis radicans	facultative													0.21	0.05
Clematis sp.	facultative wetland				0.60	0.10	0.33	0.68			0.14			0.29	
Galactia elliottii	facultative upland									0.13					
Gelsemium sempervirens	facultative														0.05
Lygodium sp.	facultative						0.04	0.09						0.07	
Melothria sp.	facultative wetland								0.17				0.13		0.14
Mikania sp.	facultative wetland			0.32	0.30		0.17				0.43	0.50	0.88	0.14	0.05
Momordia charantia	***				0.20				0.17						0.10
Parthenocissus quinquefolia	facultative					0.10		0.18		0.50	0.14			0.64	0.24
Sarcostemma clausum	facultative wetland									0.13					
Smilax sp. (bona-nox)	facultative													0.43	0.05
Toxicodendron radicans	facultative							0.18		0.38				0.29	
Valeriana scandens	facultative													0.07	
Vitis rotundifolia	facultative				0.20					0.13		0.10		0.29	0.05

*** Species not listed in The Florida Wetlands Delineation Manual or the National List of Plant Species that Occur in Wetlands (Reed 1988).

Table 7.8. Frequency of Occurrence of Herbaceous Species Found in the Understory of Constructed Forested Wetlands.

		Site Age													
Species Name	wetland status	0.5	2	5	6	8	10	10	12	14	15	16	17	18	19
Acalypha gracilens	facultative upland*	0.06													0.05
Alternanthera philoxeroides	obligate												0.50	0.50	0.57
Ambrosia artemisiifolia	facultative upland	0.06	0.08												
Ammannia latifolia	obligate		0.58												
Andropogon sp.	facultative/ fac. wet	0.06	0.25		0.40		0.33	0.64			0.14		0.25		0.05
Aster sp.	***							0.14							
Aster carolinianus	obligate							0.14			0.14		0.50		
Bacopa caroliniana	obligate			0.68											
Bacopa monnieri	obligate		0.17				0.21	0.09	0.17						
Begonia semperflorens	***					0.70									
Bidens sp.	***														0.14
Bidens alba	facultative						0.04	0.18							
Bidens laevis	obligate												0.88		
Boehmeria cylindrica	obligate							0.18			0.29		0.63	0.14	
Brachiaria ramosa	***	0.06													
Carex longii	facultative wetland*			0.11											
Centella asiatica	facultative wetland			0.37											
Chamaecrista nictitans	***	0.06													
Chenopodium ambrosioides	facultative upland	0.06													
Cicuta americana	obligate										0.57				
Commelina diffusa	facultative wetland			0.21			0.08	0.09							0.29
Conyza canadensis	facultative upland	0.35			0.10			0.09							

* Status provided by consensus of six botanists.

*** Species not listed in The Florida Wetlands Delineation Manual or the National List of Plant Species that Occur in Wetlands (Reed 1988).

Table 7.8 (Cont.) Frequency of Occurrence of Herbaceous Species Found in the Understory of Constructed Forested Wetlands.

		Site Age													
Species Name	wetland status	0.5	2	5	6	8	10	10	12	14	15	16	17	18	19
Crotalaria pallida	***	0.47													
Cuphea carthagenensis	facultative	0.12													
Cynodon dactylon	facultative upland	0.41	0.17	0.05											
Cyperus croceus	***				0.03										
Cyperus distinctus	obligate		0.25												
Cyperus haspan	obligate			0.16											
Cyperus iria	facultative wetland		0.17												
Cyperus odoratus	facultative wetland		0.08				0.21						0.50		
Cyperus polystachyos	facultative wetland	0.06	0.08			0.10							0.13		
Cyperus retrorsus	facultative upland	0.18													
Cyperus surinamensis	facultative wetland		0.17												0.14
Cyperus virens	facultative wetland		0.08	0.37											
Desmodium triflorum	facultative upland														
Dichondra caroliniensis	facultative														0.05
Digitaria bicornis	***	0.12			0.01										
Digitaria serotina	facultative														
Diodia virginiana	facultative wetland			0.21											
Drymeria cordata	facultative							0.05							0.05
Echinochloa walteri	obligate										0.14		0.13		
Eclipta alba	facultative wetland						0.08	0.05							
Eleocharis sp.	obligate														

*** Species not listed in The Florida Wetlands Delineation Manual or the National List of Plant Species that Occur in Wetlands (Reed 1988).

Table 7.8 (Cont.) Frequency of Occurrence of Herbaceous Species Found in the Understory of Constructed Forested Wetlands.

		Site Age													
Species Name	wetland status	0.5	2	5	6	8	10	10	12	14	15	16	17	18	19
Eleocharis cellulosa	obligate												0.13		
Eleocharis geniculata	obligate		0.33												
Eleocharis vivipara	obligate		0.17	0.05									0.13		
Erechtites hieraciflua	facultative				0.30	0.10	0.08								0.10
Erygium baldwinii	facultative			0.11											
Eupatorium capillifolium	facultative	0.24		0.26	0.40	0.10	0.04	0.14	0.17						0.05
Eupatorium serotinum	facultative											0.20			
Fuirena scirpoidea	obligate		0.08	0.05											
Galium tinctorium	facultative wetland			0.21	0.10		0.04	0.09					0.88	0.14	
Habenaria repens	facultative wetland											0.10			
Heterotheca subaxillaris	facultative upland	0.41													
Hydrocotyle umbellata	facultative wetland		0.58	0.63		0.10	0.13	0.05			0.71	0.80	0.75	0.21	
Imperata cylindrica	***				0.10									0.14	0.10
Indigofera hirsuta	***	0.35													
Juncus effusus	obligate		0.67	0.16		0.30	0.08	0.05							0.52
Juncus marginatus	facultative wetland			0.32											
Lachnanthes caroliniana	facultative				0.10					0.13					
Lactuca floridana	facultative upland						0.04								
Lepidium virginicum	facultative upland				0.20										
Linderia grandiflora	facultative wetland*														
Ludwigia repens	obligate		0.17			0.10							0.13		

* Status provided by consensus of six botanists.

*** Species not listed in The Florida Wetlands Delineation Manual or the National List of Plant Species that Occur in Wetlands (Reed 1988).

Table 7.8 (Cont.) Frequency of Occurrence of Herbaceous Species Found in the Understory of Constructed Forested Wetlands.

		Site Age													
Species Name	wetland status	0.5	2	5	6	8	10	10	12	14	15	16	17	18	19
Paspalum notatum	facultative upland	1.00		0.26			0.04								
Paspalum setaceum	facultative	0.12											0.63		
Paspalum urvillei	facultative														
Peltandra virginica	obligate													0.07	
Phyla nodiflora	facultative		0.08					0.05							
Phytolacca rigida	facultative upland				0.30		0.13	0.05	0.33						
Pluchea sp.	facultative wetland	0.06	0.42												0.10
Polygonum sp.	obligate			0.58				0.27					0.63	0.07	0.19
Polygonum hydropiperoides	obligate		0.08	0.05	0.20							0.10			
Polygonum punctatum	obligate		0.17	0.11			0.33					0.30			
Polypremum procumbens	facultative upland	0.18													
Pontedaria cordata	obligate		0.17	0.68									0.50		
Ptilimnium capillaceum	facultative wetland			0.21											
Rhynchelytrum repens	***	0.24													
Richardia brasiliensis	upland*	0.18													
Sacciolepis indica	facultative			0.32		0.30									
Sagitaria graminea	obligate			0.05											
Sagittaria lancifolia	obligate												0.38		
Sagittaria latifolia	obligate										0.29				
Salvinia rotundifolia	obligate											0.10			

* Status provided by consensus of six botanists.

*** Species not listed in The Florida Wetlands Delineation Manual or the National List of Plant Species that Occur in Wetlands (Reed 1988).

Table 7.8 (Cont.) Frequency of Occurrence of Herbaceous Species Found in the Understory of Constructed Forested Wetlands.

		Site Age													
Species Name	wetland status	0.5	2	5	6	8	10	10	12	14	15	16	17	18	19
Saururus cernuus	obligate		0.08								0.43	1.00			
Scirpus validus	obligate		0.08										0.50		
Sesbania sp.	facultative	0.12													
Sida rhombifolia	facultative upland	0.12			0.30	0.10									0.19
Solanum americanum	facultative upland								0.17						
Solidago fistulosa	facultative wetland				0.90	0.10									
Solidago sp.	***		0.17	0.05				0.09				0.10			
Teucrium canadense	facultative wetland														0.09
Thalia geniculata	obligate												0.13		
Thelpteris dentata	facultative wetland					0.80		0.14	0.33						
Thelpteris interrupta	facultative wetland					0.30				0.38		0.30	0.13		
Thelpteris hispidula	facultative wetland				0.10			0.09	0.33	0.50	0.43	0.30		0.43	
Thelypteris kunthii	facultative wetland						0.08	0.09							
Typha latifolia	obligate		0.33	0.15			0.04						0.25		
Urena lobata	facultative upland	0.18			0.90	0.20	0.13	0.77						0.21	0.14
Woodwardia areolata	obligate									0.13					
Woodwardia virginica	facultative wetland					0.10									

*** Species not listed in The Florida Wetlands Delineation Manual or the National List of Plant Species that Occur in Wetlands (Reed 1988).

Table 7.9. Understory Species Cover, Richness and Diversity of Vegetation Less Than 1 Meter in Height.

PROJECT NAME OR NUMBER	*AGE (years)*	*BRAUN-BLANQUET COVER*	*SPECIES RICHNESS (total)*	*SPECIES DIVERSITY*	*SPECIES EVENESS*	*SPECIES RICHNESS (canopy)*	*EARLY SUCCESSIONAL SPECIES RICHNESS*	*LATE SUCCESSIONAL SPECIES RICHNESS (subcanopy)*	*EARLY SUCCESSIONAL SPECIES RICHNESS (shrubs)*	*LATE SUCCESSIONAL SPECIES RICHNESS (shrubs)*	*SPECIES RICHNESS (vines)*	*SPECIES RICHNESS (herbs)*
LP2 Phase 1	0.5	1.9	28	1.28	0.93	0	0	0	0	0	0	26
FGGSB - 2	2	4.5	37	1.48	0.94	1	1	0	2	1	0	32
CO7984	5	4.7	41	1.44	0.90	1	1	0	3	0	1	35
HP5 Phase 3	6	4.1	29	1.37	0.94	0	1	0	4	1	5	18
Clear Springs	8	4.7	26	1.28	0.90	0	1	0	4	0	3	18
East Lobe	10	2.8	35	1.41	0.91	1	2	0	3	1	4	24
West Lobe	10	3.8	39	1.44	0.91	2	2	0	4	0	6	26
Cateye	12	2.4	13	1.08	0.97	0	1	0	3	1	2	7
SP11	14	3.9	20	1.24	0.95	2	1	0	3	0	5	9
Guy Branch	15	2.1	20	1.18	0.91	2	1	0	2		5	10
SP6	16	2.6	19	1.11	0.87	2	1	0	1	1	2	12
Morrow Swamp	17	4.9	30	1.36	0.92	1	1	0	1	0	2	25
Sink Branch	18	2.5	34	1.41	0.92	5	1	2	3	1	11	11
Parcel B	19	2.3	37	1.44	0.92	3	0	1	4	0	9	20

laurifolia was the next most common species and was found in thirty-six percent of the sites. Ten of the fourteen sites had seedlings or saplings of subcanopy species present; however, no site had more than 2 species occurring. Shrub seedlings or sapling occurred in all sites sampled except LP2 Phase 1, the youngest site. Vines occurred in all but the two youngest sites. The greatest number of vine species (11) occurred in Sink Branch (18 years).

Species diversity in the understory ranged from 1.08 to 1.57. Species evenness neared unity for all sites (0.90 to 1.0) and was less than 0.90 in only one site (0.86 at SP6).

The understory community status is provided in Table 7.10. Those sites with the lowest "Understory Community Wetland Status" contain a greater probability of sampling wetland species and perhaps a greater probability of being a wetland. Figure 7.7 is a graphical representation of community wetland status. The horizontal line in Figure 7.7 represents the average "Understory Community Wetland Status" of all sites sampled. Six of the research sites have a lower than average status suggesting that they have a greater likelihood of supporting wetlands plants. However, it is understood that just being wet does not necessarily indicate a quality wetland.

Figure 7.8 shows the number of obligate, facultative wetland and facultative plant species along transects in several research sites. These figures identify areas along the transect where the plant community is dominated by obligate wetland species. They also identify transects where facultative upland species outnumber wetland species. Notice that although East Lobe falls above the line in Figure 7.7, the plant wetland status along each of two transects (Figure 7.8b) shows a dominance of obligate, facultative wetland and facultative plant species. The center section of transect 1 corresponds to a topographic low, which results in water levels that may restrict vegetation establishment.

Figure 7.9 shows the probability of sampling understory species under varying levels of light transmittance. Frequency of occurrence under each of ten light transmittance class ranging from 0-10% to 90.1-100% transmittance were calculated for all understory species occurring in at least ten quadrats. This represents the frequency of occurrence of a species below 1 meter; it does not include the occurrence of trees or shrubs greater than one meter. *Acer* sp., *Apios* sp., *Clematis* sp., *Galium* sp., *Rubus* sp., *Sambucus* sp. and *Urena lobata* more frequently occurred in lower light transmittance classes. In contrast, *Typha* sp. and *Pontedaria cordat*a occurred more frequently in areas with greater light transmittance. Unexpectedly, *Ludwigia peruviana* and *Mikania scandens* occurred more frequently in lower light transmittance levels perhaps, as a result of control measures such as herbiciding or hand removal.

Frequency of Occurrence of Species in the Understory

Table 7.11 lists the frequency of occurrence of species of all structural categories in the understory. This provides insight into occurrence of regeneration of all structural categories.

Table 7.10. Probability of Sampling Plants of Each Wetland Status on a Scale from 0 to 1.

Site Name	Age (years)	Obligate	Facultative Wet	Facultative	Facultative Upland	Upland	Species of Unknown Wetland Status	Understory Community Wetland Status
LP2 Phase 1	0.5	0.03	0.05	0.12	0.34	0.21	0.24	2.9
FGGSB2	2	0.58	0.35	0	0.01	0	0.06	1.32
CO7984	5	0.39	0.31	0.13	0	0.03	0.07	1.55
HP5 Phase 3	6	0.24	0.14	0.29	0.18	0.04	0.09	2.31
Clear Springs	8	0.19	0.39	0.2	0.05	0	0.15	1.77
East Lobe	10	0.29	0.25	0.33	0.06	0.02	0.02	2.12
West Lobe	10	0.09	0.43	0.23	0.15	0	0.06	2.24
Cateye	12	0.21	0.32	0.36	0.16	0	0.05	2.57
SP 11	14	0.12	0.24	0.65	0.02	0	0	2.63
Guy Branch	15	0.34	0.55	0.06	0	0	0.02	1.62
SP6	16	0.43	0.43	0.14	0	0	0.03	1.71
Morrow Swamp	17	0.51	0.19	0.21	0	0	0.02	1.52
Sink Branch	18	0.09	0.43	0.38	0.02	0.01	0.07	2.22
Parcel B	19	0.26	0.22	0.33	0.11	0	0.06	2.13

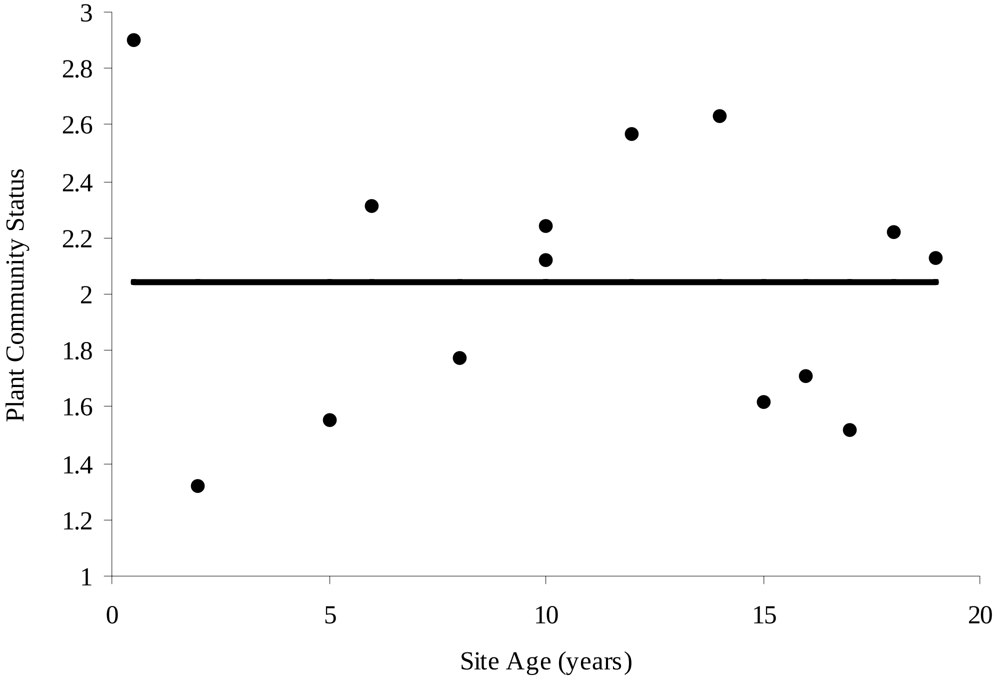


Figure 7.7. Understory Plant Community Status for the Chrono-Sequence of Wetlands Graphed Against Age. Line Represents the Mean Understory Plant Community Status for All Sites.

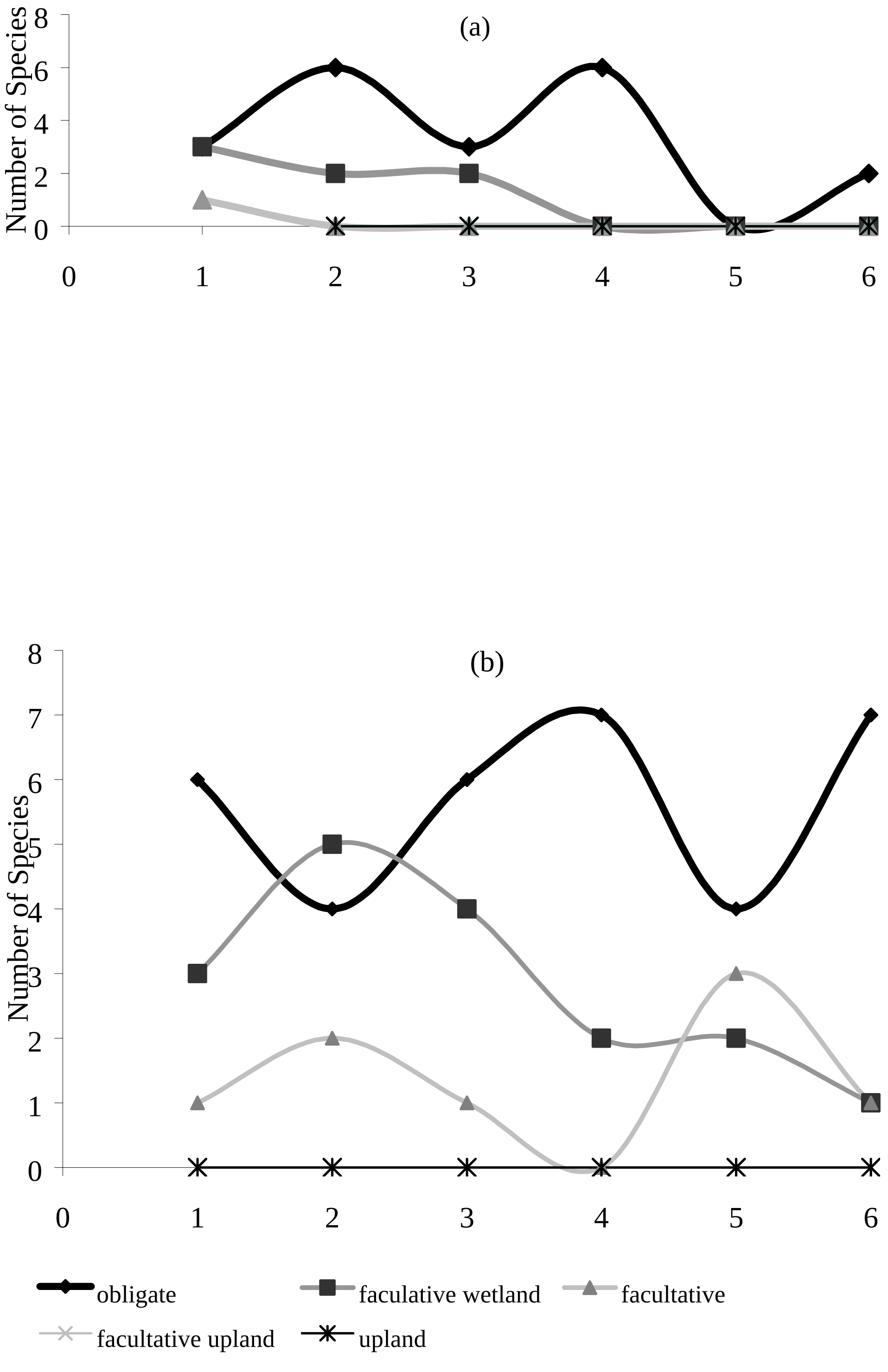


Figure 7.8. Number of Plant Species of Each Wetland Status Found in the Understory. One Sampling Quadrat Was Randomly Located in Each 10-Meter Transect Section: (a) FGGSB-2 Transect 1, (b) FGGSB-2 Transect 2, (c) East Lobe Transect 1 and (d) East Lobe Transect 2.

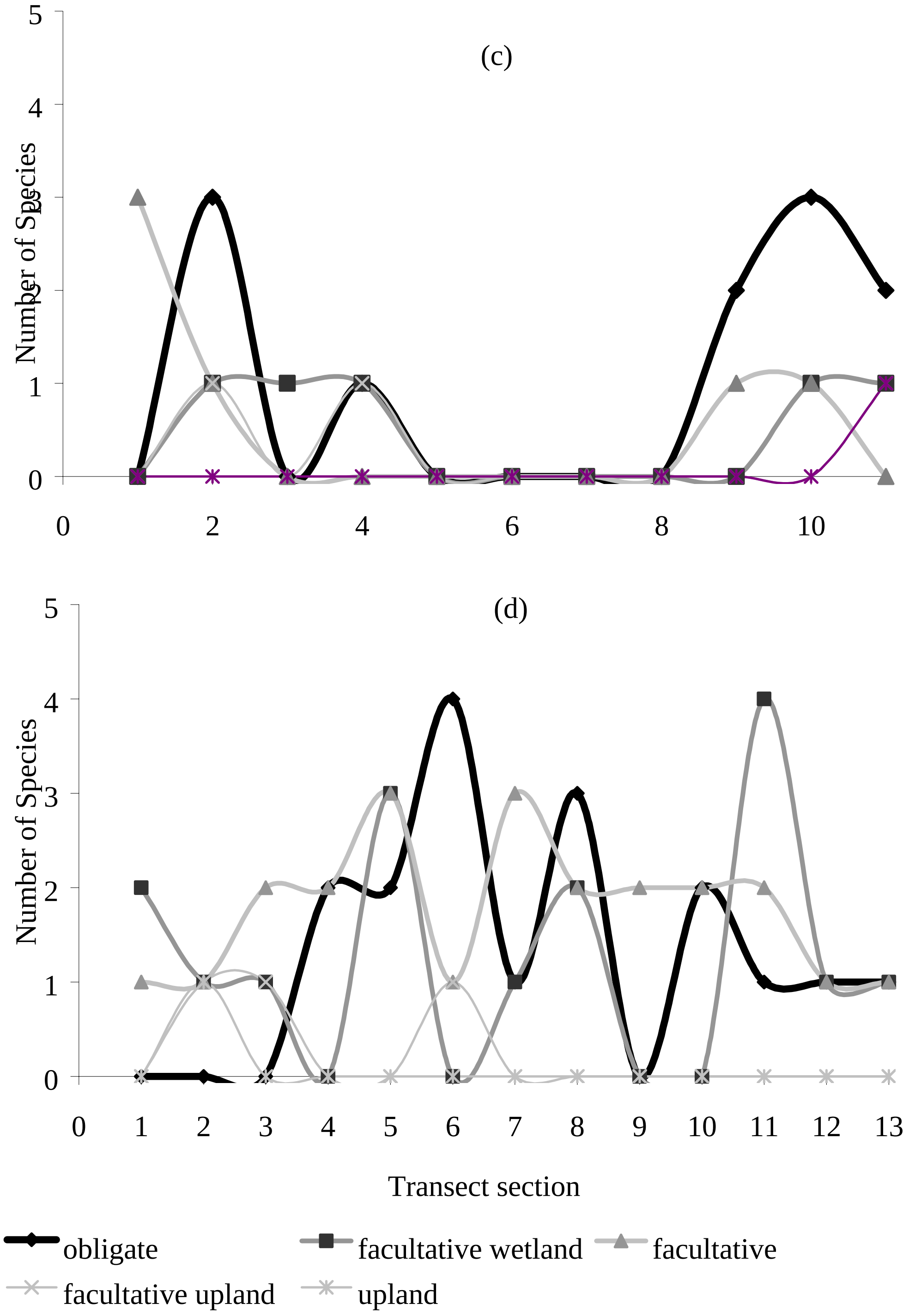


Figure 7.8 (Cont.) Number of Plant Species of Each Wetland Status Found in the Understory. One Sampling Quadrat Was Randomly Located in Each 10-Meter Transect Section: (a) FGGSB-2 Transect 1, (b) FGGSB-2 Transect 2, (c) East Lobe Transect 1 and (d) East Lobe Transect 2.

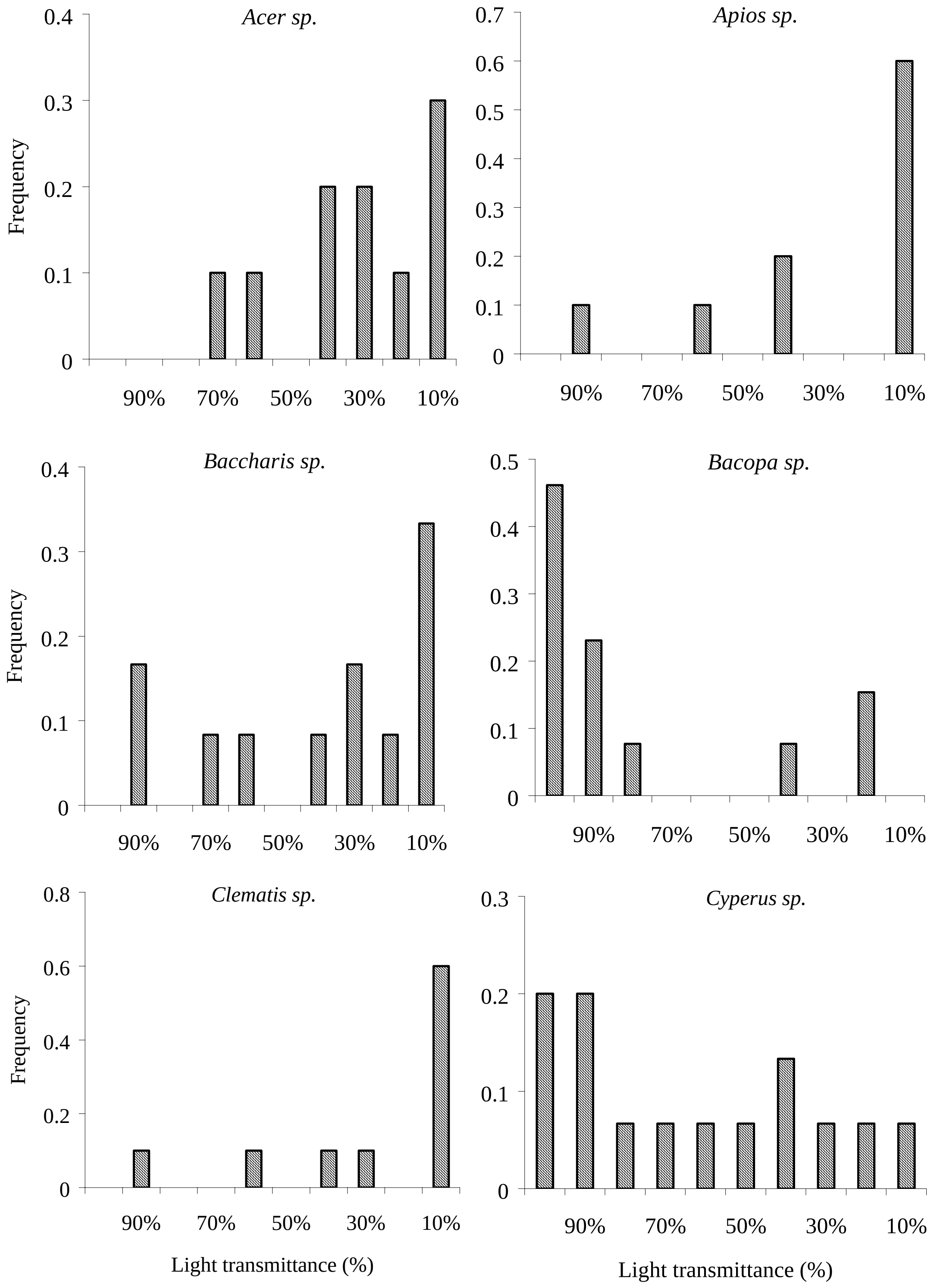


Figure 7.9. The Frequency of Occurrence of Understory Species (< 1m in Height) Under Varying Light Transmittance Classes. Those Species Occurring at a Minimum of Ten Sampling Points Throughout the Chrono-Sequence of Wetlands Are Presented. The X-Axis Is in Reverse Order So That Species Occurring Under Low Light Transmittance Levels Occur on the Right.

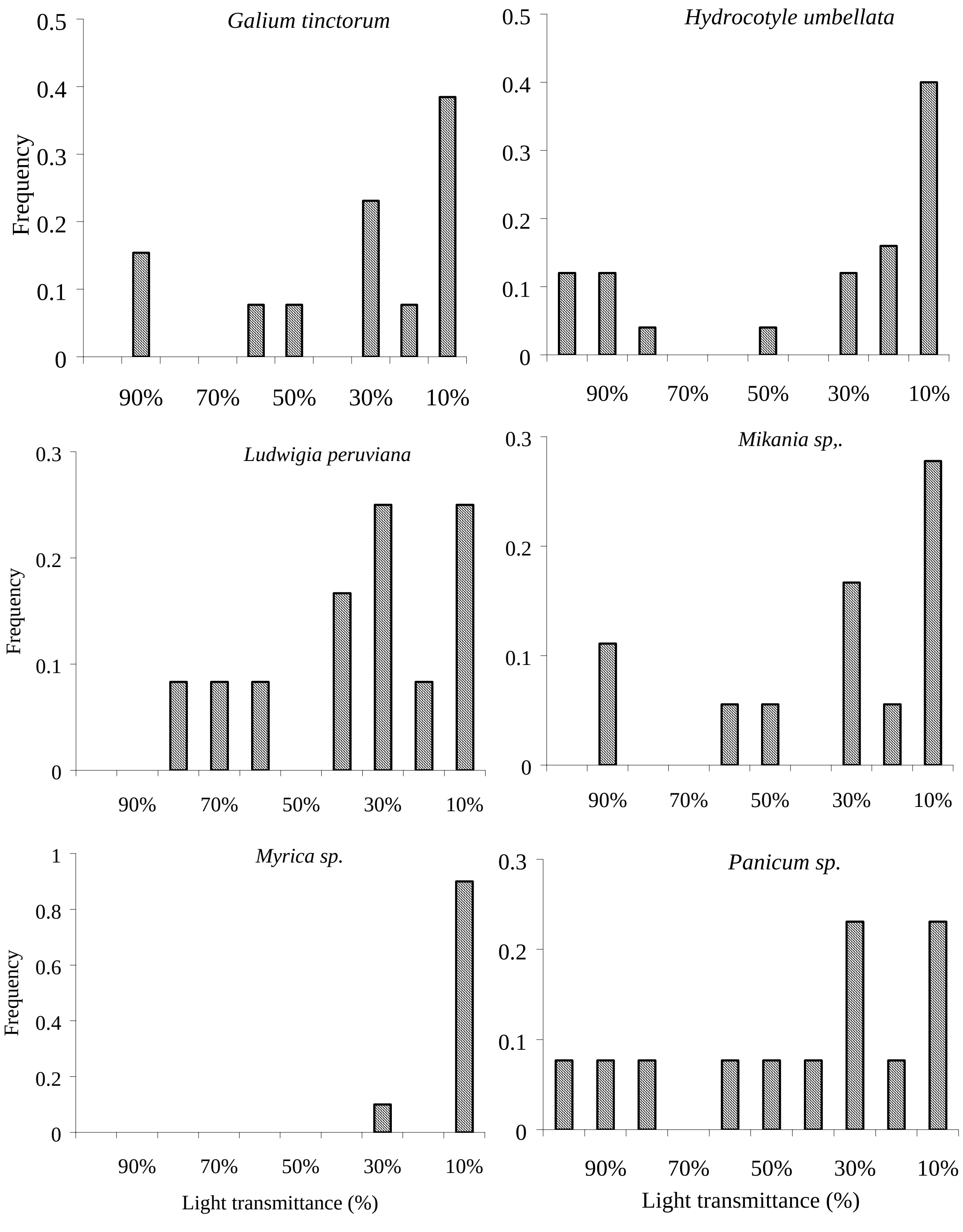


Figure 7.9 (Cont.) **The Frequency of Occurrence of Understory Species (< 1m in Height) Under Varying Light Transmittance Classes. Those Species Occurring at a Minimum of Ten Sampling Points Throughout the Chrono-Sequence of Wetlands Are Presented. The X-Axis Is in Reverse Order So That Species Occurring Under Low Light Transmittance Levels Occur on the Right.**

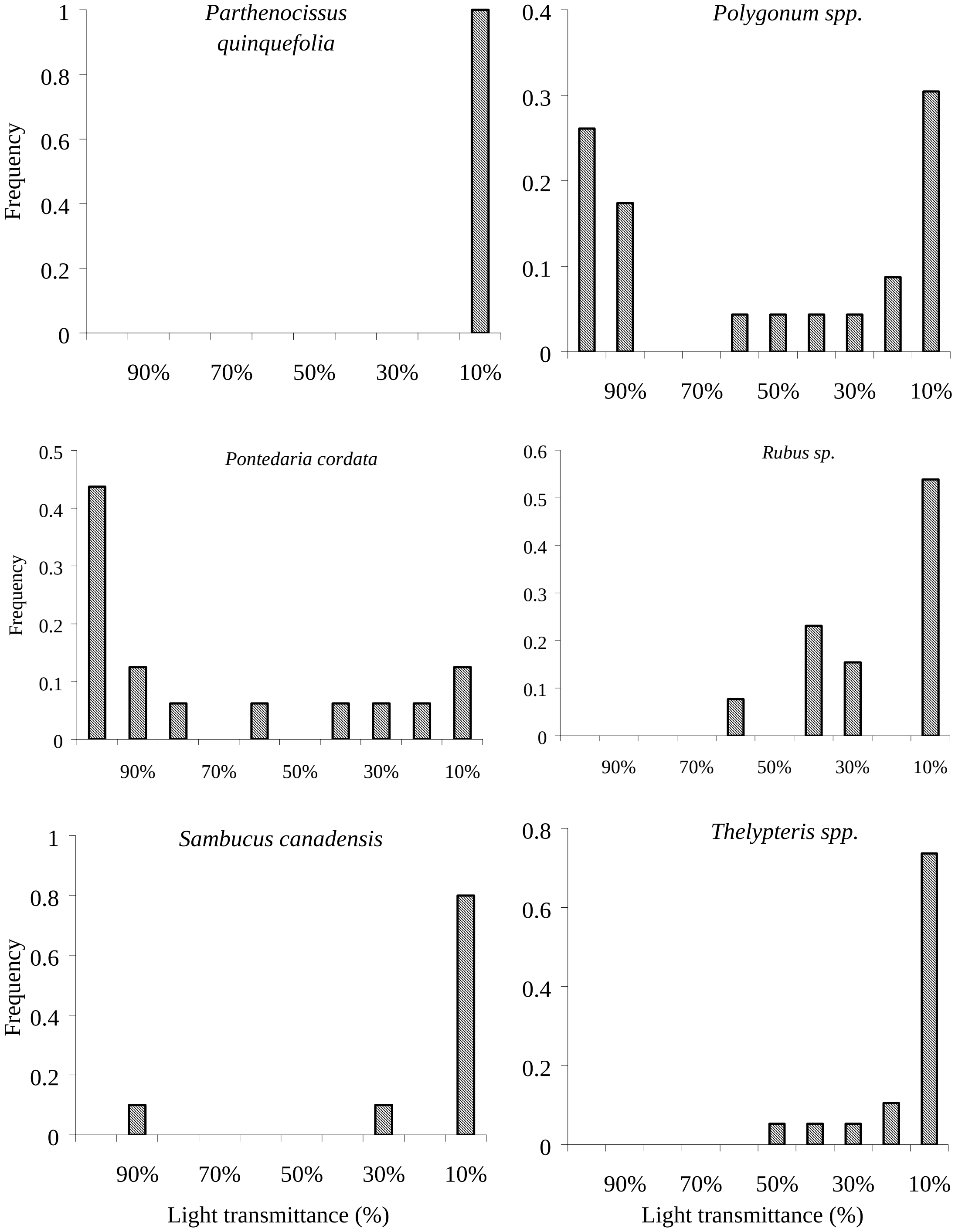


Figure 7.9 (Cont.) **The Frequency of Occurrence of Understory Species (< 1m in Height) Under Varying Light Transmittance Classes. Those Species Occurring at a Minimum of Ten Sampling Points Throughout the Chrono-Sequence of Wetlands Are Presented. The X-Axis Is in Reverse Order So That Species Occurring Under Low Light Transmittance Levels Occur on the Right.**

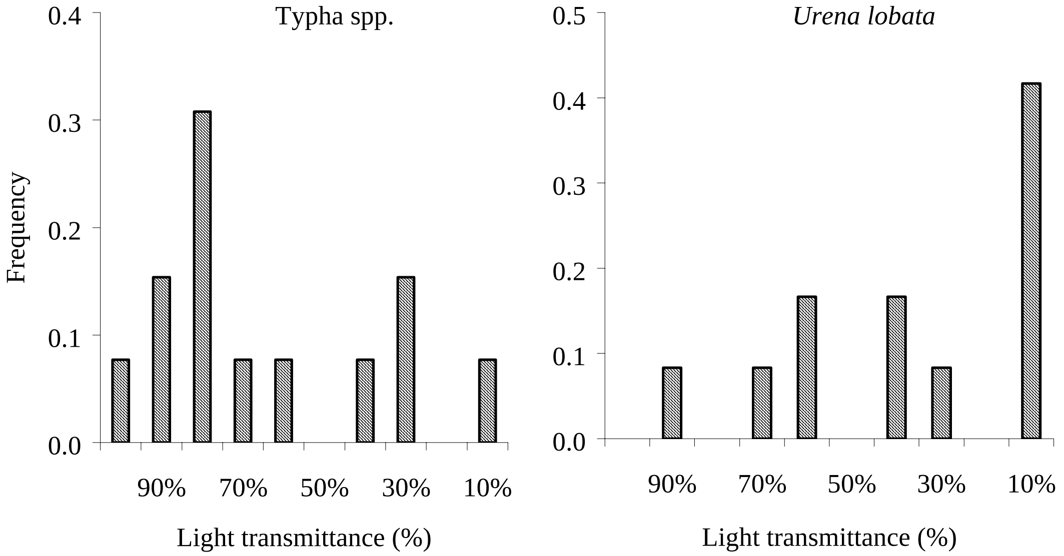


Figure 7.9 (Cont.) **The Frequency of Occurrence of Understory Species (< 1m in Height) Under Varying Light Transmittance Classes. Those Species Occurring at a Minimum of Ten Sampling Points Throughout the Chrono-Sequence of Wetlands Are Presented. The X-Axis Is in Reverse Order So That Species Occurring Under Low Light Transmittance Levels Occur on the Right.**

Table 7.11. Frequency of Occurrence of Vegetative Structural Categories (Canopy, Subcanopy, Shrub and Vine Species) in the Understory of Constructed Forested Wetlands.

Project Name or Project Number	*Age(years)*	*Canopy Tree Seedlings*	*Early Successional Subcanopy Tree Seedlings*	*Late Successional Subcanopy Tree Seedlings*	*Early Successional Shrubs*	*Later Successional Shrubs*	*Vines*
LP2 Phase 1	0.5	0.00	0.00	0.00	0.00	0.00	0.00
FGGSB - 2	2	0.17	0.17	0.00	0.58	0.43	0.00
CO7984	5	0.11	0.05	0.00	0.53	0.00	0.32
HP5 Phase 3	6	0.00	0.40	0.00	1.00	0.10	0.90
Clear Springs	8	0.00	0.30	0.00	0.60	0.00	0.50
East Lobe	10	0.04	0.25	0.00	0.29	0.00	0.46
West Lobe	10	0.28	0.28	0.00	0.55	0.00	0.73
Cateye	12	0.00	0.33	0.00	0.83	0.17	0.33
SP11	14	0.38	0.75	0.00	0.38	0.00	0.75
Guy Branch	15	0.57	0.29	0.00	0.57	0.00	0.43
SP6	16	0.50	0.10	0.00	0.10	0.20	0.50
Morrow Swamp	17	0.13	0.13	0.00	0.25	0.00	0.50
Sink Branch	18	0.64	0.07	0.21	0.64	0.07	1.00
Parcel B	19	0.38	0.00	0.14	0.67	0.00	0.67

In those sites where canopy tree species occurred in the understory, their frequency of occurrence ranged from 0.04-0.71; in other words, they were recorded in 4%-71% of the sample quadrats. A frequency of over 0.50 was recorded only in sites over fifteen years old. Frequency of *Myrica cerifera* and *Salix caroliniana* seedlings was highest in intermediate age sites (8-14 years) and lower at both younger and older sites. Late successional subcanopy species seedlings (those species other than *M. ce*rifera and *S. caroliniana*) were found only in sites greater than six years old. Frequency of occurrence of early successional shrub species ranged from 0.06-0.80. Frequency of occurrence of late successional shrub species ranged from 0.07-0.50. Frequency of occurrence of vines ranged from 0.32-1.0. Vines most frequently occurred in Sink Branch (18 years) and Morrow Swamp (17 years).

Soil Development

Table 7.12 provides a summary of soil characteristics of constructed forested wetlands in the central Florida mining district including available macronutrients (Ca, Mg, K, P, and Fe), bulk density, percent moisture and percent organic matter.

Soil macronutrients (Ca, Mg, K, P, and Fe) are evaluated in two ways. First, soil macronutrients are expressed in terms of mg of nutrients per kg of soil. Second, they are expressed on an areal basis (kg of nutrient m^{-2} soil to a depth of 20 cm). The second method takes into consideration differences in soil bulk density and more effectively quantifies available nutrients within the rooting zone of vegetation. Figure 7.10a provides calcium concentrations (mg Ca kg^{-1} soil), while Figure 7.10b represents calcium areal availability. There are no differences in soil calcium (mg kg^{-1}) between sites when bulk density is considered are the lack of significant differences is easily observed. The same is true for other soil macronutrients (Figure 7.10c-7.10j)

Table 7.13 and Figure 7.11 show the relationships between KCl extractable NO_3-N and NH_4-N and site age. Figure 11a, 11c, and 11e provide nutrient values in mg kg^{-1} of soil and g m^{-2}.

The relationships between three soil properties were evaluated. Bulk density was plotted as a function of soil water content and soil organic matter and soil organic matter was plotted as a function of soil water content. As expected, Figure 7.12 shows that bulk density decreases exponentially with increasing soil water content ($r^2 = 0.92$; $p < 0.01$) and soil organic matter ($r^2 = 0.85$; $p < 0.01$). Soil organic matter increased with increasing soil water content ($r^2 = 0.75$; $p < 0.01$). Soil water content explains more of the variation in bulk density than does soil organic matter in the developing soil of these sites.

Figures 7.13, 7.14, and 7.15 show each of the relationships depicted in Figure 7.12 for the chrono-sequence of the research sites. The sites are presented in chronological order. Soil samples represent a cross section of wetland perpendicular to the moisture gradient from wetland edge to center.

Table 7.12. Soil Characteristics of Constructed Forested Wetlands, Including Mehlich I Extractable Nutrients.

Site Name	Age	Sampling date	**Ca**		**Mg**		**K**		**P**		**Fe**		Organic Matter	Bulk Density	Soil Moisture
	(years)		(mg kg^{-1})	(g m^{-2})	(mg kg^{-1})	(g m^{-2})	(mg kg^{-1})	(g m^{-2})	(mg kg^{-1})	(g m^{-2})	(mg kg^{-1})	(g m^{-2})	(%)	(g cm^{-3})	(%)
LP2 Phase 1	0.5	Aug-98	1197.94	61.66	125.81	5.50	16.29	0.72	452.53	24.14	45.68	2.42	2.1	1.71	11.0
FGGSB 2	2	Jul-98	2865.75	134.34	330.23	15.19	7.13	1.80	760.23	34.83	51.43	2.90	5.1	1.30	25.0
CO 7984	5	Jun-98	2601.74	176.84	100.48	6.76	26.65	1.80	1030.16	69.80	67.63	4.94	2.0	1.27	14.0
HP5 Phase 3	6	Jul-98	3415.00	90.19	216.60	5.01	22.34	1.47	897.40	25.64	25.29	0.72	10.1	0.95	22.0
Clear Springs	8	Jul-97	528.20	109.47	129.90	2.74	28.75	6.10	101.88	23.37	70.53	17.92	4.4	1.01	34.0
East Lobe	10	Jun-97	6041.25	***	1276.25	***	92.60	***	1199.75	***	16.55	***	8.2	***	36.0
East Lobe	10	Nov-97	6524.09	110.29	1293.36	19.93	101.55	1.47	1368.91	25.41	23.57	0.39	7.7	0.75	41.0
West Lobe	10	Jul-97	6290.95	***	1504.76	***	125.90	***	1114.38	***	8.08	***	8.3	***	38.0
Cateye	12	Jul-99	4985.00	294.16	215.97	14.92	30.95	1.97	1500.50	82.86	62.82	4.41	7.2	0.94	25.0
SP11	14	Jul-99	1747.13	60.02	43.84	1.67	14.76	0.65	738.51	25.70	47.76	2.90	3.4	1.39	18.0
Guy Branch	15	Aug-99	6517.14	150.93	1411.57	12.80	67.10	1.00	987.66	32.00	23.64	1.06	13.2	0.42	58.0
SP6	16	Aug-98	3895.00	256.71	696.90	5.50	43.16	2.21	508.20	27.80	75.47	11.04	27.4	0.27	68.0
Morrow Swamp	17	Aug-99	5692.50	383.94	358.05	24.91	50.32	0.97	1896.25	128.93	68.16	4.85	4.1	0.92	35.0
Sink Branch	18	Jun-98	4199.29	210.29	299.39	12.80	29.91	1.31	1408.43	73.96	49.60	2.80	4.3	1.17	17.0
Parcel B	19	Jun-97	6487.14	1699.55	350.32	87.79	25.08	7.33	2339.60	626.19	57.66	14.13	5.1	1.35	22.0

*** Bulk density data not available at these sites.

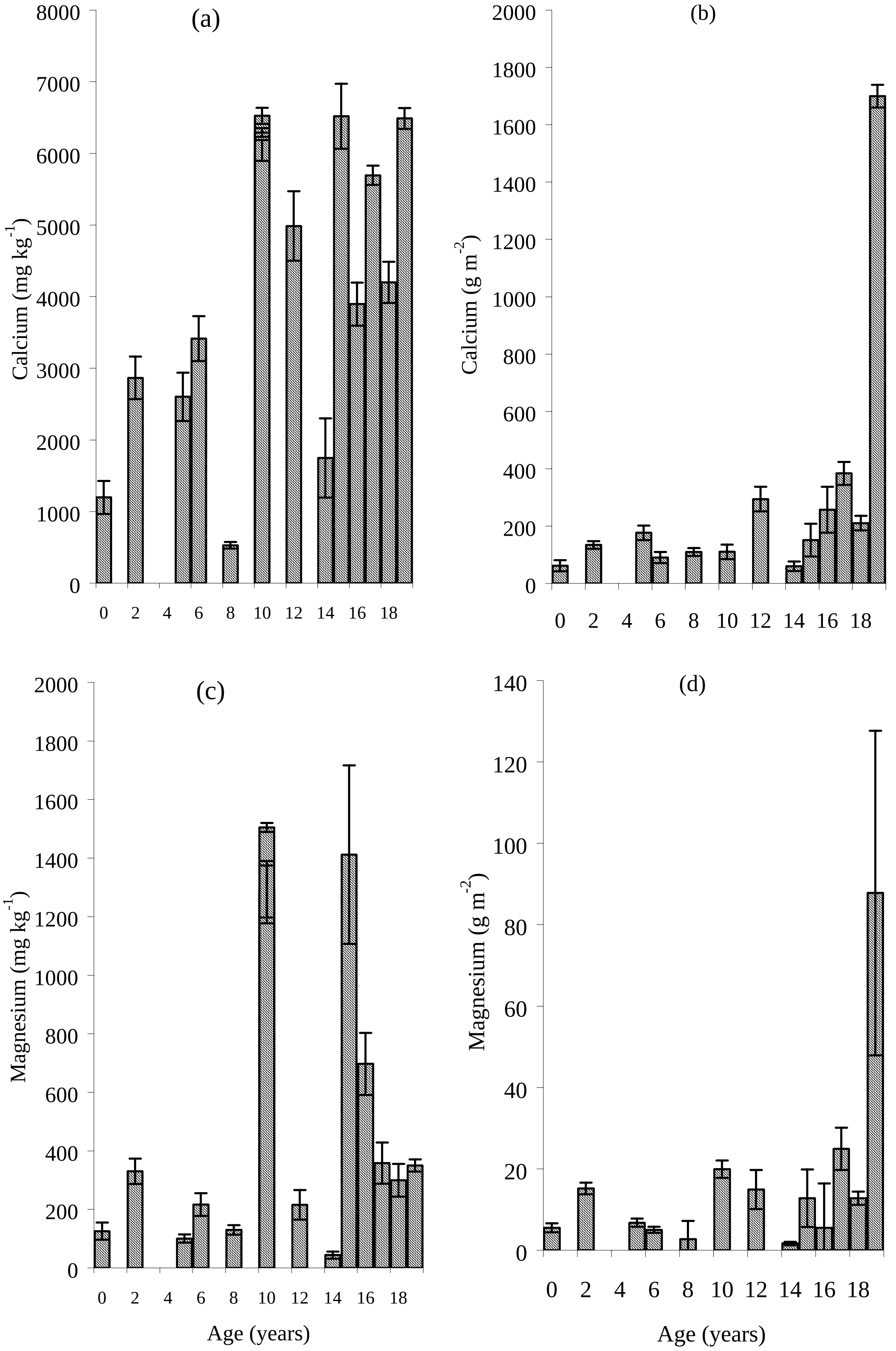


Figure 7.10. On the Left, Available Nutrients on a Mass Basis (mg Nutrient g^{-1} Soil) and an Areal Basis (g Nutrient m^{-2} to a Depth of 20 cm, on the Right). Ca (a,b), Mg (c,d), K (e,f), P (g,h) and Fe (i,j).

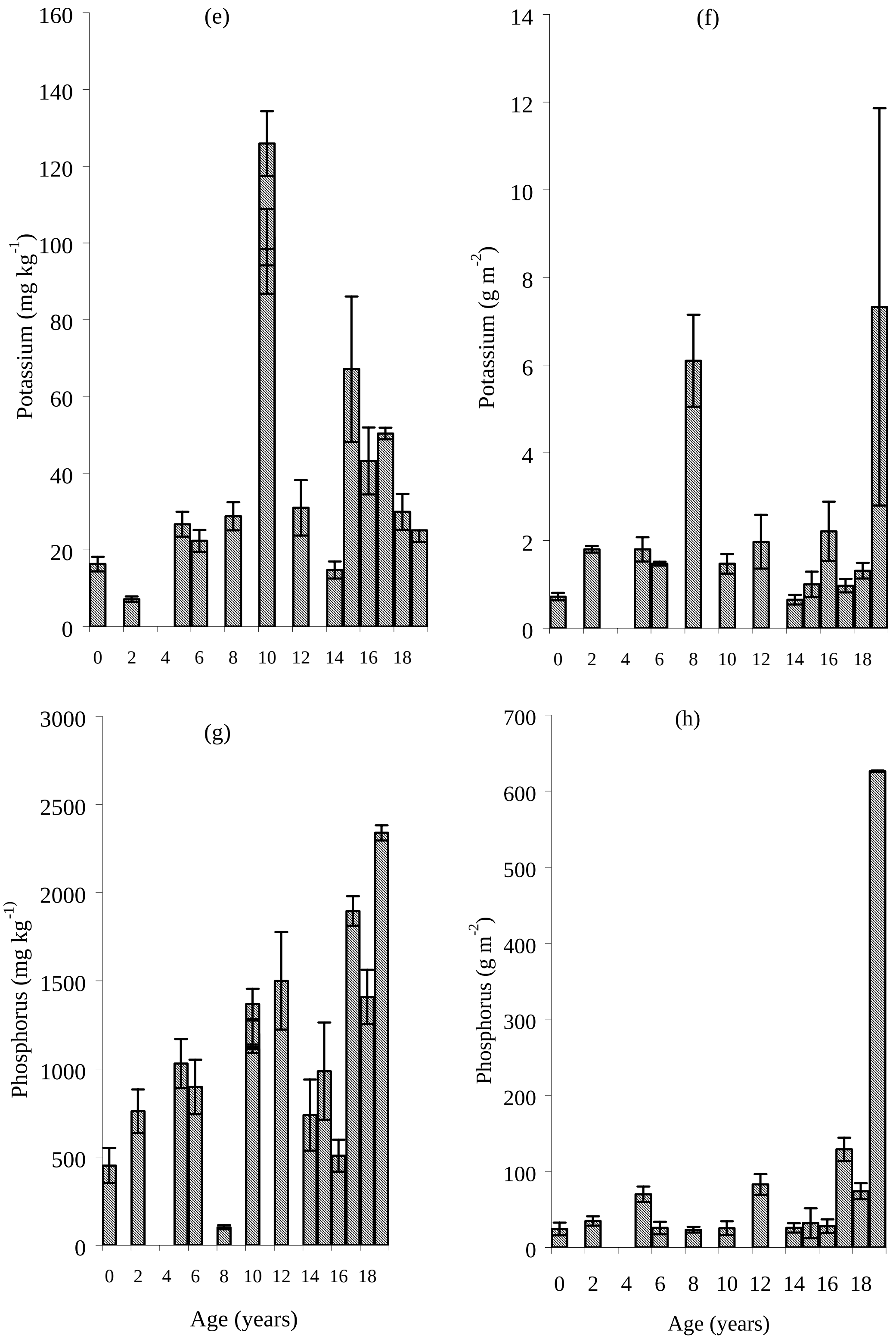


Figure 7.10 (Cont.) **On the Left, Available Nutrients on a Mass Basis (mg Nutrient g^{-1} Soil) and an Areal Basis (g Nutrient m^{-2} to a Depth of 20 cm, on the Right). Ca (a,b), Mg (c,d), K (e,f), P (g,h) and Fe (i,j).**

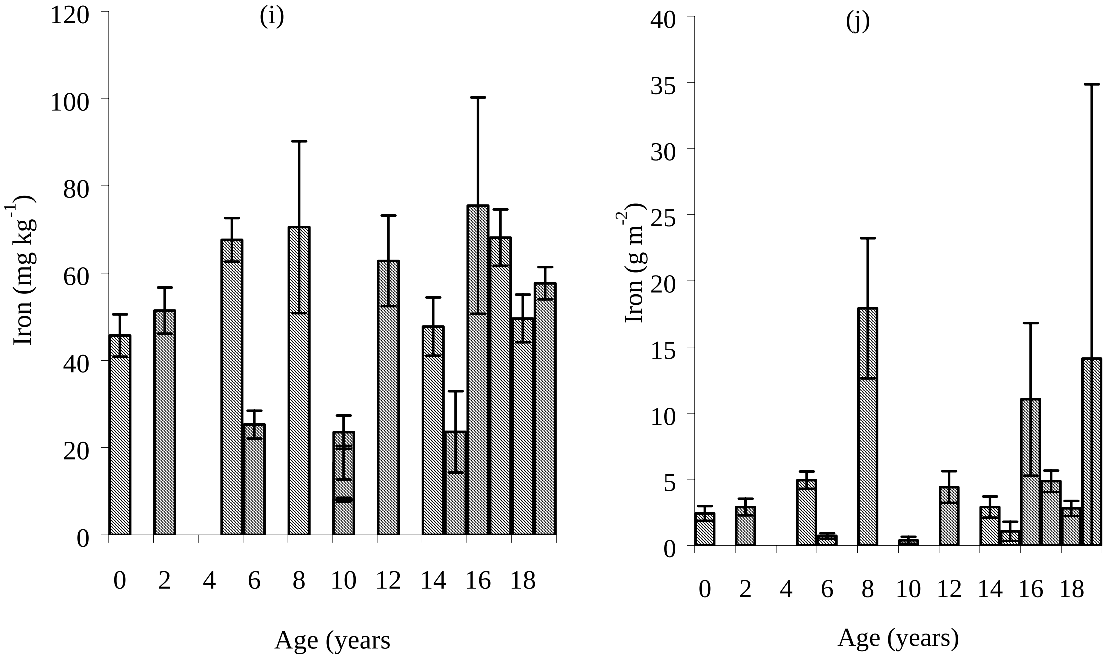


Figure 7.10 (Cont.) **On the Left, Available Nutrients on a Mass Basis (mg Nutrient g^{-1} Soil) and an Areal Basis (g Nutrient m^{-2} to a Depth of 20 cm, on the Right). Ca (a,b), Mg (c,d), K (e,f), P (g,h) and Fe (i,j).**

Table 7.13. Available (KCl Extractable) NO_3-N and NH_4-N in Constructed Forested Wetlands.

Site Name	Age	NH_4-N (mg kg^{-1})	NH_4-N (mg m^{-2})	NO_3-N (mg kg^{-1})	NO_3-N (mg m^{-2})	NO_3-N + NH_4-N (mg kg^{-1})	NO_3-N + NH_4-N (mg m^{-2})
LP2 Phase 1	0.5	2.2	747.0	1.648	569.9	3.892	1316.9
FGGSB - 2	2	3.9	940.5	7.430	1600.4	11.293	2540.9
CO7984	5	2.9	729.8	10.192	2597.6	13.076	3327.4
HP5 Phase 3	6	9.5	1736.1	20.423	3533.9	29.895	5270.0
Cateye	12	15.3	1812.3	6.872	1000.2	22.140	2812.5
SP11	14	1.0	286.3	0.601	179.5	1.630	465.8
Guy Branch	15	34.6	7465.9	0.610	110.8	35.186	7576.6
SP6	16	15.7	602.6	7.940	316.6	23.632	919.2
Morrow Swamp	17	38.4	6261.2	1.227	77.9	39.581	6339.1
Sink Branch	18	5.9	990.6	25.698	5574.1	31.601	6564.7

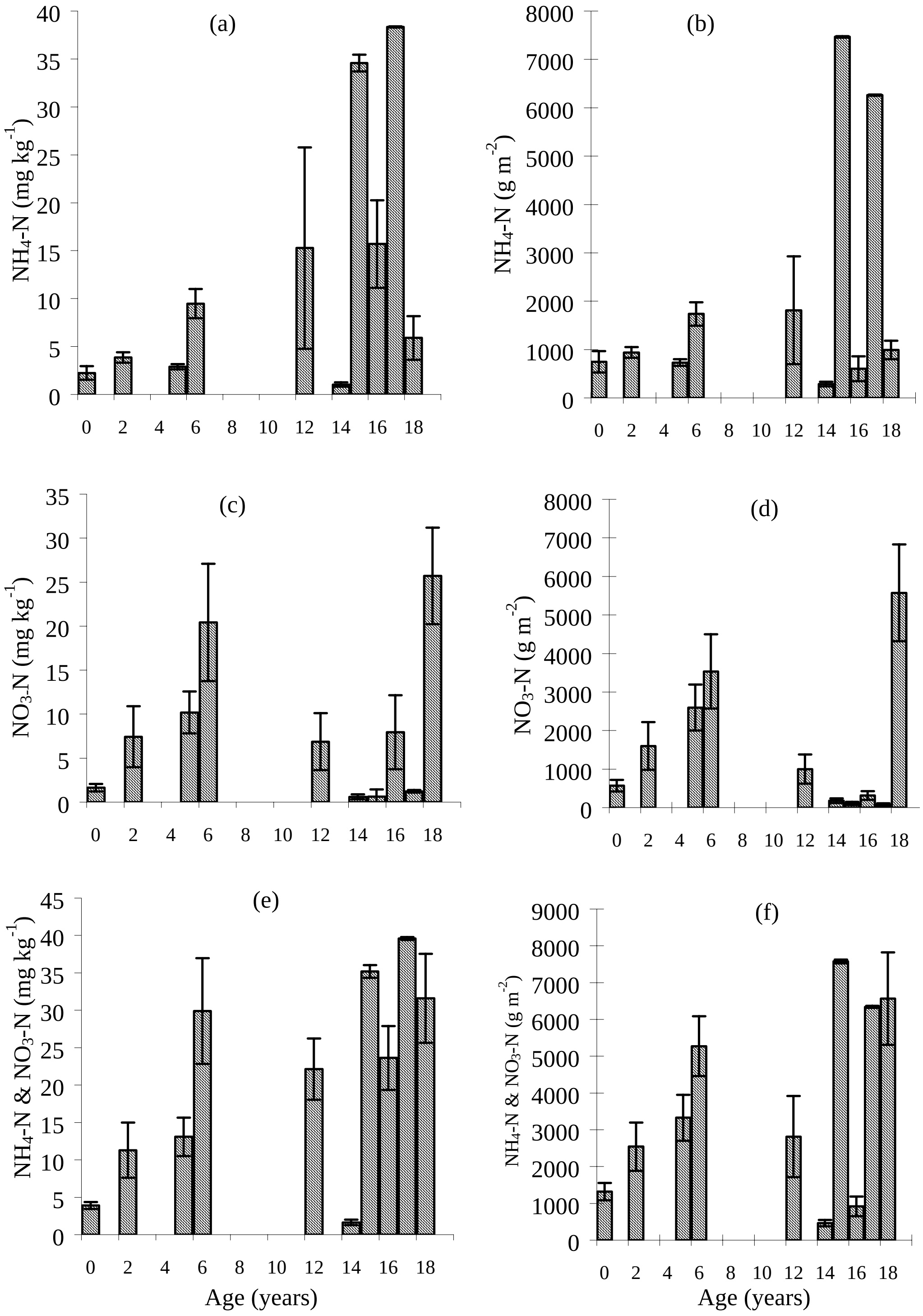


Figure 7.11. Average KCl Extractable NO_3-N, NH_4-N and Combined NO_3-N and NH_4-N at Each Site. In Graphs (a), (c), and (e) Nutrient Values Are Expressed in Milligrams Nutrient Per Gram of Soil. In Graphs (b), (d), and (f), Nutrient Values Are Expressed in Grams of Nutrient per Square Meter to a Depth of 20 cm.

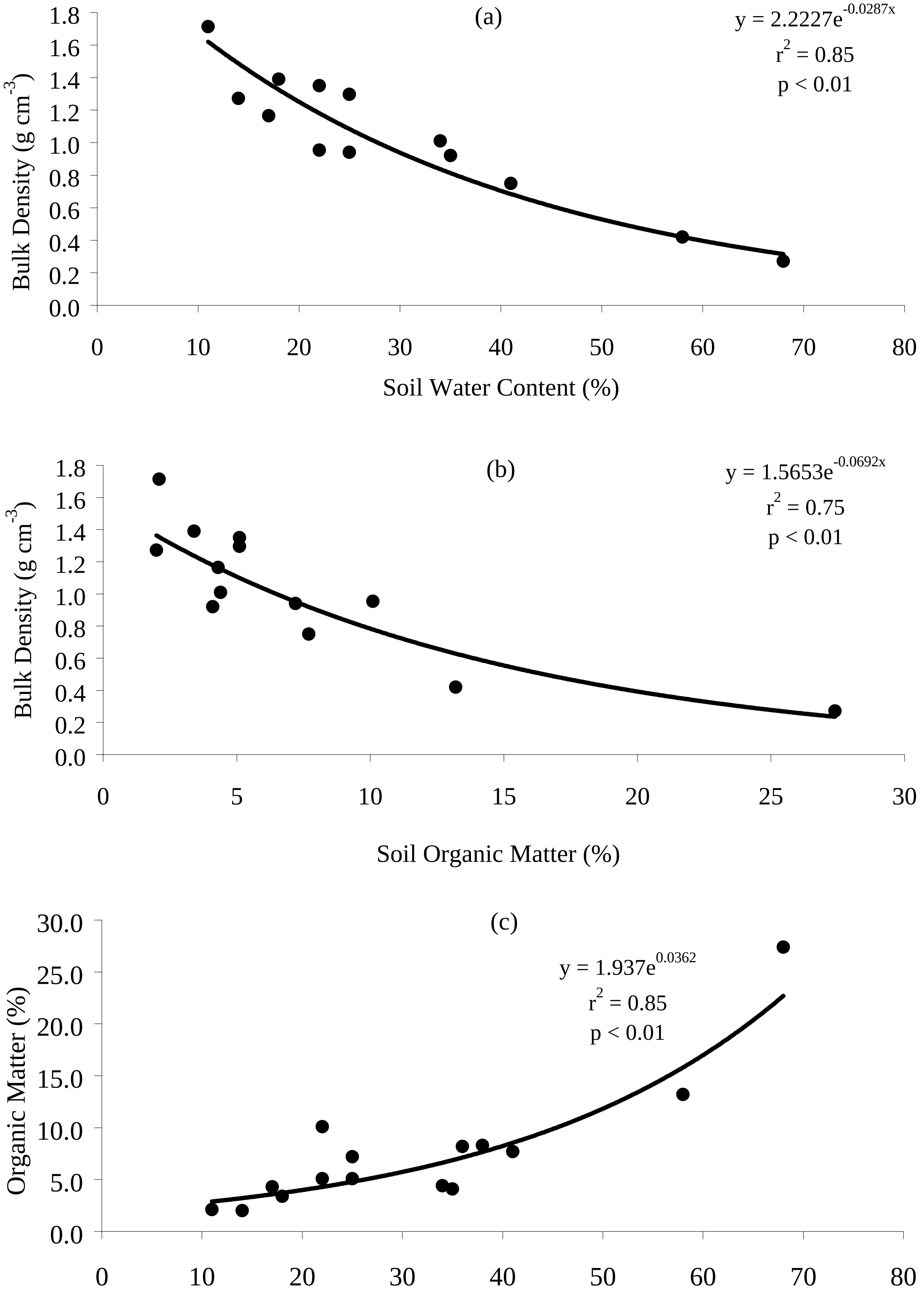


Figure 7.12. Three Relationships Among Soil Parameters Are Graphed: (a) Soil Water Content vs. Bulk Density, (b) Soil Organic Matter vs. Bulk Density and (c) Soil Water Content vs. Organic Matter.

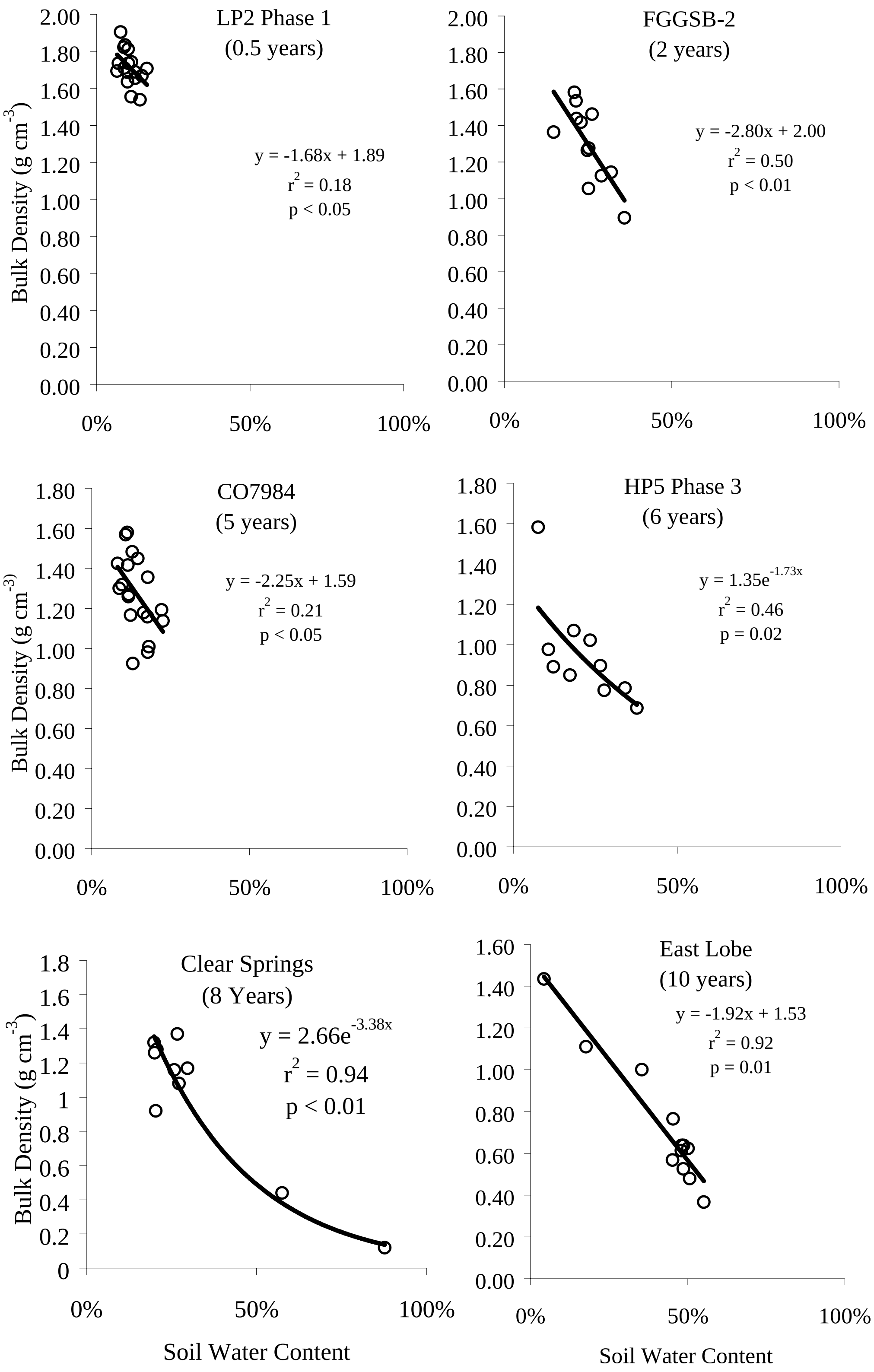


Figure 7.13. The Relationship Between Soil Water Content and Bulk Density in a Chrono-Sequence of Constructed Forested Wetlands. Sites Are Presented in Chronological Order.

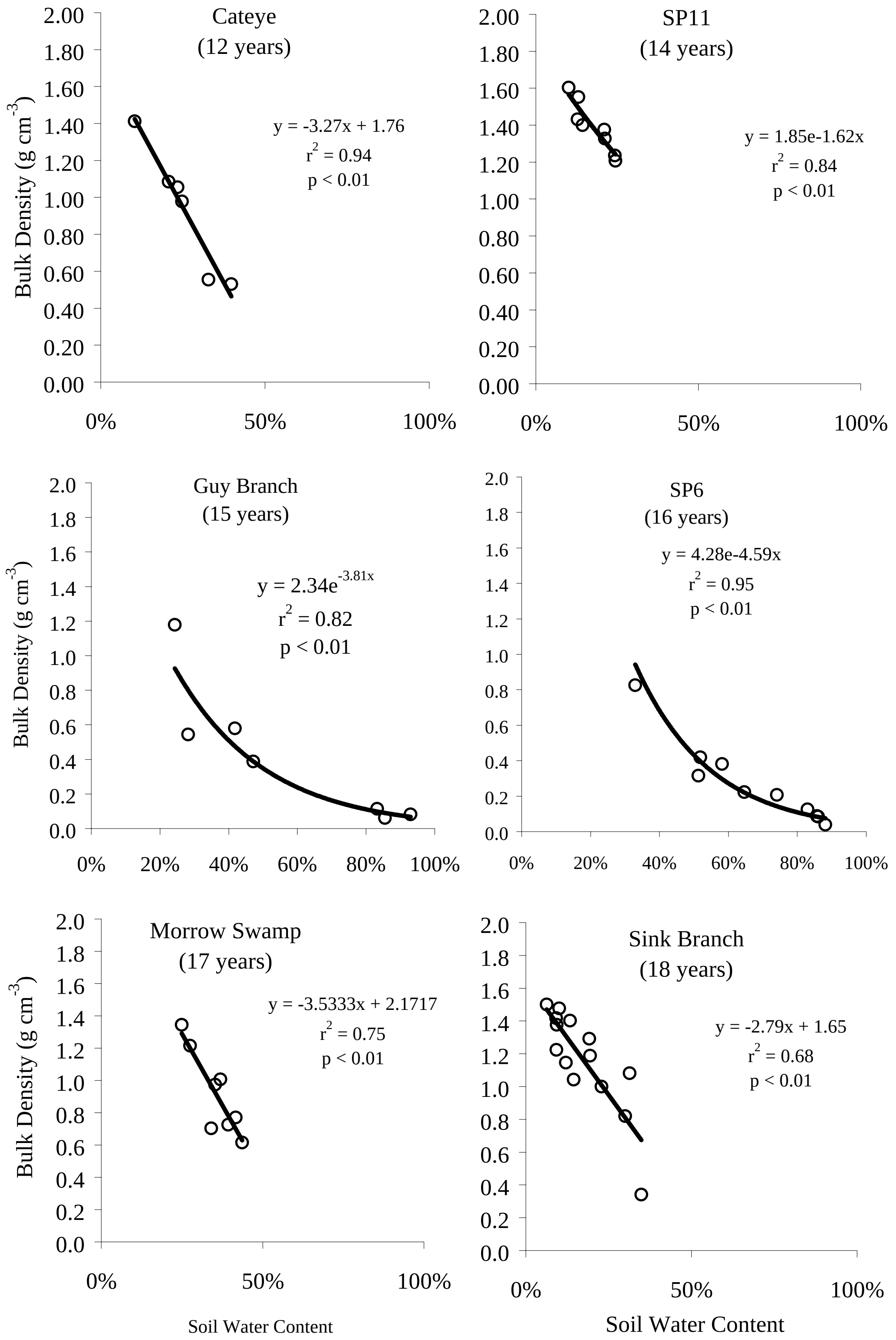


Figure 7.13 (Cont.) **The Relationship Between Soil Water Content and Bulk Density in a Chrono-Sequence of Constructed Forested Wetlands. Sites Are Presented in Chronological Order.**

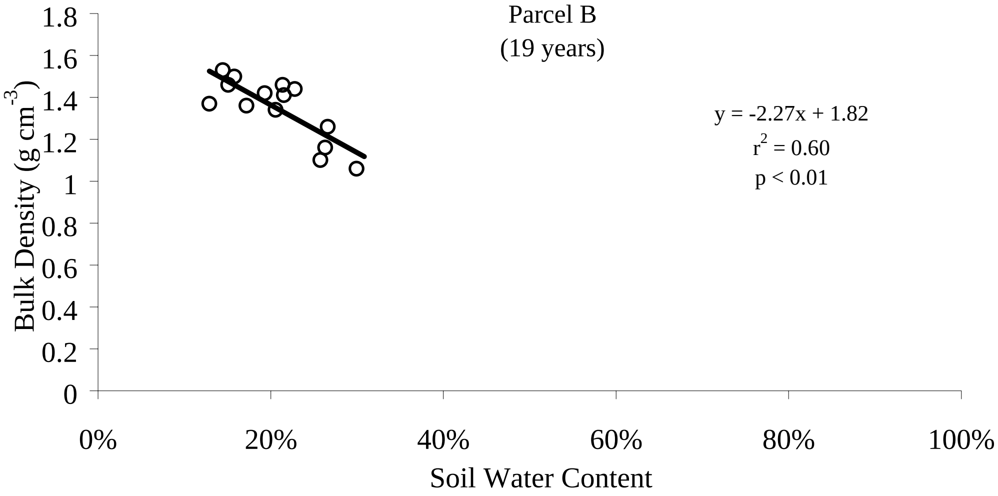


Figure 7.13 (Cont.) **The Relationship Between Soil Water Content and Bulk Density in a Chrono-Sequence of Constructed Forested Wetlands. Sites Are Presented in Chronological Order.**

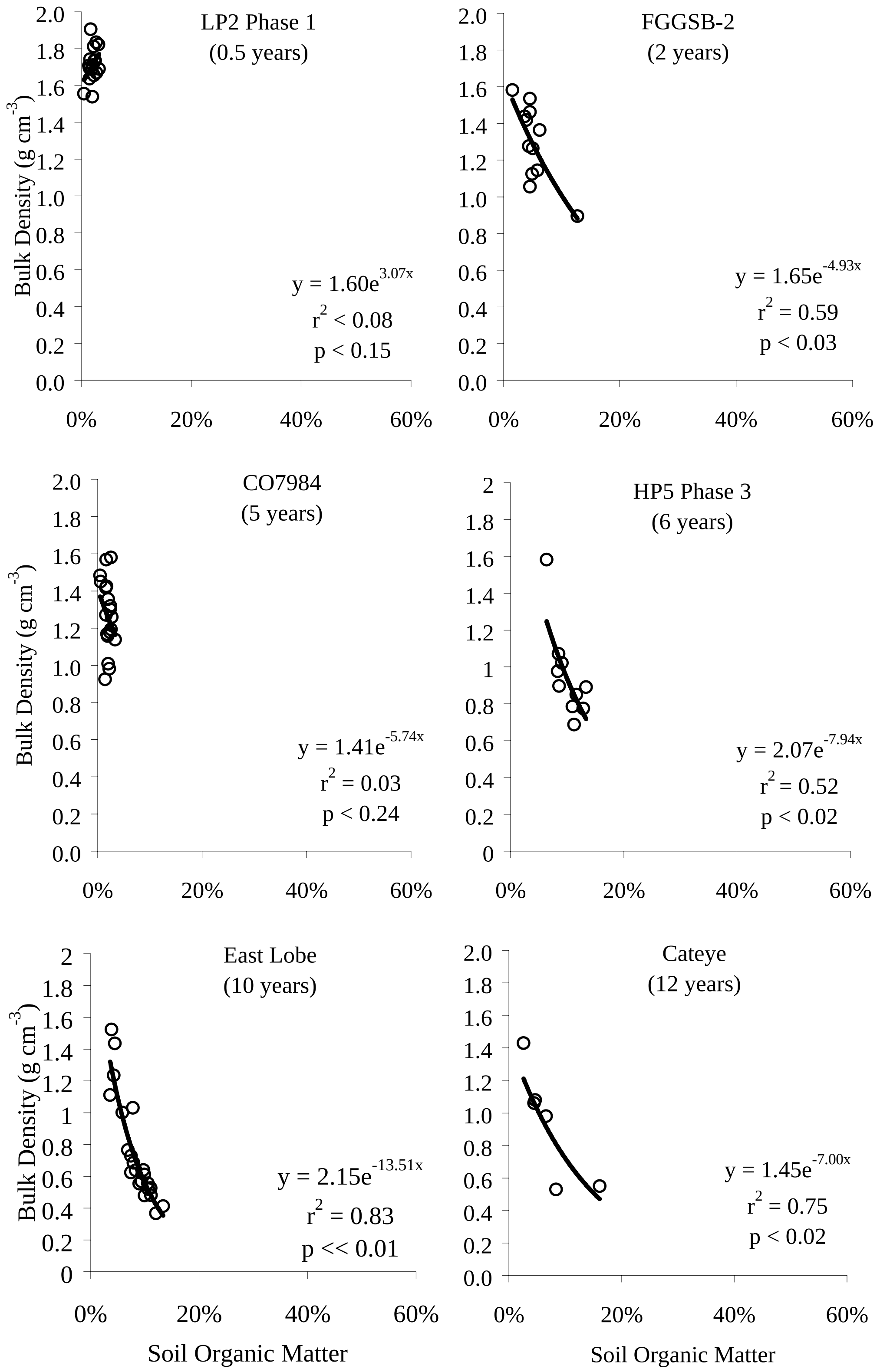


Figure 7.14. The Relationship Between Soil Organic Matter and Bulk Density in a Chrono-Sequence of Constructed Forested Wetlands. Sites Are Presented in Chronological Order.

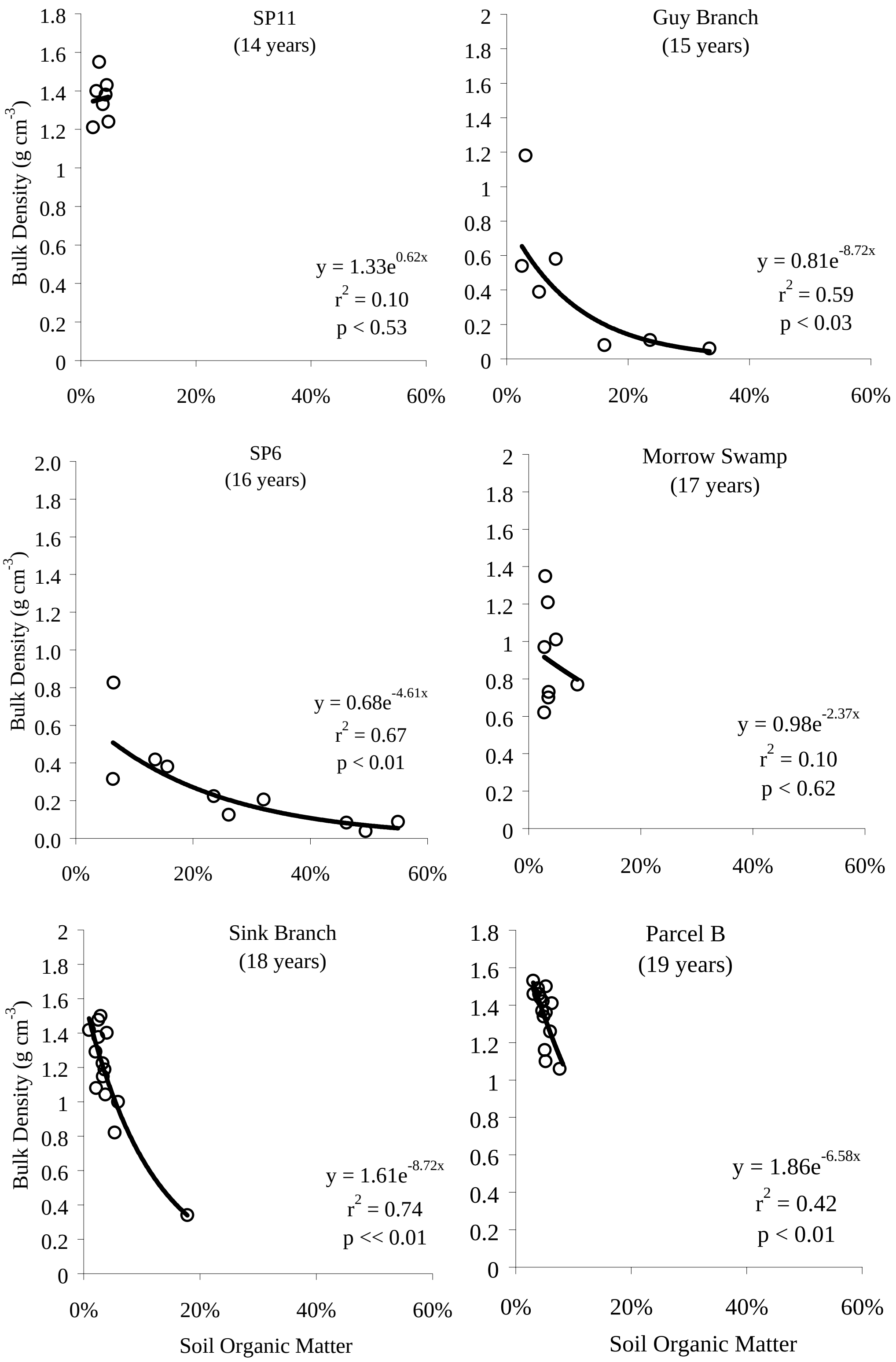


Figure 7.14 (Cont.) The Relationship Between Soil Organic Matter and Bulk Density in a Chrono-Sequence of Constructed Forested Wetlands. Sites Are Presented in Chronological Order.

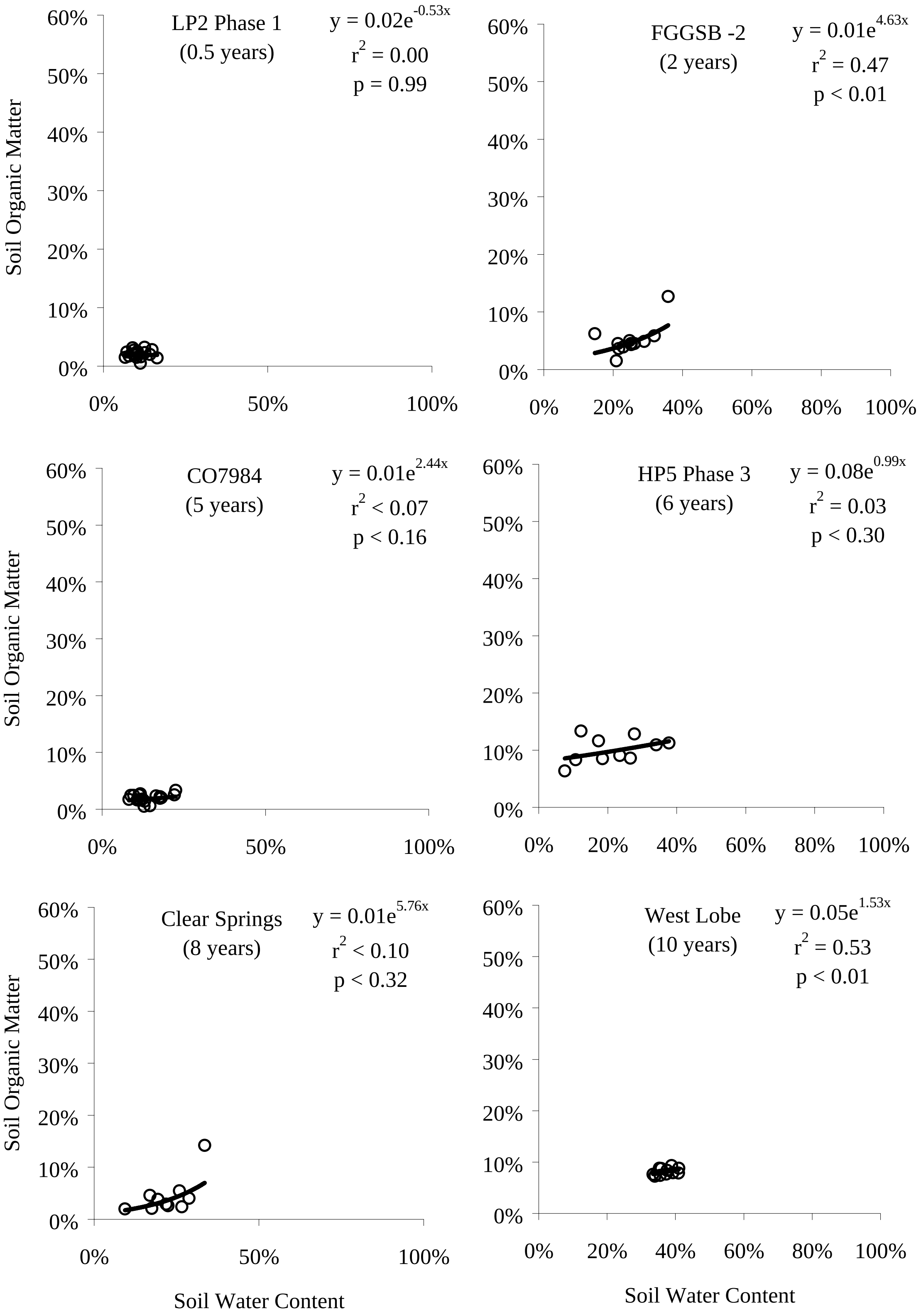


Figure 7.15. The Relationship Between Soil Water Content and Organic Matter in a Chrono-Sequence of Constructed Forested Wetlands. Sites Are Presented in Chronological Order.

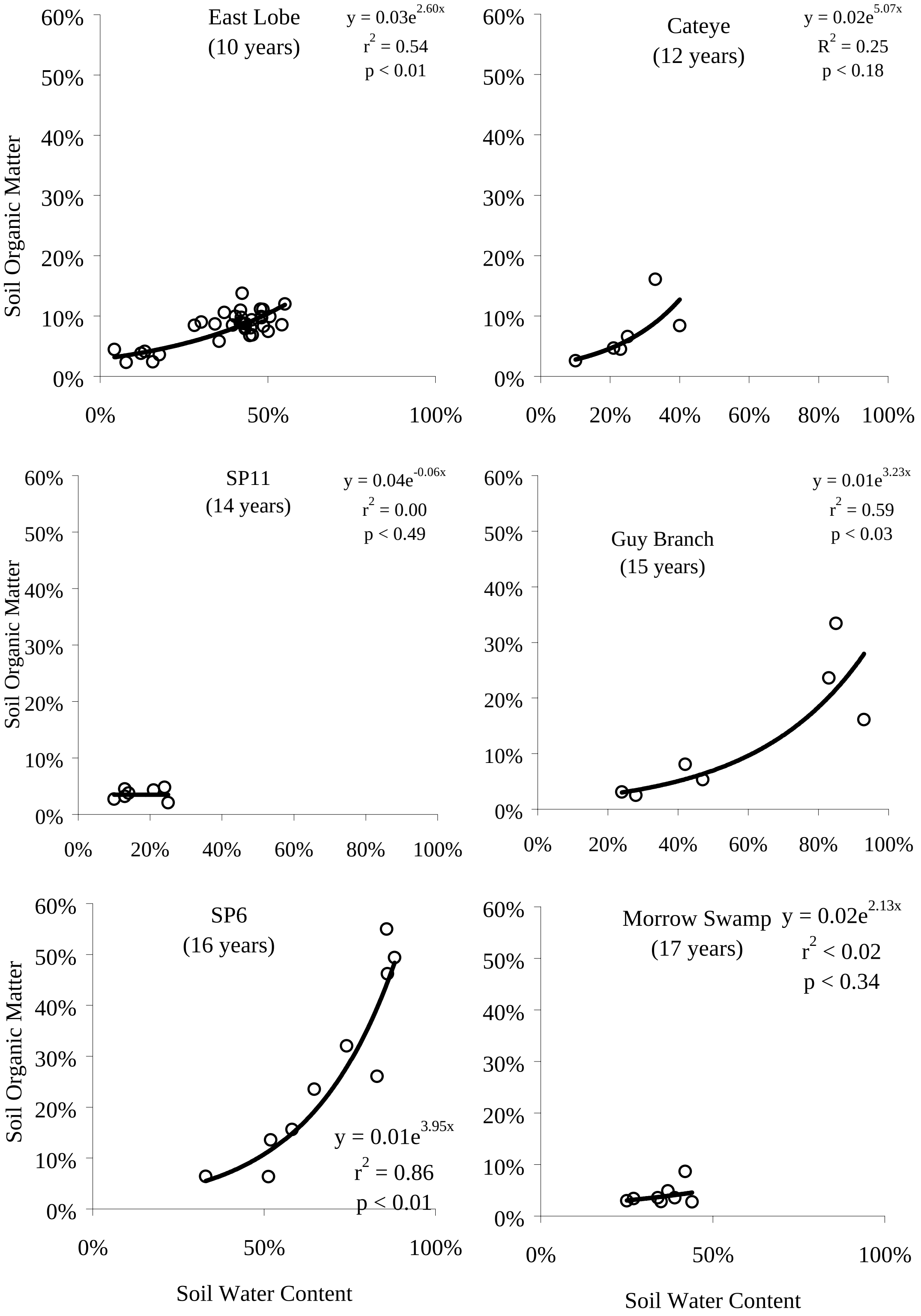


Figure 7.15 (Cont.) **The Relationship Between Soil Water Content and Organic Matter in a Chrono-Sequence of Constructed Forested Wetlands. Sites Are Presented in Chronological Order.**

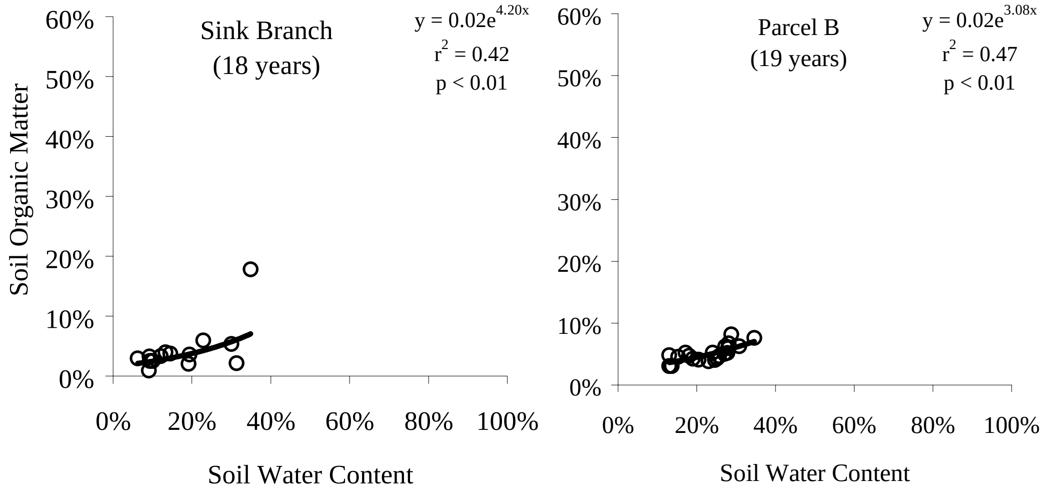


Figure 7.15 (Cont.) The Relationship Between Soil Water Content and Organic Matter in a Chrono-Sequence of Constructed Forested Wetlands. Sites Are Presented in Chronological Order.

SUCCESSIONAL TRAJECTORIES OF CONSTRUCTED FORESTED WETLANDS

Canopy Trajectories

Figure 7.16 shows three successional trajectories of canopy tree species based on ten to fourteen site averages. Figure 7.16a suggests that 83 % of the variation in tree height is explained by age ($r^2 = 0.83$; $p < 0.01$), leaving only 17 % of the variation in height to be explained by other site factors. Sixty-four percent of the variation in tree dbh is explained by age ($r^2 = 0.61$ $p < 0.01$). The other 39% is explained by other site variables (Figure 7.16b). The successional trajectory depicted in Figure 7.16c shows 85 % of the variation in canopy cover is explained by age ($r^2 = 0.85$; $p < 0.01$).

Subcanopy Trajectories

There are no trends associated with the subcanopy structure component of the research sites (Figure 7.17). The data may suggest slightly greater species richness, stem density and stem diameter of late successional subcanopy species in the youngest and oldest sites. This trend in older sites may be attributed to age and recruitment. The occurrence of these species in younger sites is a result of planting.

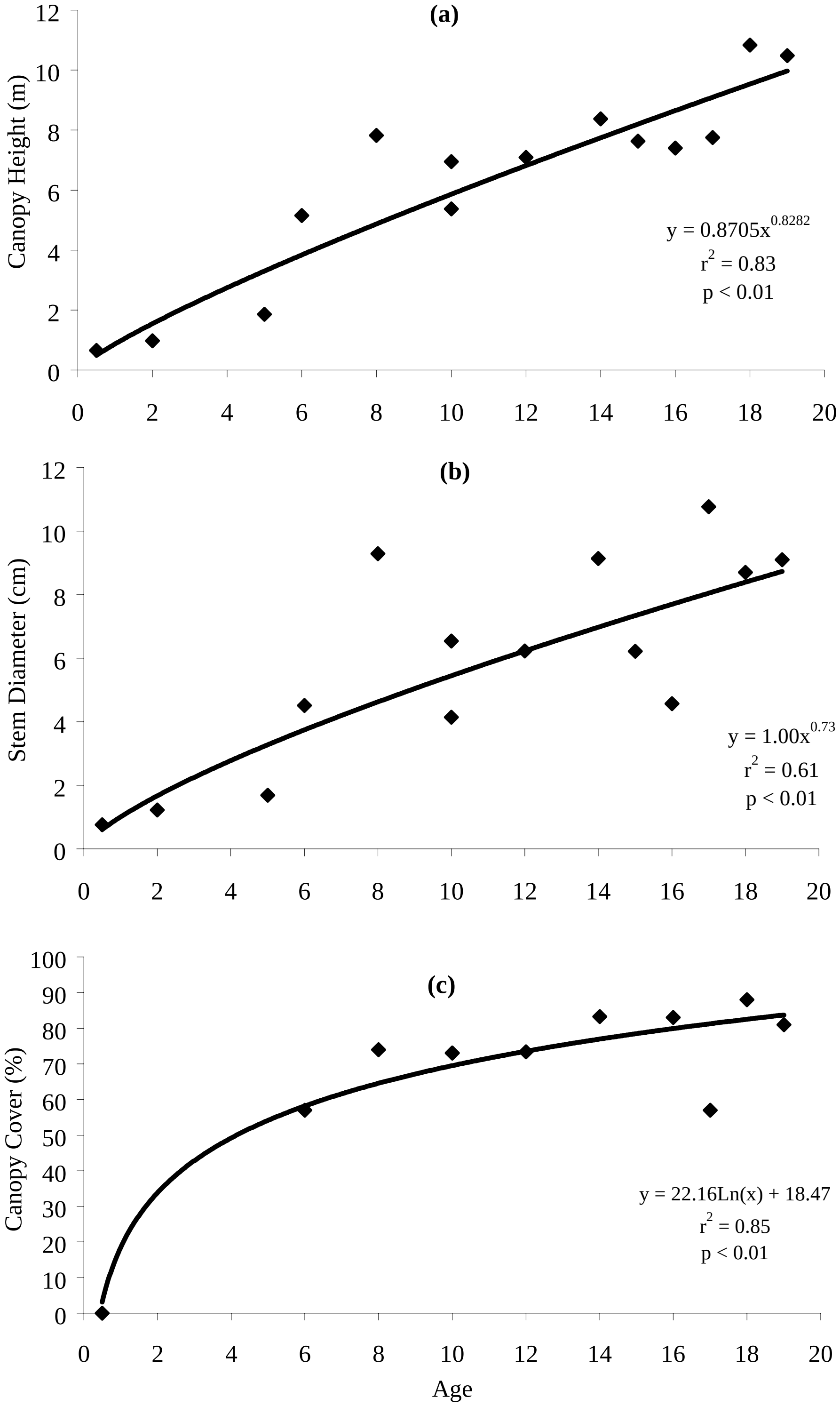


Figure 7.16. Canopy Tree Trajectories in Constructed Forested Wetlands: (a) Power Regression on Tree Height, (b) Power Regression on Tree Diameter, and (c) Logarithmic Regression on Canopy Cover.

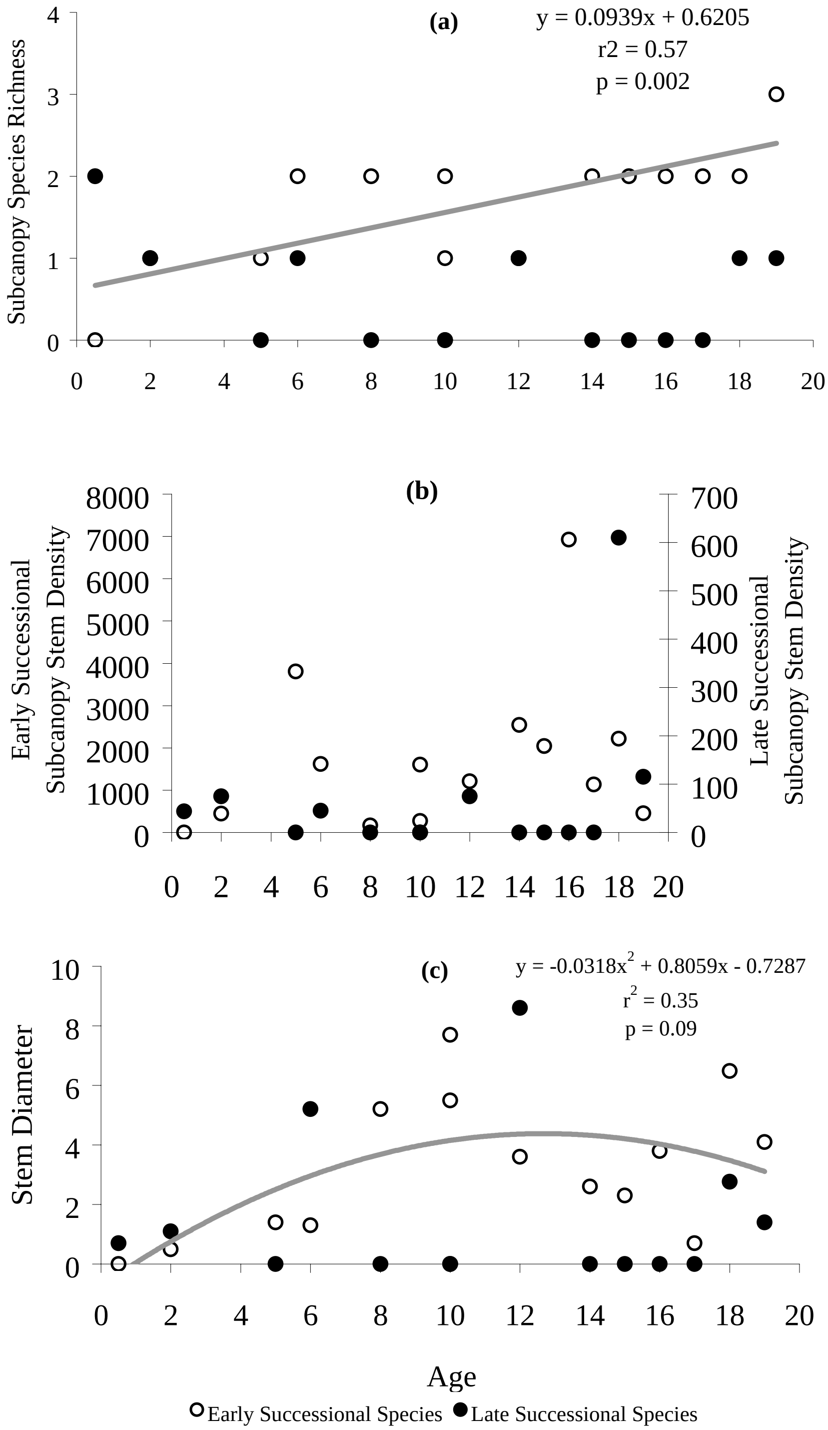


Figure 7.17. Subcanopy Tree Trajectories in a Chrono-Sequence of Constructed Forested Wetlands: (a) Species Richness Including Early and Late Successional Species, (b) Subcanopy Species Stem Density, (c) Subcanopy Stem Diameter.

Shrub Trajectories

There are no trends with time associated with the shrub structure (Figure 7.18) of constructed wetland research sites. There appears to be a peak in stem diameter of early successional species around 8-10 years.

Understory Trajectories

There is a significant trend ($p < 0.05$) in herbaceous species richness (Figure 7.19a); however time explains only 29% of the variation. There are no trends with time associated with richness, diversity or cover (Figure 7.19b, 7.19c and 7.19d) of combined understory species.

Species richness (Figure 7.20a) of seedlings of canopy tree species showed an increasing trend with age ($r^2 = 0.45$; $p < 0.01$). Species richness of subcanopy trees (Figure 7.20b) differed very little between sites. Shrub seedlings showed no trends in species richness (Figure 7.20c) with time. Vine species richness (Figure 7.20d) showed a weak trend of increasing with age ($r^2 = 0.38$; $p < 0.01$).

Frequency of occurrence of canopy tree species showed a weak trend with time (Figure 7.21a). Canopy species frequency of occurrence increased with time ($r^2 = 0.42$; $p < 0.01$). The frequency of occurrence of vines (Figure 7.21b) also increased with time ($r^2 = 0.31$; $p < 0.02$). There was a weak trend in the frequency of occurrence of early successional subcanopy species (Figure 7.21c). Early successional subcanopy species increased with age, showing a peak in frequency around age ten and then declining. Shrub seedlings showed no trends with time in frequency of occurrence (Figure 7.21d).

Soil Trajectories

The only soil parameter to show a trend with time was bulk density. Figure 7.22b shows that about 35% of the variation in bulk density can be explained by age ($r^2 = 0.35$, $p = 0.05$).

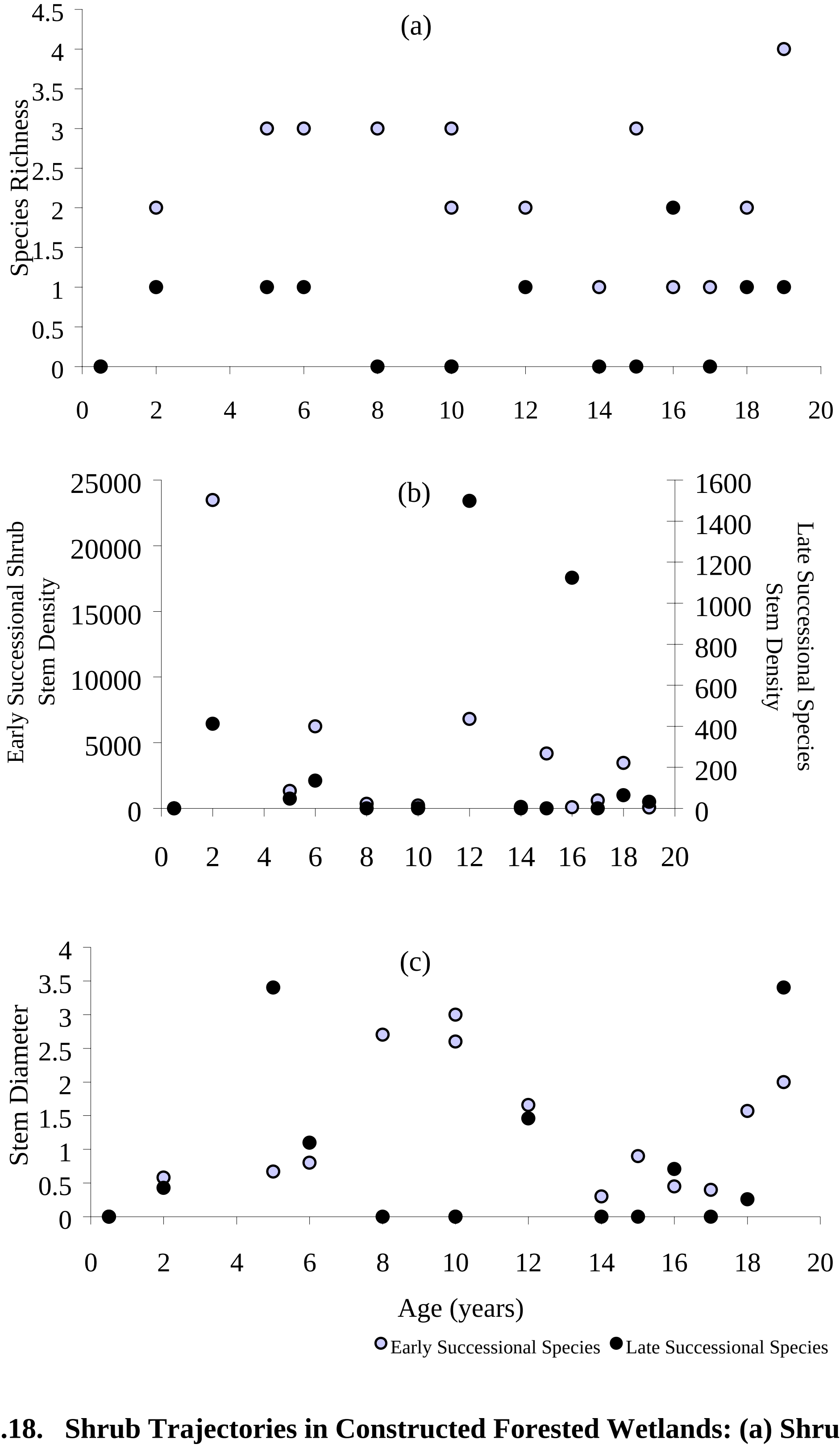


Figure 7.18. **Shrub Trajectories in Constructed Forested Wetlands: (a) Shrub Species Richness, (b) Shrub Stem Density, and (c) Stem Diameter.**

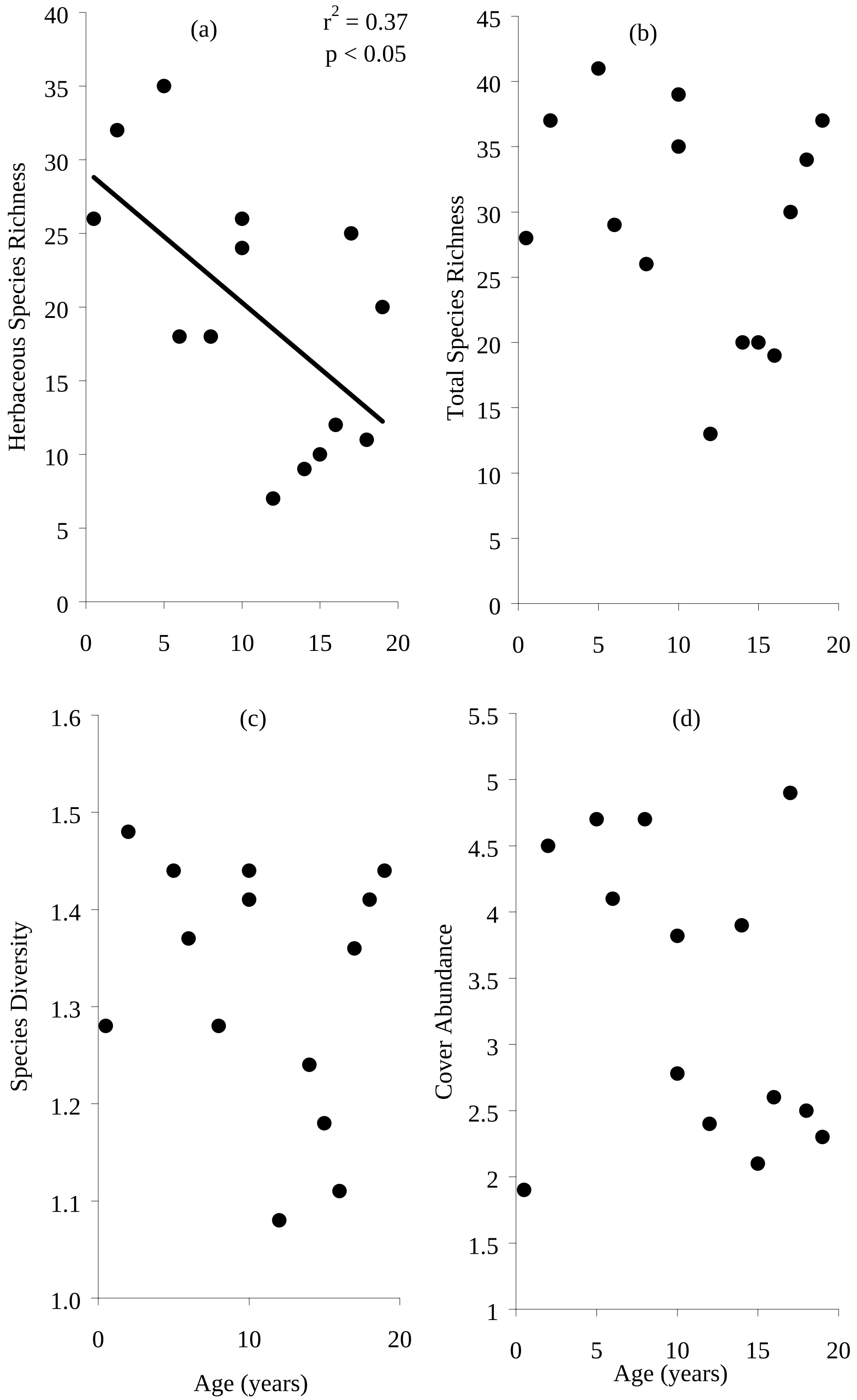


Figure 7.19. **Understory Trajectories in Constructed Forested Wetlands: (a) Herbaceous Species Richness, (b) Species Richness of All Herbaceous and Woody Species, (c) Species Diversity, and (d) Cover Abundance.**

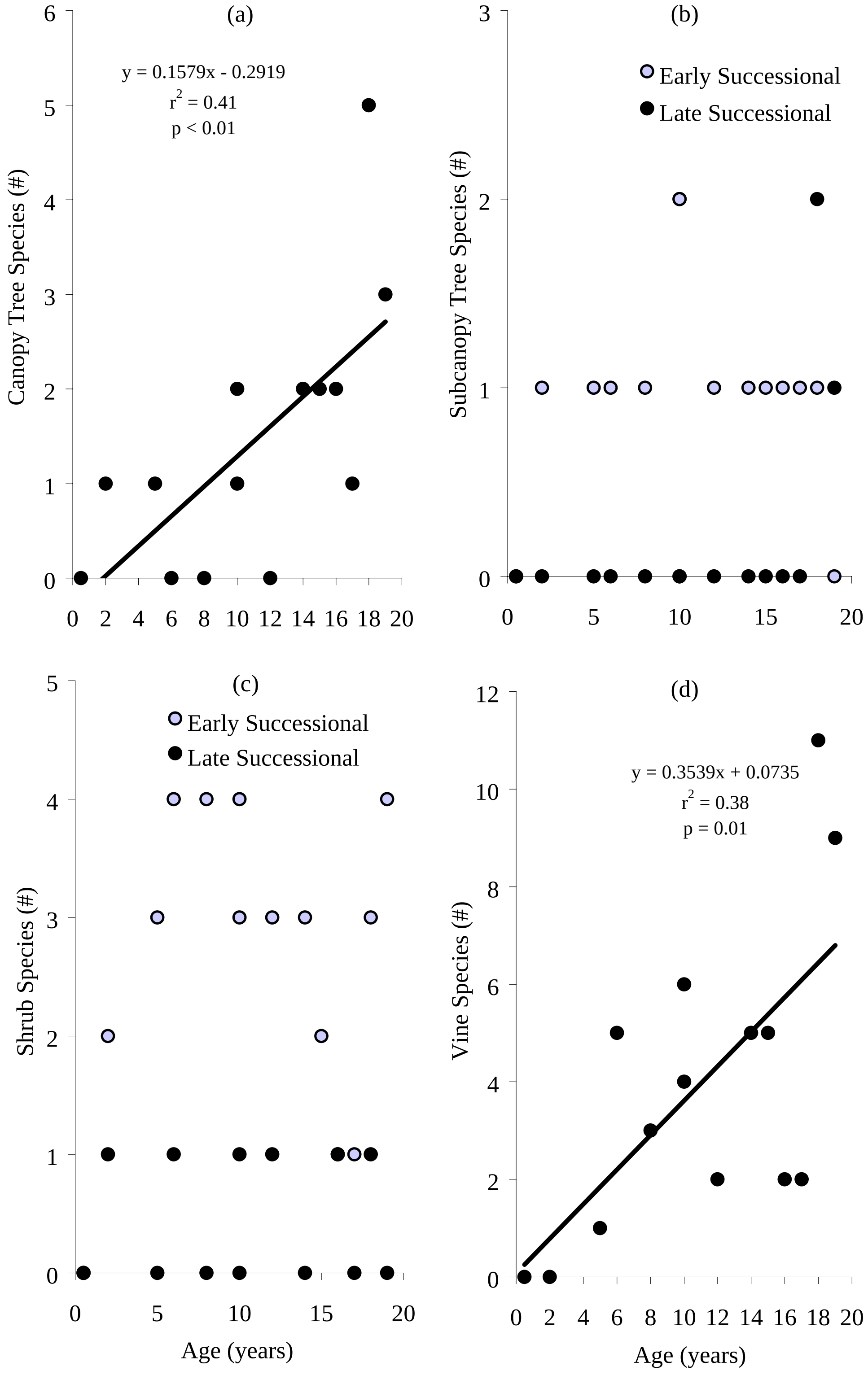


Figure 7.20. Understory Trajectories in Constructed Forested Wetlands (a) Canopy Tree Species Richness, (b) Subcanopy Tree Species Richness, (c) Shrub Species Richness, and (d) Vine Species Richness Plotted Against Site Age.

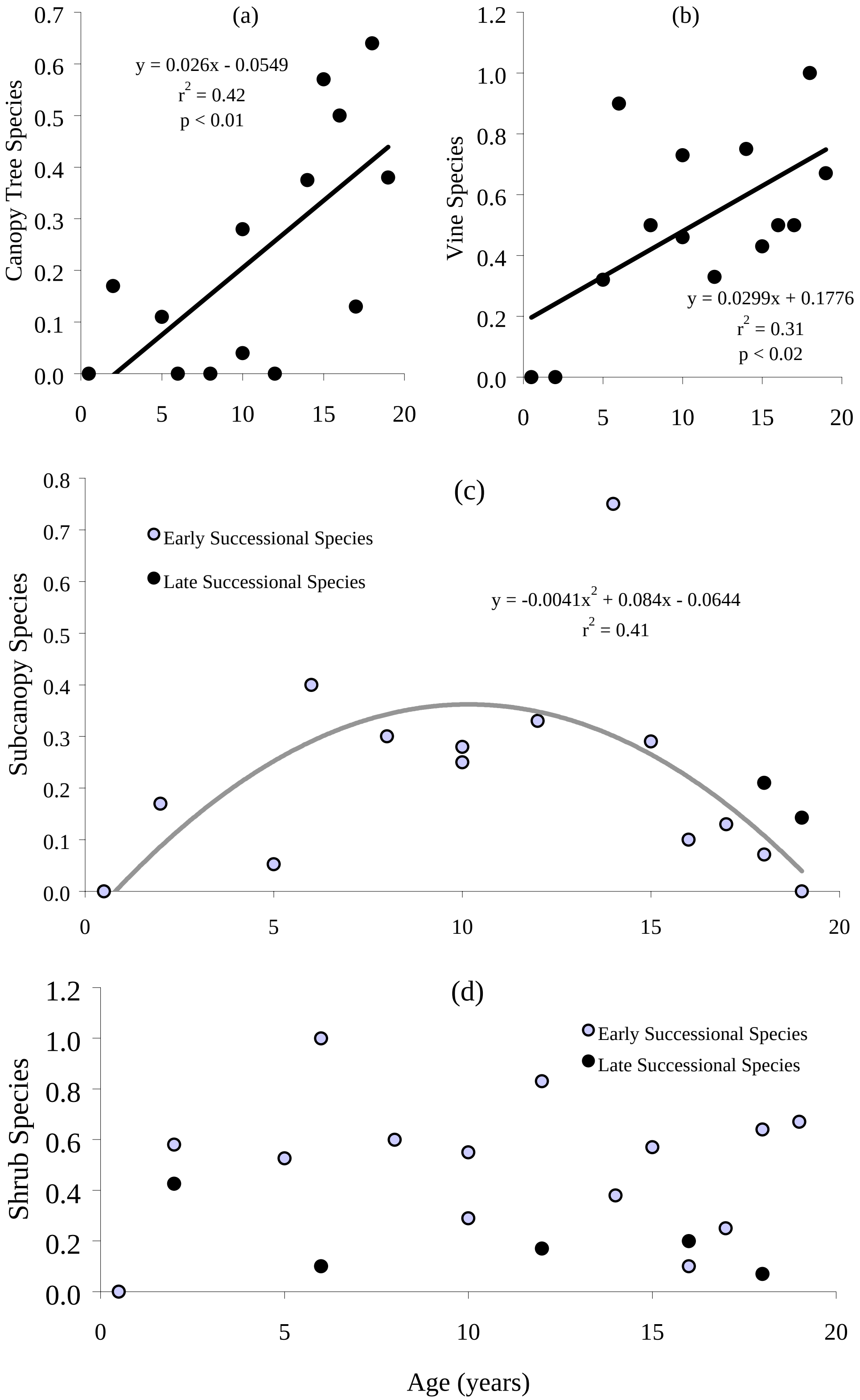


Figure 7.21. **Frequency of Occurrence of (a) Canopy Tree Seedlings, (b) Vines, (c) Subcanopy Species, and (d) Shrub Species in the Understory of Constructed Forested Wetlands.**

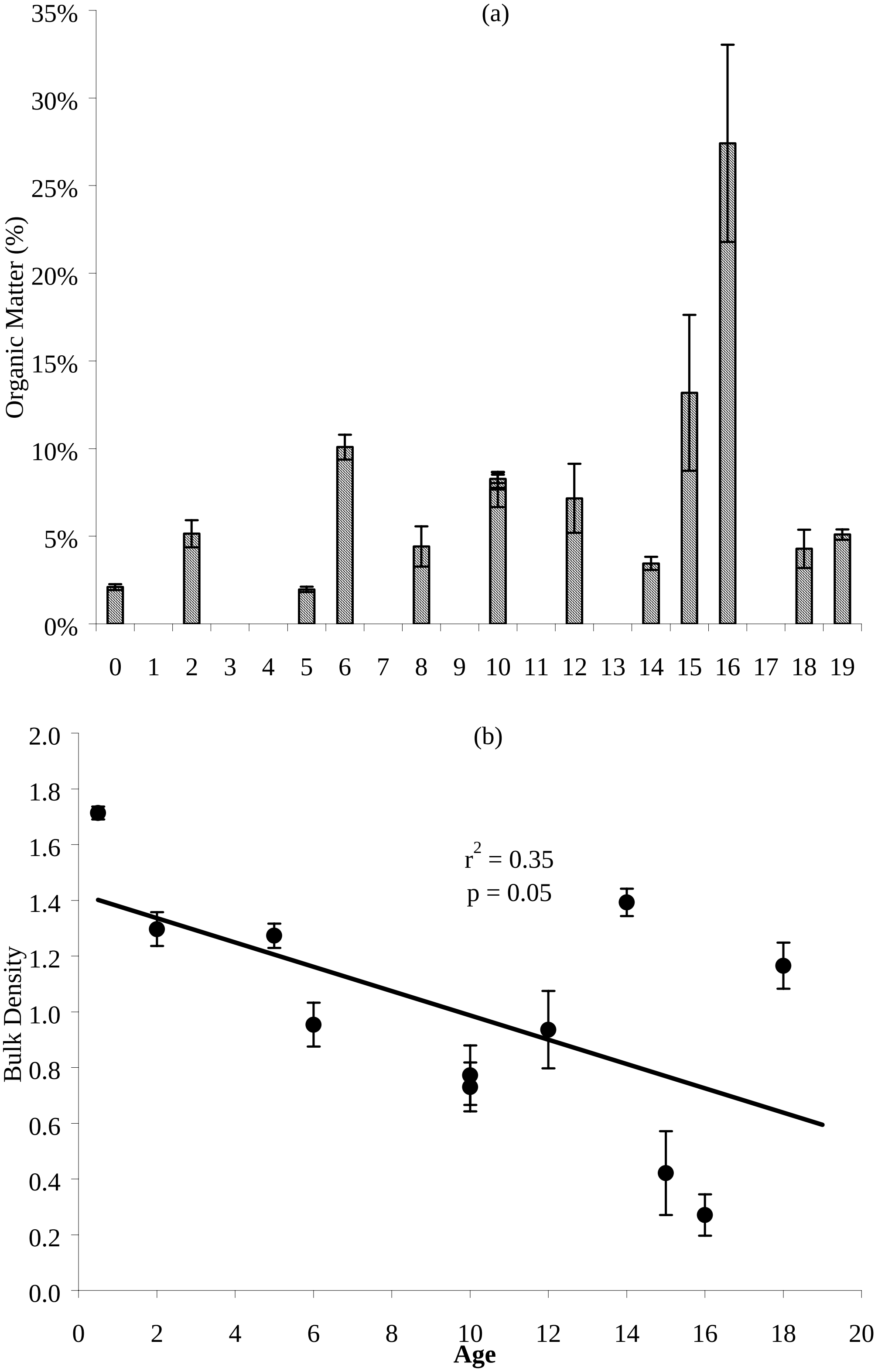


Figure 7.22. Average (a) Soil Organic Matter and (b) Bulk Density Plotted by Site Age.

DISCUSSION

In this report, measurements of selected biotic and abiotic parameters were conducted on constructed forested wetlands to answer the question, “Do development of constructed forested wetland ecosystems result in measurable successional trajectories?”

- Field measurements documenting the results of self-organization of constructed wetlands suggest that the developing ecosystems represented by the chronosequence of research sites are quite different in several respects, but that time alone is not responsible for the differences.
- Successional trajectories with time for only a few individual parameters are apparent, but the successional trajectory of an ecosystem may not be discernible from trajectories of individual components.
- Successional trajectories may be far more complex than a simple parameter trajectory and may only be observable as changes in emerging properties resulting from interactions among ecosystem components.

CHRONOSEQUENCE OF CONSTRUCTED FORESTED WETLANDS

Canopy Tree Species

The self-organization of many aspects of the canopy tree component of constructed forested wetlands on phosphate mined lands is initially more dependent on human intervention than natural processes. Species richness is more a factor of the number of species planted during the construction process than of recruitment of species from natural areas. When comparing species richness of constructed forested wetlands with that of natural wetlands, the number of dominant species are similar. Sharitz and Mitsch (1993) provide a list of dominant species for a variety of bottomland hardwood swamps in the Southeast. Species richness ranged from one dominant species in cypress swamps to three dominant species in several other forest types. When including not only dominant tree species but also major associates, only three research sites match the species richness of natural systems (10-12 species). Davis and others (1991) report species richness in cypress domes, bayheads and hardwood swamps of Florida as 7.2, 6.8 and 13.5, respectively. Species richness in constructed forested wetlands ranged from 2 to 12 species.

Davis and others (1991) provides the frequency of occurrence of dominant species in Florida wetlands. Frequency of occurrence in their study was considered as the number of transects on which a species occurred divided by the total number of transects. Figure 7.23a shows the frequency of occurrence of canopy tree species in three types of natural forested wetlands in Florida. Table 7.14 provides the species codes for Figure 7.23. The six dominant species found in constructed forested wetlands were selected for comparison, and their frequencies in natural Florida wetlands are depicted in

Table 7.14. Species Codes for Canopy and Subcanopy Species Found in Natural Wetland Communities in Florida.

Species Name	Species Code
Acer rubrum	AR
Gordonia lasianthus	GL
Ilex cassine	IC
Liquidambar styraciflua	LS
Myrica cerifera	MC
Magnolia virginiana	MV
Nyssa sylvatica var. biflora	NSB
Persea palustris	PEP
Pinus palustris	PP
Pinus elliottii	PE
Quercus laurifolia	QLA
Quercus nigra	QN
Quercus virginiana	QV
Taxodium ascendens	TA
Taxodium distichum	TD
Ulmus americana	UA

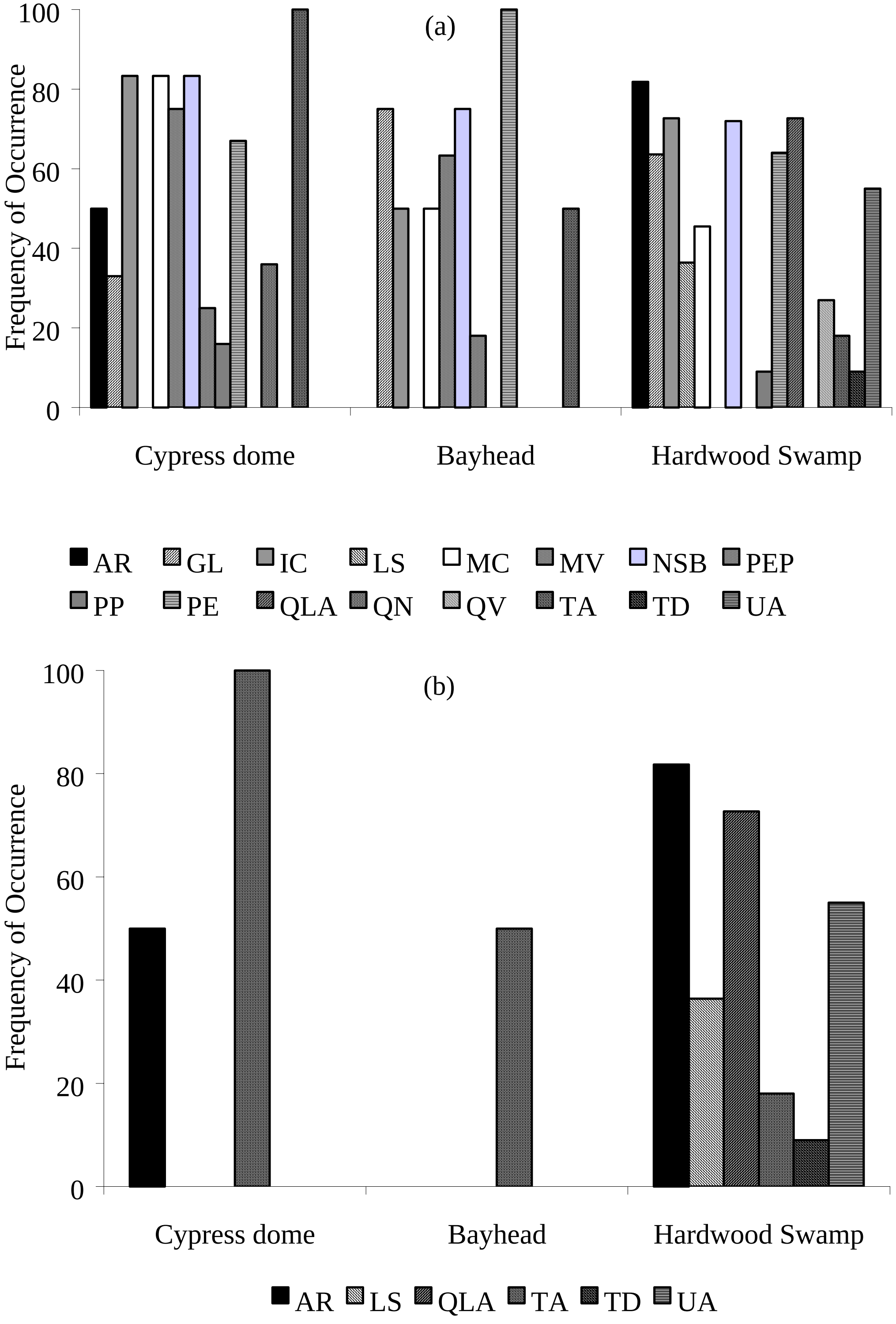


Figure 7.23. Frequency of Occurrence of Canopy Tree Species in Florida's Wetland Communities: (a) All Dominant Species (from Davis and others 1991) and (b) Only Those Species Occurring in Both Natural and Constructed Communities. See Table 17 for Species Code.

Figure 7.23b. Figure 7.24 provides the relative frequency of these six species in each of the sites in the chronosequence of constructed forested wetlands. The methods of determining frequency in this study result in relative frequency, number of individuals of a species divided by the total number of species. These methods may not be comparable, so direct comparisons are considered tentatively. It is suggested, however, that tracking of species dominance within a constructed wetland with time may elucidate the direction of self-organization processes occurring within a wetland. Species may sort themselves by environmental variables that reflect past and current site conditions.

As with species richness, canopy tree density is at least initially dependent more on humans than recruitment from natural areas. Davis and others (1991) reported densities of trees greater than 5 cm from 1183-1809 trees ha^{-1}. Cypress domes had the highest densities followed by hardwood swamps and bayheads. Constructed forested wetlands had tree densities (>5 cm) from 0-1102 trees ha^{-1}. The eight-year-old site was the youngest to reach the densities of natural systems, while two ten-year-old sites and a sixteen-year-old site failed to achieve those densities. A fire in the sixteen-year-old site may explain low densities in this site, and the low planting densities during construction may explain the low density in the ten-year-old sites.

Shannon-Weaver canopy tree diversities for natural wetlands range from 1.08 to 2.07 (Davis and others 1991). Diversity of constructed forested wetlands in this study ranged from 0 to 0.85. Species richness and diversity of canopy tree species in constructed forested wetlands begins to approach that of natural systems but only in a few of the richest and most diverse sites.

Tree height, diameter at breast height and canopy cover are easily measured parameters, and the variability in these parameters may be useful in assessing success, but they provide little insight into the organization of the constructed wetland as a viable system. Results of this study suggest that 83% of the variation in tree height is explained by age, while only 61% of the variation in diameter at breast height is explained by age. Variation in driving energies (environmental variation) associated with the site and the resulting probability that a site has been created that can maintain a self sustaining forested wetland may be more apparent from evaluating aspects of tree diameter at breast height rather height or canopy cover since a greater percentage of the variation in dbh and canopy cover is explained by some factor other than age.

Frequency distributions of tree diameter at breast exhibit a hierarchical pattern in natural systems with many smaller trees and few larger trees (Odum 1983). Odum (1983) presents a size class distribution pattern typical of an even aged stage that slowly moves up the size classes with age. In agroforestry, this represents a cohort of trees established by planting at one time. This pattern of size class distribution also occurs in nature. It can result from a stochastic event such as fire in a pineland or drawdown in a cypress dome creating a period for recruitment and may be typical of specific species of trees.

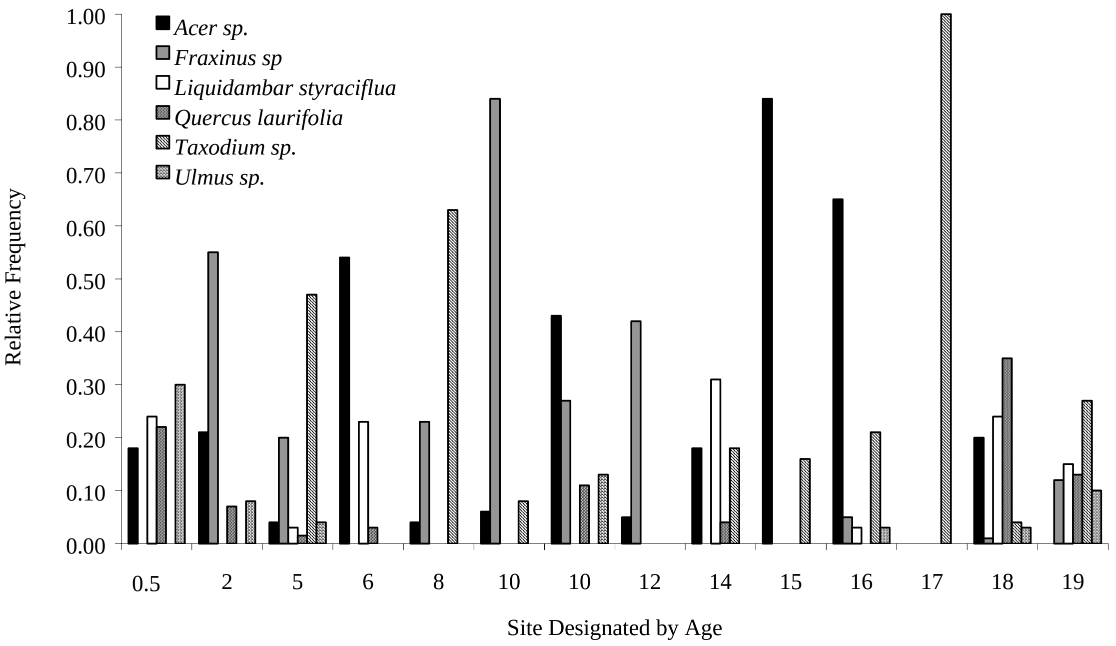


Figure 7.24. Relative Frequency of Canopy Tree Species in Constructed Forested Wetlands. The Graph Includes Only Those Species Found in Natural and Constructed Wetlands.

The results of this study support the existence of a hierarchical pattern of tree size class distribution in constructed forested wetlands, and this distribution appears to change with time. When all tree species are lumped together, the system as a whole exhibits this hierarchical pattern. This hierarchical distribution can be explained by recruitment into the smallest size class and differential growth and survival rates, which result in only a portion of the individuals within a size class entering the next larger size class with time. SP6 and Morrow Swamp are the only sites that deviate from this distribution. A fire occurring in SP6 may have killed a sizable number of trees in each of the larger size classes. The large number of trees in the small size class results from recruitment after the fire and/or supplemental planting. Morrow Swamp also shows a unique size class distribution reflecting the presence of only one species, which exhibits the distribution of an even age stand.

Size class distributions of individual species show a variety of patterns. *Acer sp.* has a hierarchical distribution in many sites where it occurs, regardless of age. This suggests that the recruitment of *Acer sp.* is an ongoing occurrence and that stochastic events or environmental conditions that inhibit recruitment have not occurred. In two sites, *Acer sp.* occurs in only the smallest size class. This could result from relatively recent recruitment or site conditions that are not suitable for growth and survival. *Taxodium sp.*, on the other hand, does not demonstrate a hierarchical distribution, but rather resembles a cohort of trees established at one time moving up through the size classes. *Taxodium sp.* may depend on a drawdown of water levels for germination and seedling establishment. Therefore, this type of distribution may be expected in natural systems experiencing infrequent drawdowns. The majority of constructed wetlands in this study have, as yet, not demonstrated recruitment of a new cohort of *Taxodium* sp. saplings. Only in Parcel B is the probability of sampling *Taxodium sp.* in the smallest size class equal to that of larger size classes. Limited regeneration may be occurring at Parcel B and explain this variation in size class distribution. Regeneration may be occurring at Parcel B, and not at other sites, for at least two reasons. First, a hydrological drawdown may have occurred to facilitate germination and establishment or the hydrology at this site may not be interacting with *Taxodium sp.* and limiting germination and establishment. If regeneration is not occurring, then this skewed distribution could be explained by slow growth rates in a greater than expected portion of the population.

Fraxinus caroliniana demonstrated a hierarchical size class distribution in all study sites where it was present except for one. At this one site, the size class resembles that of an even aged stand. In a previous study (Miller 1983) of natural wetlands impacted by adjacent mining activity, size class distributions of *Fraxinus caroliniana* resembled that of an even aged stand.

Tree basal area measured at breast height or above the buttressing of wetland species appears to reflect the environmental variability within a site, and community basal area integrates information about tree size class distributions. For these reasons, greater information about the self-organization of constructed forested wetlands may be available from the evaluation of community basal area (m^2 ha^{-1}) than from diameter at breast height of individual trees. Community basal area of trees greater than 5 cm in diameter at breast height in Florida wetlands range from 27.68 m^2 ha^{-1} in bayheads to 38.89 m^2 ha^{-1} in hardwood swamps (Davis 1991). Community basal area in this study ranged from 0 to 9 m^2 ha^{-1}. In these sites, tree height and canopy cover may reflect values typical of natural wetlands; the community basal area of trees is not yet indicative of natural wetlands.

Subcanopy Tree Species

The subcanopy component of constructed forested wetlands in this study are still dominated by *Myrica* sp and *Salix* sp. *Myrica* sp. is considered a subcanopy or shrub component of natural forested wetlands. Frequency of occurrence of *Myrica* sp. is high in cypress domes (83%), but its importance value is low relative to other subcanopy species (Davis and others 1991). Both, the frequency and importance value of *Myrica* sp are lower in bayheads and hardwood swamps (Davis and others 1991).

Relative frequency of *Myrica sp.*and *Salix sp.* in constructed forested wetlands ranged from 0.03-0.94 and 0.15-1.0, respectively. The data suggest that *Salix* sp. is more likely to dominate the subcanopy component in younger sites, while *Myrica* sp. dominates in older sites. The transition in dominance occurs around 10-12 years.

Stem density for *Myrica* sp. was reported as 400, 200 and 800 stems ha^{-1} in cypress domes, bayheads and hardwood swamps, respectively (Davis and others 1991). This study found stem densities ranging from 420 to over 10,000 stems ha^{-1}. The relatively large number of stems reported in this study may result from data collection methods. Each stem reaching above 1m was counted and measured regardless of origin. Therefore, the growth architecture of *Myrica* sp. and *Salix* sp. results in multiple stems and does not represent the number of individual plants. The definition of a stem is not clearly stated in other studies. Regardless of methodology, *Myrica* sp. is a component of natural and constructed forested wetlands.

Clearly, there is a lack of species richness in the subcanopy component of constructed forested wetlands. Perhaps *Myrica* sp. and *Salix* sp. are able to out compete other subcanopy species until community basal area (and the corresponding increase in below-ground competition), and lower light levels accompanying canopy closure create conditions where other subcanopy species have a competitive advantage.

Shrub Species

Shrub species are a component of most wetland systems including marshes, where they are often relegated to the ecotones between wetland and upland. Davis and others (1991) reported that the number of shrub species found in Florida wetland communities ranged from 13 species in bayheads and 19 species of shrubs in marshes and cypress domes, to over 30 species of shrubs in hardwood swamps. However, a list of the ten most common shrubs provided by Davis and others (1991) included *Myrica* sp., which in this study is considered a subcanopy tree, and several vine species, which are treated separately from shrubs in this study. Even when including *Myrica* sp. and vines in the total number of shrubs found in constructed forested wetlands in this study, there were considerably fewer (0-15) shrub species than in hardwood swamps. This is only half the species richness of hardwood swamps. Of the four most common shrubs occurring in natural wetlands (Davis and others 1991) that were also considered shrubs in this study only *Cephalanthus occidentalis* and *Vaccinium* sp. occurred in both natural and constructed sites. In sites where these species occurred, they were included in planting during construction or were part of supplement planting after establishment of the canopy. There is evidence of recruitment of shrubs, considered desirable by regulatory agencies, in only a few older sites.

Understory Species

Understory species include all structural categories, but will be discussed by individual category for clarity and comparisons. Herbaceous species richness ranged from 7-35, with the greatest number of herbaceous species found in the younger sites. Herbaceous species richness in constructed forested wetlands although similar to that of bayheads (26 species) falls short of that reported for marshes (157), cypress domes (74) and hardwood swamps (111) (Davis and others 1991). In light of the differences in species richness between natural marshes and each of the natural forested wetland types, it is not surprising that the herbaceous species richness of constructed wetlands shows a decreasing trend with age. Young constructed forested wetlands bear a closer resemblance to marshes than forests and have greater herbaceous richness during early marsh-like conditions with decreasing richness as they begin to resemble a forest.

Evaluating the occurrence of vegetation from structural categories other than herbaceous can be valuable. The potential for future shifts in species dominance may be reflected in species establishment in the understory. Figure 7.25a shows the frequency of occurrence of canopy tree species in the understory of constructed forested wetlands. Although canopy tree seedlings occur throughout the age-range; the two, five and ten year old sites are located immediately adjacent to an unmined floodplain forest. Seedlings in the two-year-old and five-year-old sites result from recruitment from the adjacent forest since there are no mature trees in either site or they may have resulted from supplemental planting.

The occurrence of subcanopy tree seedling other than *Myrica* sp. and *Salix* sp. is rare except in the two oldest sites (Figure 7.25). There appears to be a shift from recruitment of *Salix sp*. to *Myrica sp*. between 8 and 12 years. Prior to 8 years, canopy cover is less than 50%, resulting in light transmittance conditions, which may be more conducive to *Salix sp*. Between 8 and 10 years, average canopy cover is slightly less than 75%, and both *Salix sp*. and *Myrica sp*. are recruited. After 12 years, canopy cover has exceeded 80% and *Myrica sp*. appears to be favored. The only apparent exception to this trend with age is the 17-year-old site, but with only 57% canopy cover, this site still provides conditions favoring *Salix sp.*

Early successional shrub species continue to be recruited in the understory of constructed wetlands of all ages. Only two late successional species occurred in the understory, *Cephalanthus occidentalis* and *Itea virginica*. *C. occidentalis* occurred in 36% of the sites, while *I. virginica* occurred in only one.

Figure 7.26a provides the frequency of occurrence of *Parthenocissus quinquefolia*, *Smilax* sp. *Toxicodendron radicans*, and *Vitis rotundifolia* in natural ecosystems in Florida (Davis and others 1991). Frequency of occurrence represents the fraction of the total number of transects sampled in which each species occurred. Figure 57b shows the frequency of occurrence, the fraction of total number of quadrats in which each of these four species occurred, of vines in constructed forested wetlands. Natural and constructed forested wetlands show some similarities with respect to these four species, but Figure 7.25c shows the frequency of occurrence of six other vine species found in constructed forested wetlands. It is not clear if these species are found in natural systems to the extent to which they occur in constructed systems.

Soil Development

Soil properties play a deterministic role in the self-organization of ecosystems. It has been suggested that soil properties influence the type of community that develops in a

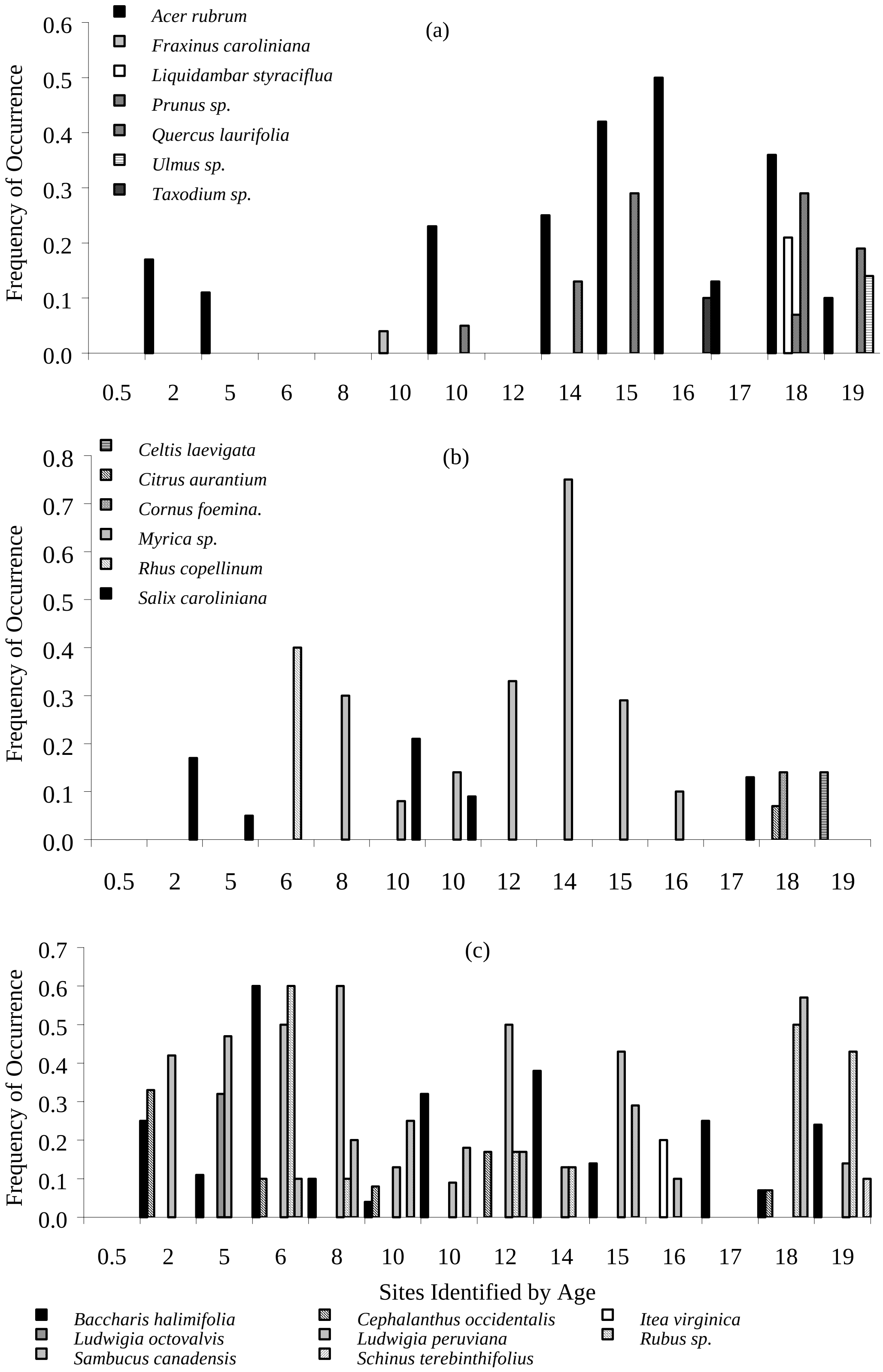


Figure 7.25. Frequency of Occurrence of (a) Canopy, (b) Subcanopy and (c) Shrub Species in the Understory of Constructed Forested Wetlands.

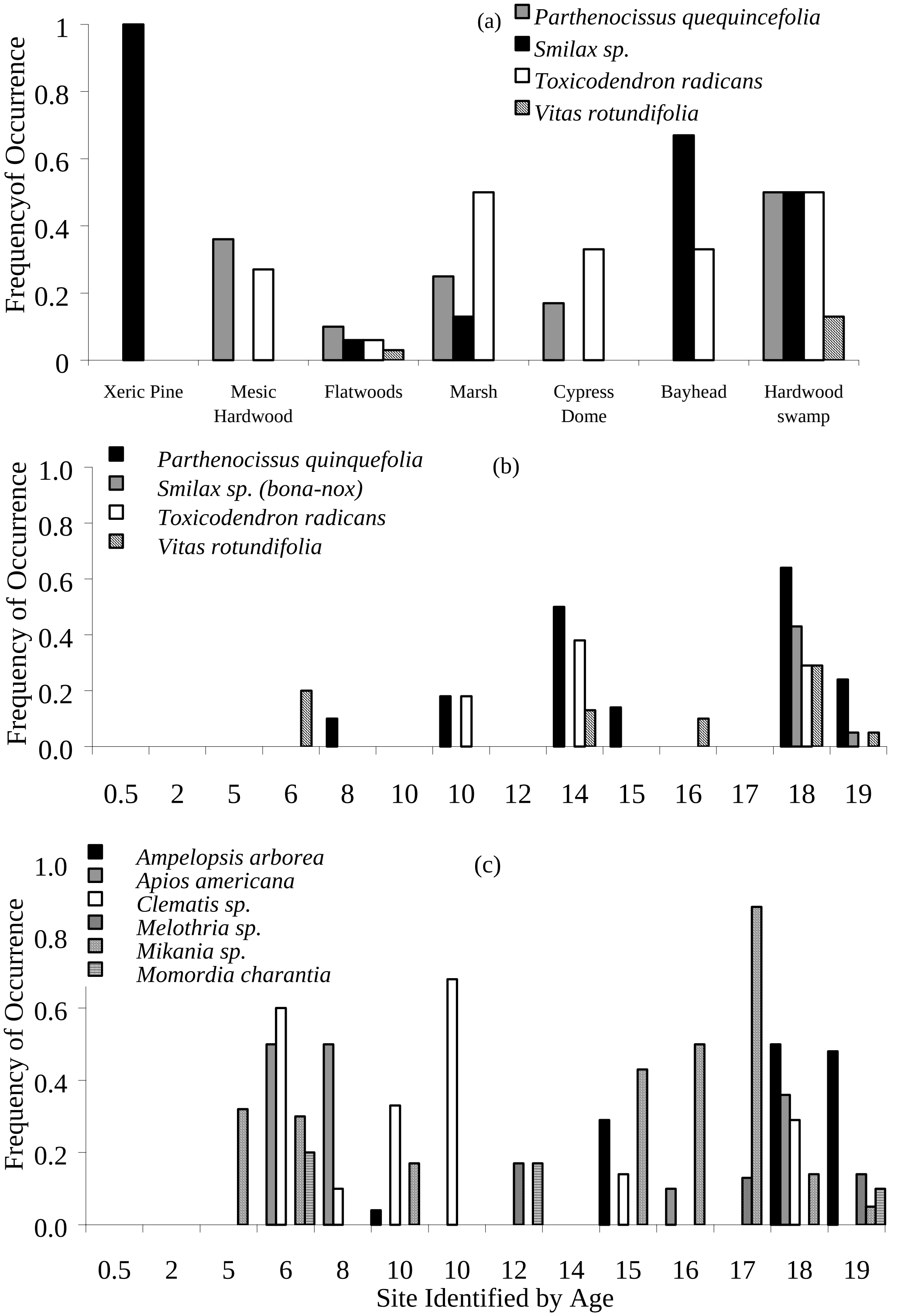


Figure 7.26. Frequency of Occurrence of *Parthenocissus quinquefolia, Smilax* sp., *Toxicodendron radicans* and *Vitas rotundifolia* in (a) Natural Communities in Florida and (b) Constructed Forested Wetlands; and (c) Frequency of Occurrence of Other Vines Species in Constructed Forested Wetlands.

given area (Tansley 1935). Davis and others (1991) present soil nutrient data for a variety of Florida ecosystems. Figure 7.27 shows available Ca, Mg, K, P, and Fe in Florida communities ranging from a xeric pine community to a hardwood swamp. The differences in nutrient availability are greater between xeric pine and wetland systems, but there are subtle differences even between wetland types.

Figure 7.28 shows the nutrient signatures or available plant nutrients found in constructed forested wetlands. When comparing nutrient availability in constructed forested wetlands from this study with natural systems, calcium levels were up to two and one half times that of the mean found in hardwood swamps. Magnesium and phosphorus were found in excess of three times that of natural systems. Available iron was within the range found in natural hardwood swamps. Available potassium fell below the mean of hardwood swamps in all but two of the constructed forested wetlands in this study. Wharton and others (1982) reported P (11.2 ppm) Ca (607 ppm), Mg (98 ppm), and K (48 ppm) values for blackwater swamps in the southeastern United States. These values show the greatest similarity to the values for cypress domes reported by Davis and others (1991) in Florida. Calcium, magnesium, potassium and phosphorus concentrations in constructed forested wetlands show even greater differences from the values reported by Wharton and others (1982).

Across a topographic gradient, greater values of nutrients have been reported at topographic lows where higher soil water content is often found. Lower nutrient concentrations are often found higher up the gradient into increasingly drier areas of a community (Wharton and others 1982). Graetz and Reddy (1997) found increasing concentrations of calcium, magnesium, potassium and iron in the A horizon on a gradient from upland to wetland in several constructed wetlands. This may be a consequence of leaching and transport from upland to wetlands. In the case of constructed forested wetlands in this study, nutrient concentrations in wetlands were already higher than natural wetlands. Data from this study showed weak trends of increasing available calcium and phosphorus with time. Therefore, self-organization of constructed forested wetlands may not result in nutrient signatures typical of natural Florida wetlands.

SUCCESSIONAL TRAJECTORIES OF SINGLE PARAMETERS

Some vegetative structural categories show trends over time within constructed forested wetlands. Canopy tree height and percent cover each show strong trends, increasing with time. The trend in diameter at breast height is only slightly less significant. There appears to be greater variability in tree diameter at breast height than in the other two parameters. Percent transmittance of sunlight through the canopy decreased with time and is inversely related to increases in percent canopy cover.

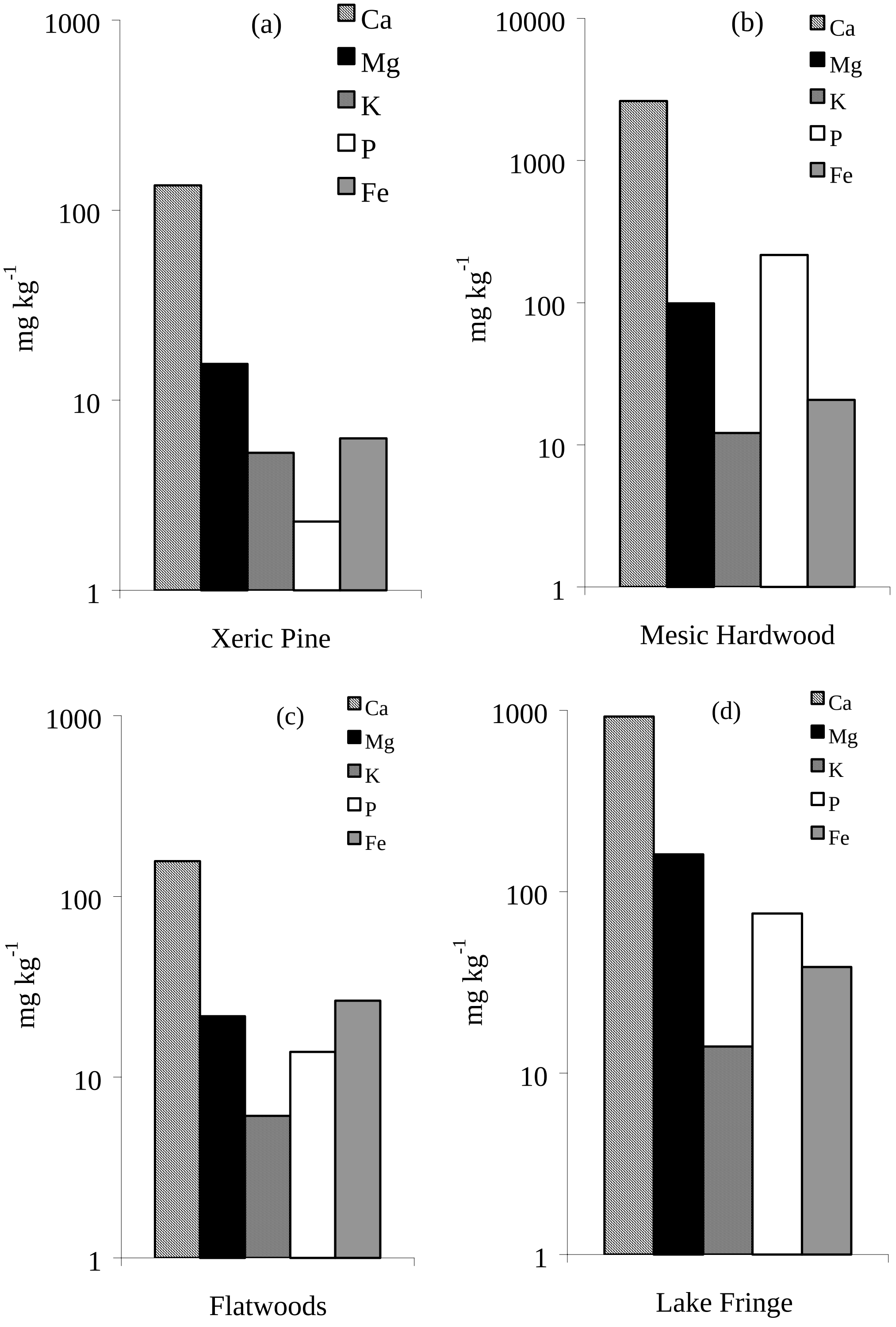


Figure 7.27. Available Soil Nutrient Signatures in Florida's Natural Communities: (a) Xeric Pine, (b) Mesic Hardwood, (c) Flatwoods, (d) Lake Fringe, (e) Marsh, (f) Bayhead, (g) Cypress Dome, and (h) Hardwood Swamp (from Davis and others 1991).

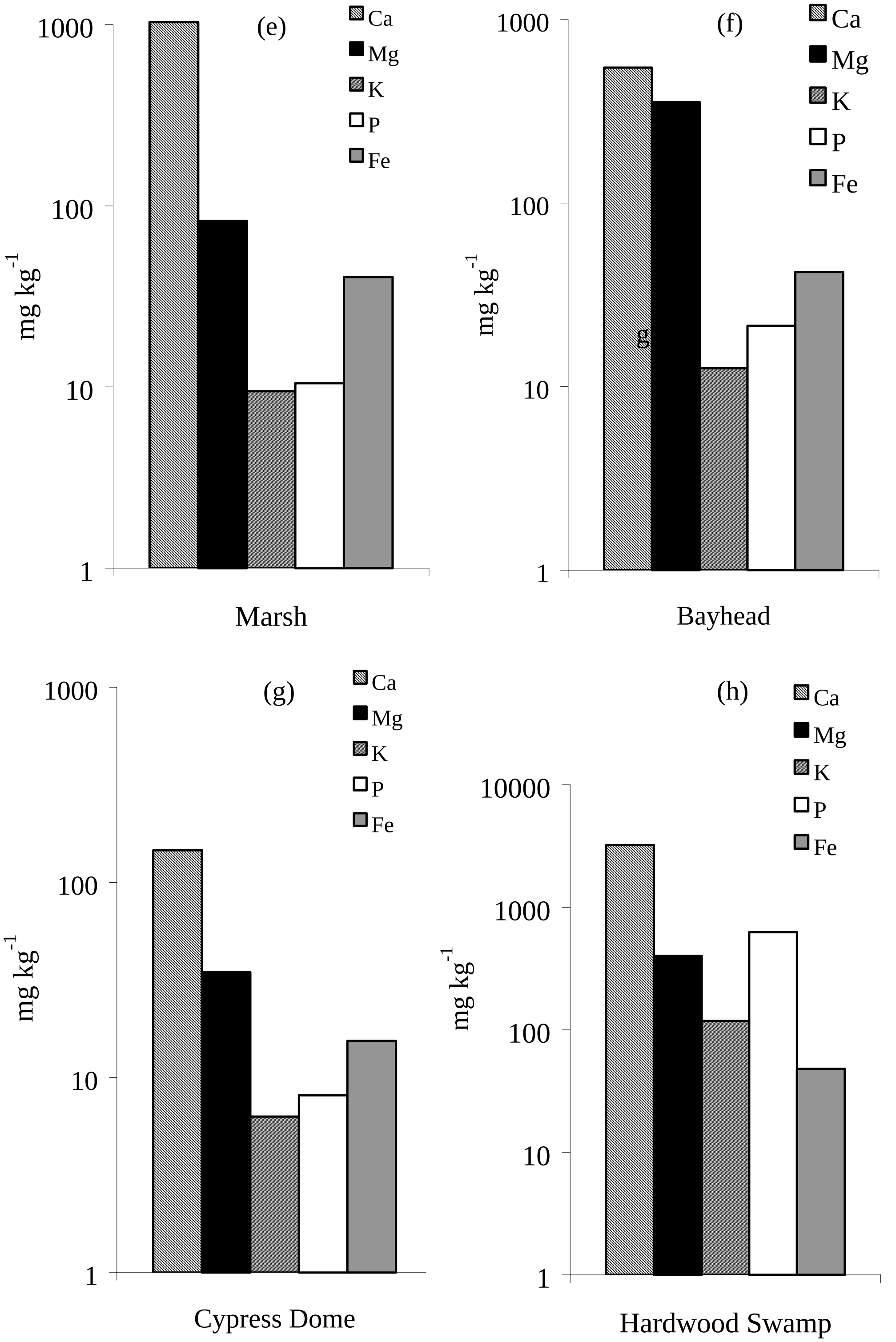
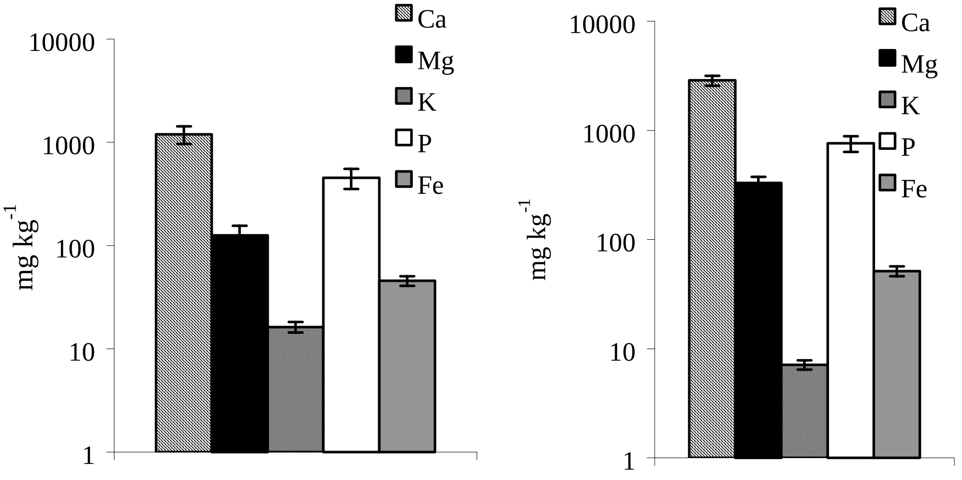


Figure 7.27 (Cont.) **Available Soil Nutrient Signatures in Florida's Natural Communities: (a) Xeric Pine, (b) Mesic Hardwood, (c) Flatwoods, (d) Lake Fringe, (e) Marsh, (f) Bayhead, (g) Cypress Dome, and (h) Hardwood Swamp (from Davis and others 1991).**



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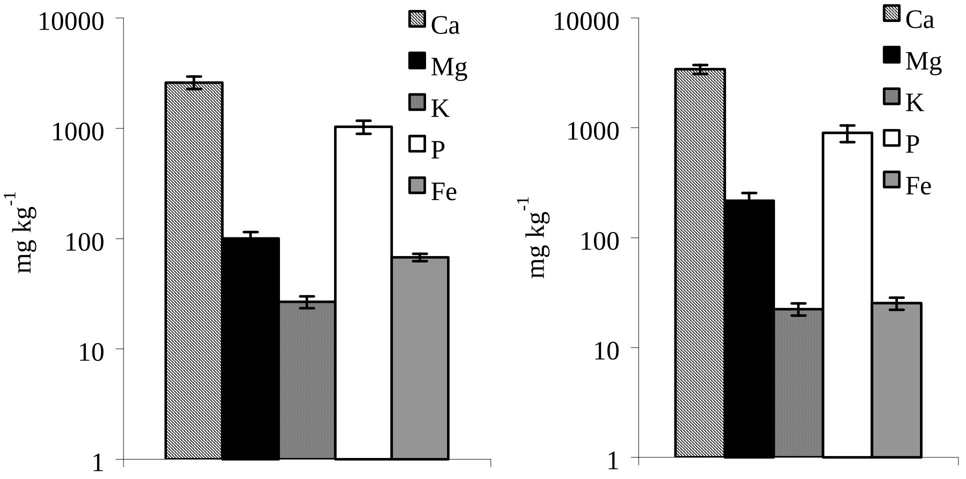

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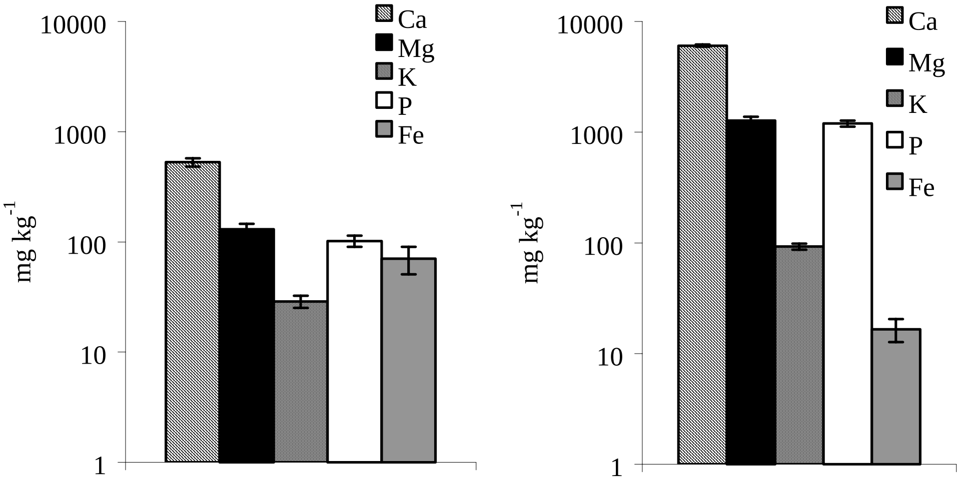
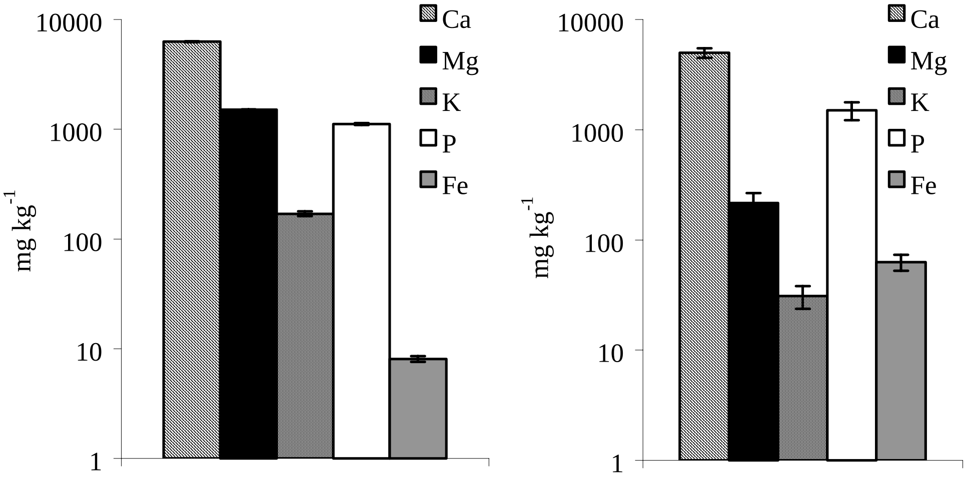


Clear Springs

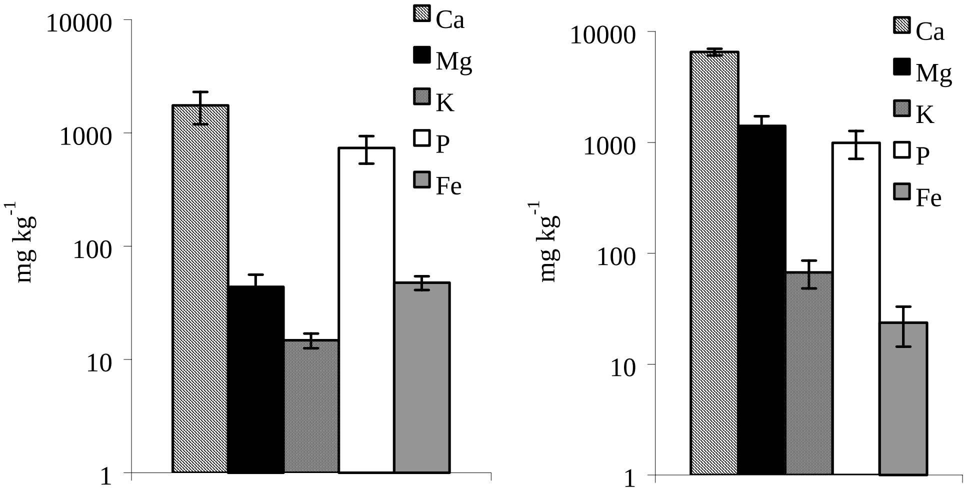
East Lobe

Figure 7.28. Available Soil Nutrient Signatures for Constructed Forested Wetlands.



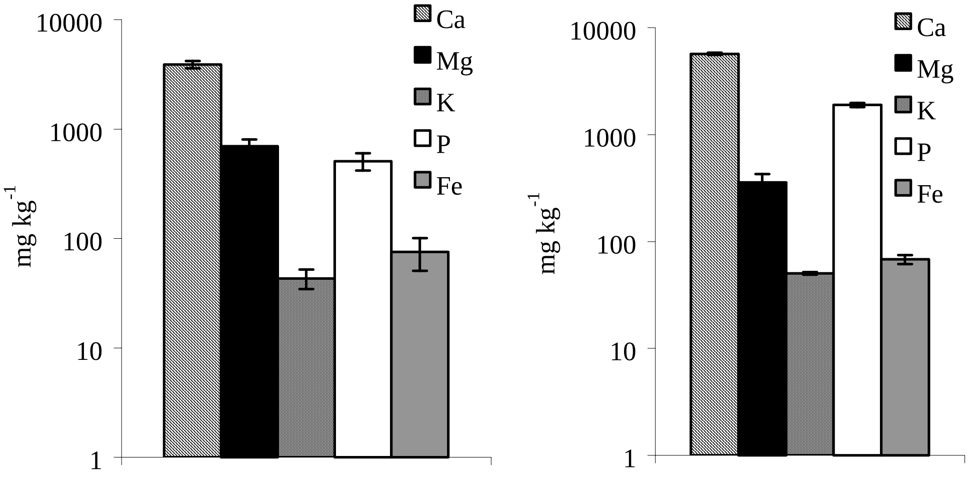
West Lobe

Cateye



SP11

Guy Branch



SP6

Morrow Swamp

Figure 7.28 (Cont.) Available Soil Nutrient Signatures for Constructed Forested Wetlands.

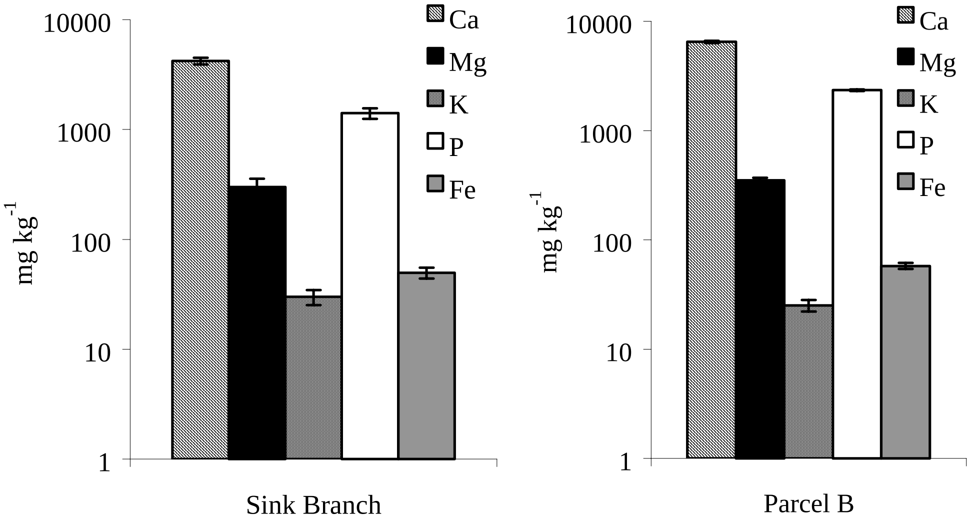


Figure 7.28 (Cont.) Available Soil Nutrient Signatures for Constructed Forested Wetlands.

Canopy Trajectories

Canopy tree species richness shows no trend over time. Species richness within constructed forested wetlands is primarily a function of the number of species planted during reclamation. The greatest species richness was found in the two oldest and the two youngest sites. Parcel B (19 years) was an experimental project that incorporated the planting of floodplain tree species not normally found in central Florida, as well as others more commonly found in the area. This resulted in unusually high species richness. Sink Branch (17 years) had a broader range of habitats within the site, ranging from mesic to wet. This provided areas for upland species not normally found in a wetland to establish, resulting in greater species richness. The species richness of the younger sites results from a greater number of species being planted during reclamation. Therefore, increases in canopy species richness in constructed wetlands do not necessarily reflect wetland success but are simply a result of human interactions with the wetland.

Frequency of occurrence of tree seedlings and saplings shows a very weak positive trend with age. Occurrence of saplings was probably more closely related to distance from unmined forested areas, which would provide a seed source. The demonstration of tree reproduction and seedling establishment is important in assessing the success of wetland reclamation. With increases in sample size including sites of various ages and distances from seed source, the time necessary for seedling establishment for both isolated constructed wetlands deprived of a seed source and those adjacent to seed sources may be determined. The data collected suggest that very young sites (2 years) are capable of supporting establishment of wind dispersed seeds such as *Acer sp.* Perhaps the best way to determine if constructed forested wetlands are capable of recruitment, and which species have a greater likelihood of being recruited, could best be determined with humans continually providing a diversity of seeds and evaluating which species become established.

Subcanopy Trajectories

Only weak positive trends with time were found in early successional subcanopy species richness and stem diameter , while no trends were found with late successional species. *Salix caroliniana* and *Myrica cerifera* are the most common species in the subcanopy structural category. Only the youngest sites and the two oldest sites had subcanopy tree species other than *S. caroliniana* and *M. cerifera* present. Subcanopy tree species were planted during reclamation in the three youngest sites. Subcanopy species were not on the planting list for the older sites and appear to have been naturally recruited. Only one of the two older sites was immediately adjacent to an unmined floodplain. The seed source for the other older site (Sink Branch) is unclear. Seedlings of *Celtis laevigata* and *Cornus sp*. were present in the two oldest sites, although not in large numbers.

Shrub Trajectories

There are no clear trends in shrubs with site age, neither in decreasing trends in early successional species nor increasing trends in late successional species. *Cephalanthus occidentalis* was present in six of ten sites. It had been planted at each of the sites. *Sambucus canadensis* was present in five of ten sites and appears to be recruited naturally. *Itea virginica* was present at one site (16 years); it was not included on any planting lists and appears to have been naturally recruited.

Understory Trajectories

There were only a few weak trends in herbaceous understory vegetation associated with site age. This was explained in a previous section by the differences in species richness of marshes and forests with young forested wetlands more closely resembling marshes. The number of vine species and species of tree seedlings increased with site age. No other structural category increased in species richness with age. There are weak increasing trends in frequency of occurrence of canopy tree seedling and vines. Vines increased in both number of species and frequency of occurrence with site age. There was a weak trend with site age in the frequency of occurrence of early successional subcanopy species, increasing to a peak around 10 years and then declining.

Soil Trajectories

There is a weak trend in soils associated with age of wetland. Soil bulk density decreases with time. If wetland hydrology has been successfully reproduced, and environmental variables are suitable for vegetative productivity, then soil organic matter should increase with time as plants grow and die. As organic matter is added to the soil, bulk density should decrease. Since most sites are constructed with mineral soil, increases in organic matter should be apparent and should be greater in wetter and more productive sites. If wetland hydrology has not been successfully established, this trend my not be discernible.

By selecting those sites, which have been determined from the results of this study to have a greater than average probability of supporting wetland plants, the trends in both increases in organic matter and decreases in bulk density should become more apparent. Those sites falling below the average, as shown in Figure 7.7, were selected and it was inferred from these data that these sites are wetter than average. Figure 7.29 shows the relationships between soil organic matter and age ($r^2 = 0.70$, $p = 0.08$) and the relationship between decreasing bulk density and age are even stronger ($r^2 = 0.\ 97$, $p = 0.002$).

SUCCESSIONAL TRAJECTORIES OF EMERGING PROPERTIES

Tree growth rates can vary greatly, depending on site environmental conditions, and the chronological age of a site, more than likely, does not describe adequately the influence of canopy trees on self-organization. Trees, as they grow, increasingly interact with driving energies (sunlight, nutrients) and modify the environment. Below-ground competition for soil resources and above-ground competition for light increase as trees increase in size. Trees are what make a forest a forest and provide a proportionally greater feedback to the self-organization of the community. The combination of community basal area and canopy cover are fairly simple parameters that, when combined, can quantify the influence of trees on the surrounding community.

Community basal area (of trees greater than 5 cm) has been reported for several forested wetland types in Florida. Davis and others (1991) found 35.66 m^2 ha^{-1}, 27.68 m^2 ha^{-1} and 38.89 m^2 ha^{-1} in cypress domes, bayheads and hardwood swamps, respectively. Community basal area in all constructed forested wetlands in this study was less than 10 m^2 ha^{-1}. Figure 7.30 is a graph of the best-fit line to community basal area over time in constructed forested wetlands. The best-fit line can be extended to the horizontal line representing the community basal area of hardwood swamps (Davis and others 1991). The horizontal line may be considered the target or goal for constructed forested wetlands. Figure 7.30b represents a hypothetical trajectory (based on Figure 7.30a), that was modified to represent a shift to a logistic growth curve. The constructed forested wetlands in this study are quite young in comparison to natural wetlands.

Community basal area alone is insufficient to adequately describe the influence of trees on self-organization. Depending upon site conditions, trees may be allocating greater resources to diameter at breast height and less to canopy development. Trees that are competing with other species for light may allocate greater resources to height than diameter at breast height. Tree density can also influence percent canopy cover. A dense

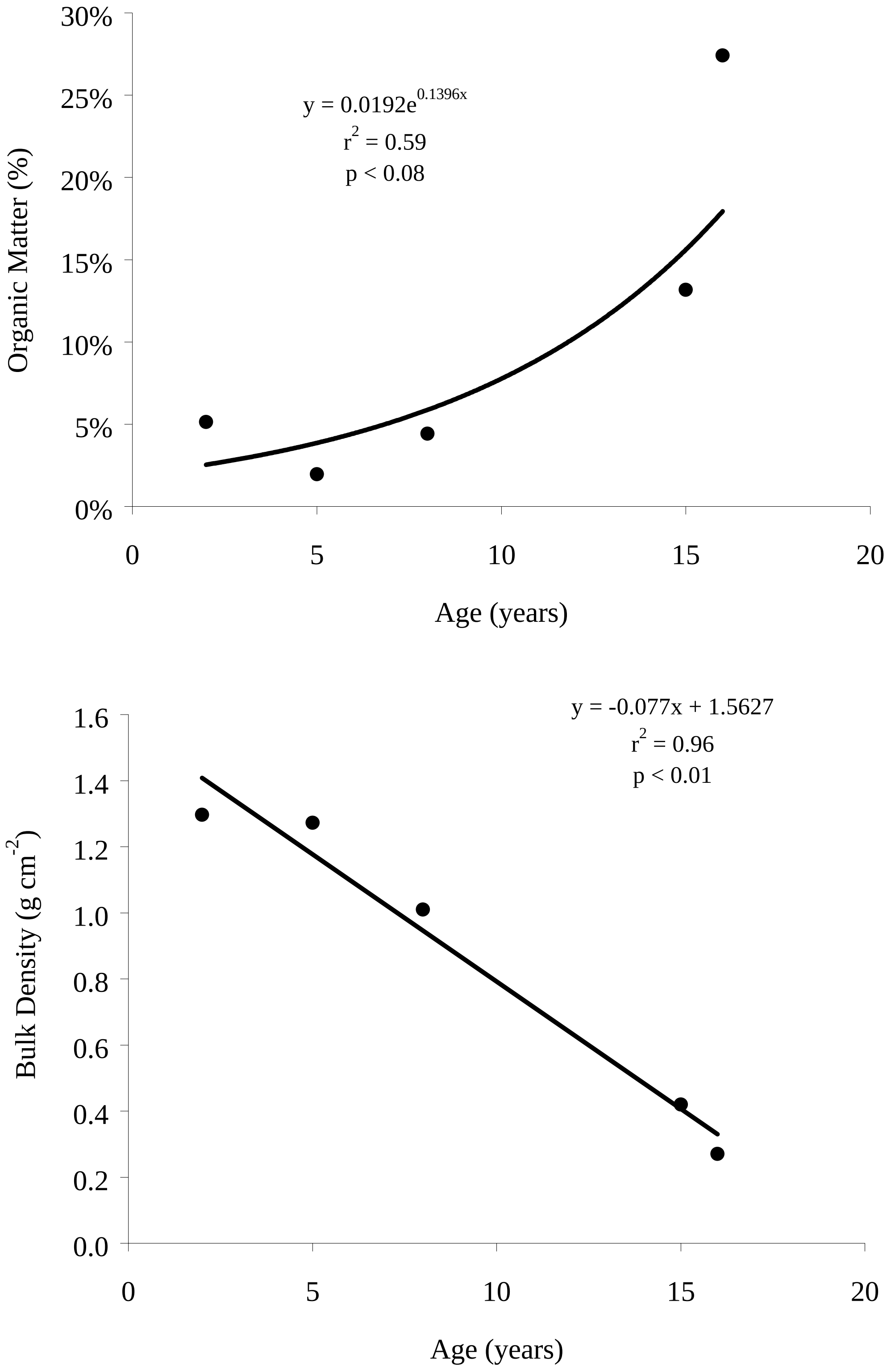


Figure 7.29. **The Successional Trajectories of Organic Matter and Bulk Density in Those Sites That Were Identified as Better Than Average Wetlands Using the Understory Community Wetland Status.**

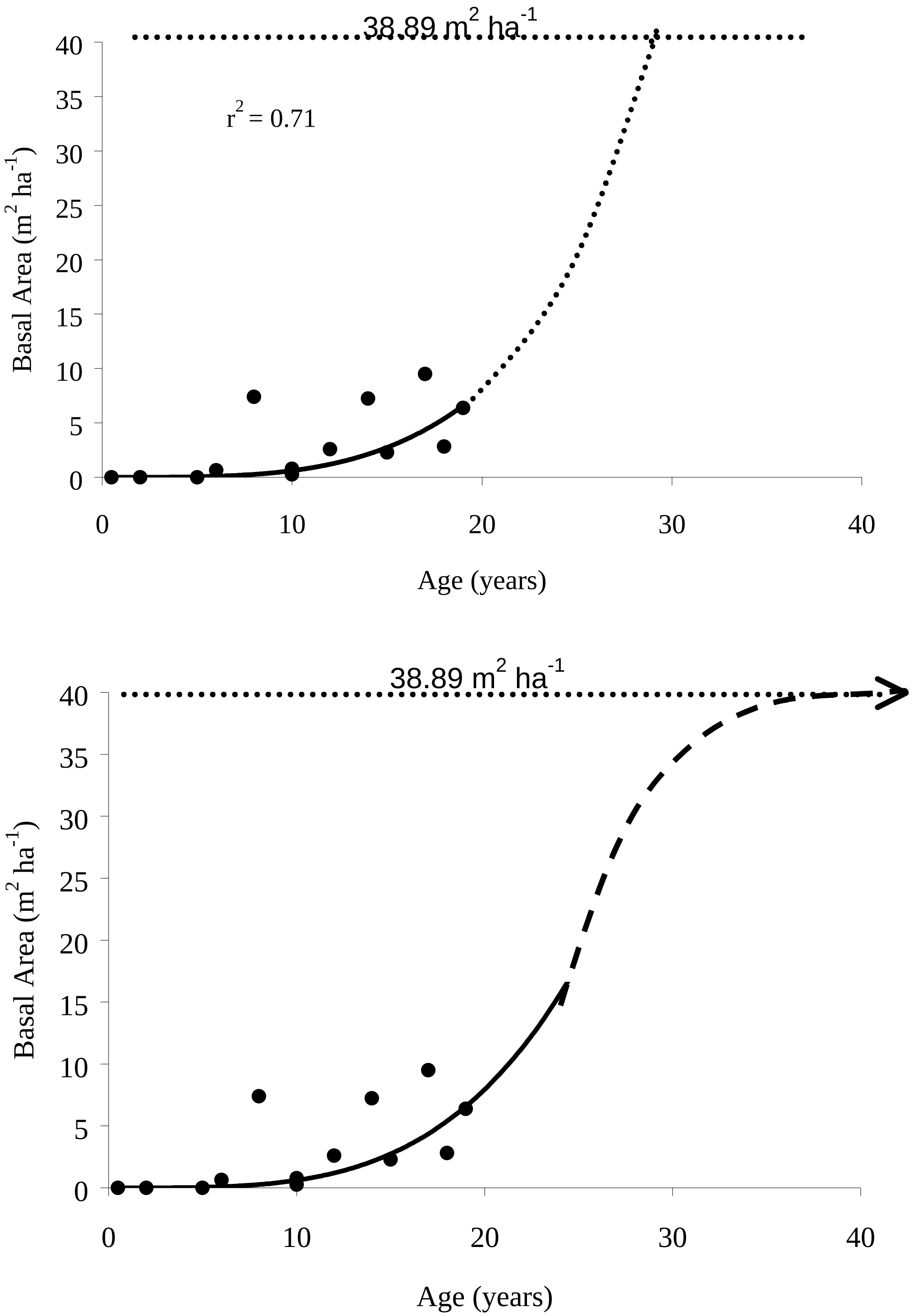


Figure 7.30. **Hypothetical Community Basal Area Trajectories Based on (a) Exponential Regression of Mean Community Basal Area of Research Sites and (b) Exponential Curve Modified to a Logistic Growth Curve. Horizontal Dotted Line Represents the Community Basal Area of a Natural Mixed Hardwood Swamp.**

stand of young trees and a sparse stand of mature trees may result in equivalent canopy cover. In addition, trees in wetland conditions are often buttressed, a morphological response of increased cell size, as a result of flooding. Under either circumstance, trees with greater basal area may not have the greatest canopy cover. The following formula is suggested for establishing a forest successional status, which more adequately quantifies the influence of trees on self-organization than chronological age.

Community Basal Area * Canopy Cover = Forest Successional Status

Table 7.15 compares the chronological age of the research sites with their forest successional status. Notice the similarity in successional status between the eight-year-old site and the seventeen-year-old site. Site comparisons made using successional status rather than age reveal that the oldest site is chronologically fourteen while an eighteen-year-old site is at a much earlier stage of succession. While this method can quantify the impact of a developing forest on some aspects of the self-organization of a community, it does not differentiate between a wetland and upland.

Table 7.15. A Comparison of Chronological Age and Forest Successional Status in Constructed Forested Wetlands.

Site Name	Chronological Age (years)	Forest Successional Status
LP2 Phase 1	0.5	0.00
CO7984	5	0.00
HP5 Phase 3	6	0.36
Clear Springs	8	5.48
East Lobe	10	0.56
West Lobe	10	0.19
Cateye	12	1.89
SP11	14	6.07
SP6	16	0.16
Morrow Swamp	17	5.41
Sink Branch	18	2.48
Parcel B	19	5.17
Natural Hardwood Swamp	???	35.00

Individual soil parameters graphed against age provided little information on the development of wetland soil properties with time. However as expected based on basic soil science, when soil parameters were graphed against each other, stronger trends emerged. Figure 7.12 shows site means for bulk density, soil water content and organic matter graphed against each other. Figures 7.13, 7.14 and 7.15 show these relationships for each site.

Some assumptions can be made concerning the condition of wetland soil in constructed wetlands that could make any changes in these relationships within a site useful for assessment. These include:

- Upon completion of construction, the initial conditions of bulk density and organic matter content are reasonably uniform throughout the wetland. Wetlands are often constructed from either overburden or sand tailing with perhaps a layer of mulch.

- Any changes in soil bulk density or organic matter content result from self-organizational processes being driven primarily by soil water content and site productivity. Increased soil water content often creates in anaerobic conditions within the soils, resulting in decreased organic matter decomposition rates and provided there is sufficient productivity with the site storage of organic matter in the soil will increase.

While the relationships in Figure 7.31a and 7.31c are often represented with organic matter and bulk density as the independent variable, the reverse is done here. Throughout this research the assumption was made that data collected from a chronosequence of similar wetlands would resemble data collected from an individual site over time. With this in mind, the initial soil organic matter and bulk density of a site have the potential to decrease throughout the site differentially dependent upon the variation of soil moisture content throughout the site.

First, as was done in this study, soil samples within a given wetland must be taken across the moisture gradient from the edge of the wetland inward. The sampling of the moisture gradient within the wetland is essential if this method is to work.

If the assumptions are true, then initial graphs of bulk density vs. soil water content of newly constructed wetlands would result in a straight horizontal line at some initial value. Very little change in bulk density of primarily mineral soils is expected from increased soil water content, since water should be filling empty space and contributing very little to increasing volume. In addition, the initial graphs of organic matter vs. soil water content should result in a straight horizontal line. (The first graph in Figures 7.13, 7.14 and 7.15 shows the graphs of these relationships in LP2 Phase 1.)

With time, there should be differential increases in organic matter and a decrease in bulk density across the moisture gradient, with greater changes occurring with greater soil water content. The graph of bulk density vs. soil water content should begin to show exponential decreases in bulk density with increasing soil water content. In addition, the points representing individual soil samples should shift to the right as decreasing bulk

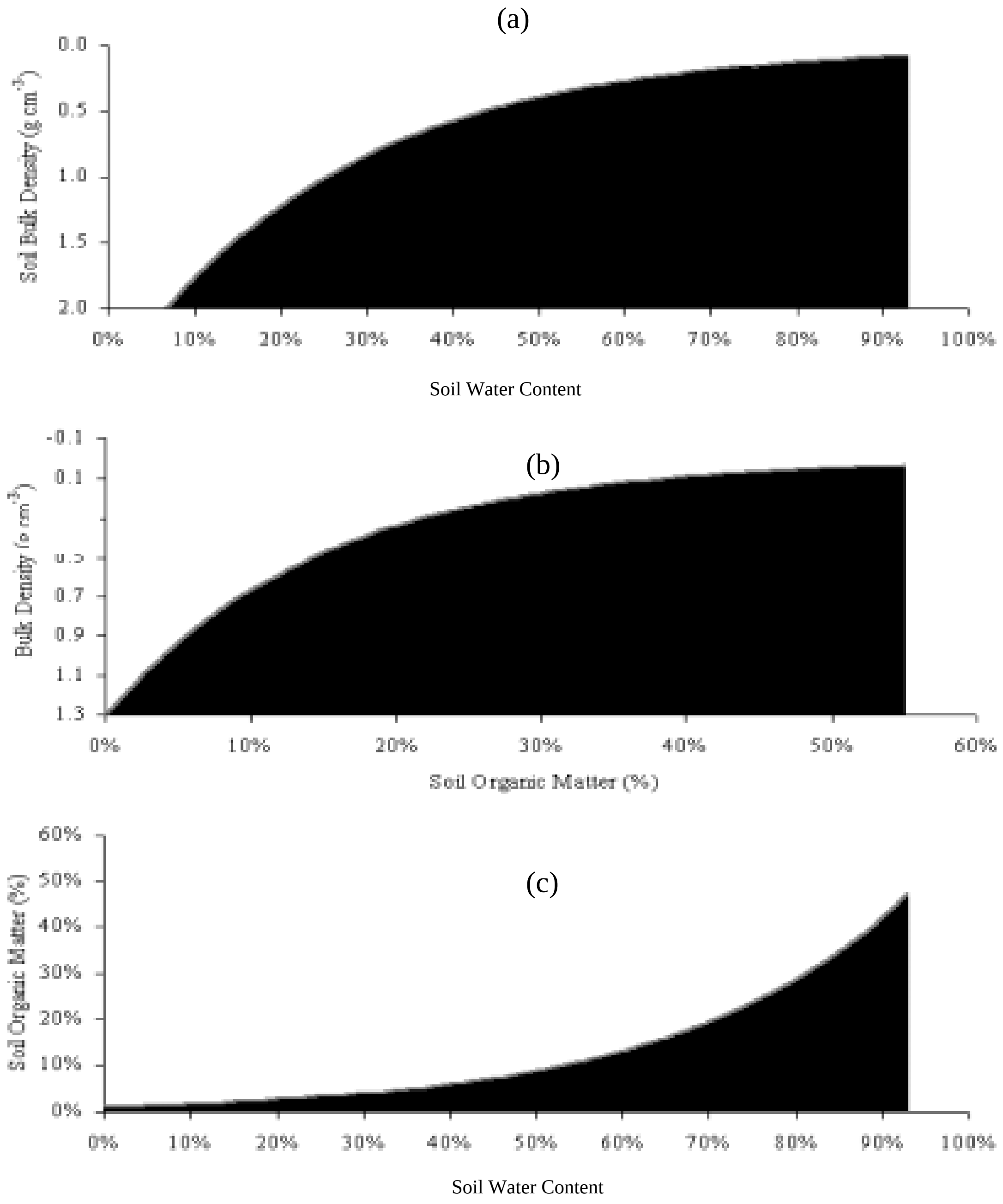


Figure 7.31. Three Relationships Between Soil Parameters: (a) Soil Moisture vs. Bulk Density, (b) Soil Organic Matter vs. Bulk Density and (c) Soil Water Content vs. Soil Organic Matter. Data Used to Construct the Relationships Were from Those Sites Falling Below the Average for Plant Community Wetland Status in Figure 13. The Gray Line Represents the Regression for All Subsamples. Those Samples Falling in the Unshaded Region Above the Gray Line Have Exceeded the Mean for That Relationship.

density (with associated increases in organic matter) increases water-holding capacity of the soil. There should be a similar change with time in the graph of organic matter vs. soil water content. Samples with greater soil water content have greater potential for accumulation of organic matter due to decreases in rates of decomposition associated with saturated soils.

The change in these relationships is driven by natural processes and should occur provided the site is capable of supporting vegetation and other biota. These relationships integrate site hydrology and productivity and provide information on historical site conditions, while methods of assessing wetlands by current vegetation, particularly herbaceous vegetation, take into account only current conditions.

Figure 7.31 used data from all soil subsamples from this study to represent the relationships discussed previously. Using the same data, Figure 7.32 was constructed to illustrate the 95% confidence intervals around the best-fit line. These graphs represent a target for these relationships that has been reached and even exceeded by some sites, while others have failed. Four methods could be used to assess the development of wetland soils based on these relationships.

- All soil samples within a given site must fall above the shaded areas.

- The residuals associated with the exponential regression, upon which the curve is based, and the soil samples from a wetland could be summed. Soil samples falling in the shaded areas would have positive residuals, meaning they have exceeded the standard, and samples falling elsewhere would have negative residuals. A residual score greater than or equal to zero would be considered successful.

- Compare the regressions of soil relationships from individual sites with the standard. Regression relationships that are not significantly different from the standard would be considered successful.

- All subsamples for an individual constructed wetland must fall within the 95% confidence intervals.

Figures 7.33, 7.34, 7.35, 7.36, and 7.37 show results of these comparisons for each of five wetland sites. Figure 7.33 depicts a young site that lies on the lower range of soil water content and soil organic matter, while bulk density is still high. This site also falls above the mean of community wetland status (Figure 7.7). Over one half of the samples are above the mean for constructed forested wetlands in Figure 7.33a and 7.33b and above the mean in Figure 7.33c. In addition, there is little differentiation in bulk density or organic matter along the soil water content gradient. This information combined suggests that it is too early to determine if this will develop into and be sustained as a forested wetland.

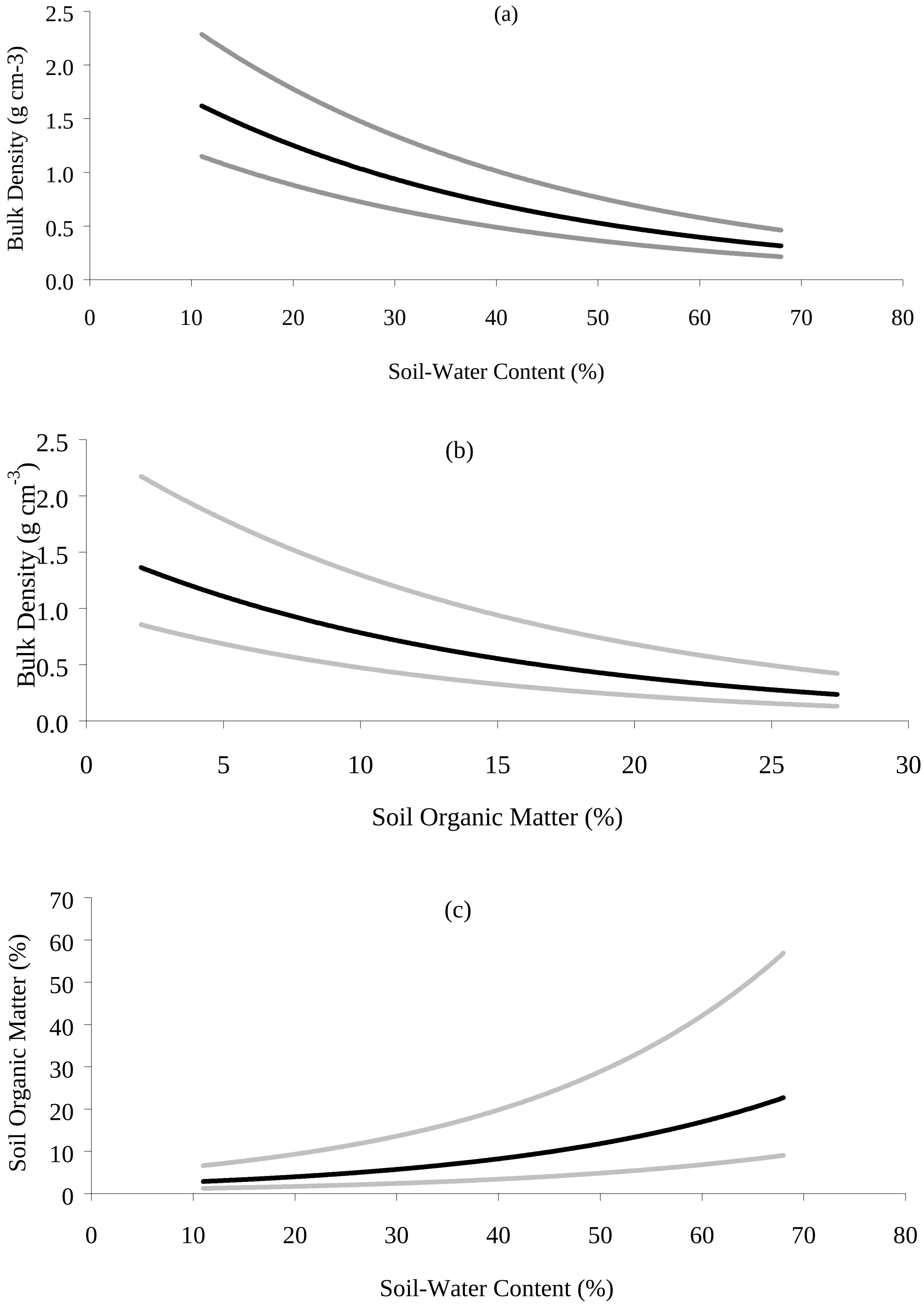


Figure 7.32. **Ninety-Five Percent Confidence Intervals for Relationships Between (a) Soil Water Content and Bulk Density, (b) Soil Organic Matter and Bulk Density, and (c) Soil Water Content and Soil Organic Matter. Gray Lines Represent the Upper and Lower Bounds of a 95% Confidence Interval.**

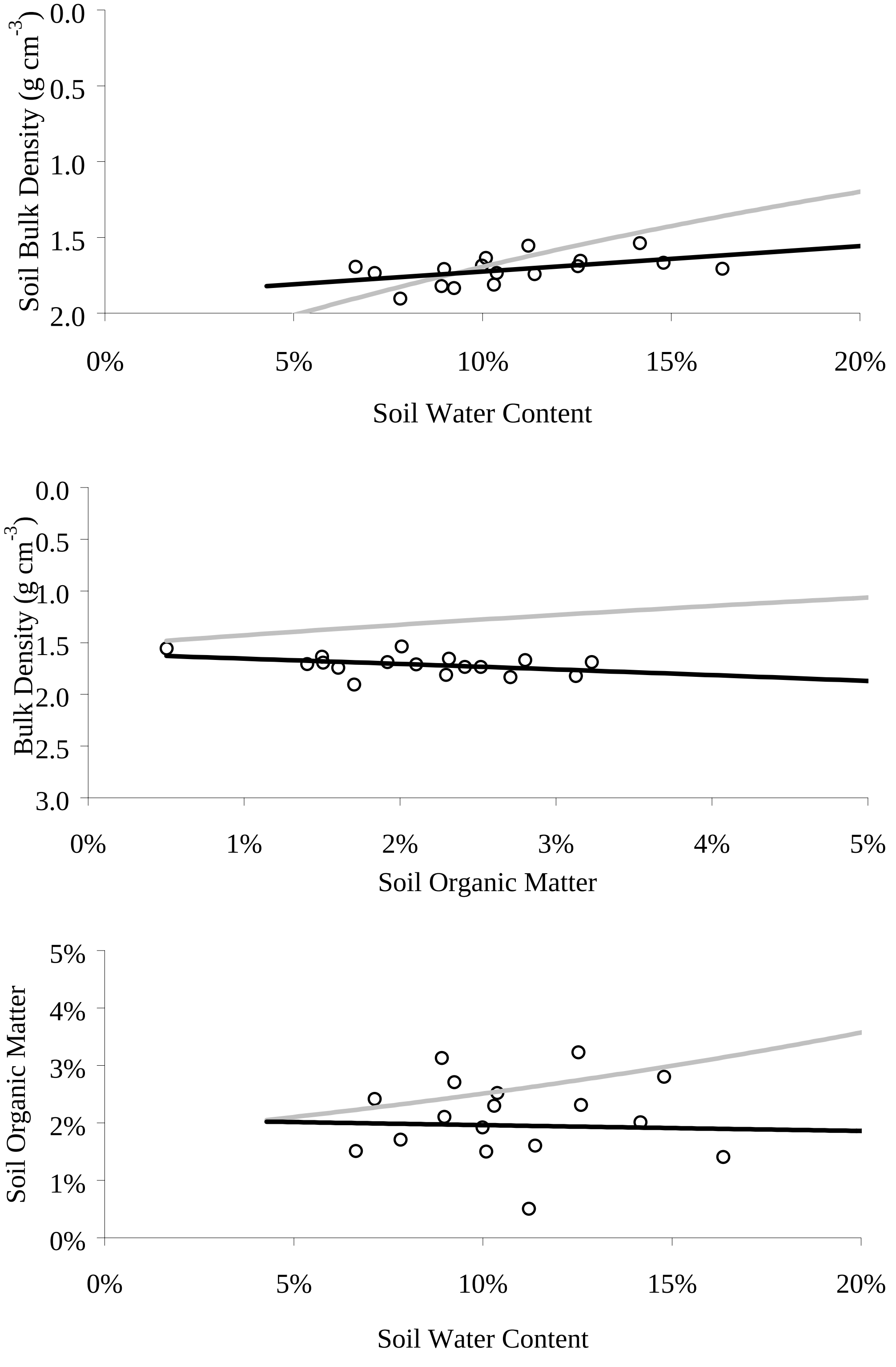


Figure 7.33. **Soil Relationships at LP2 Phase 1, a One-Half-Year Old Constructed Forested Wetland. Gray Line Represents the Composite Value for All Sites. Circles and Black Line Are from LP2 Phase 1 Only.**

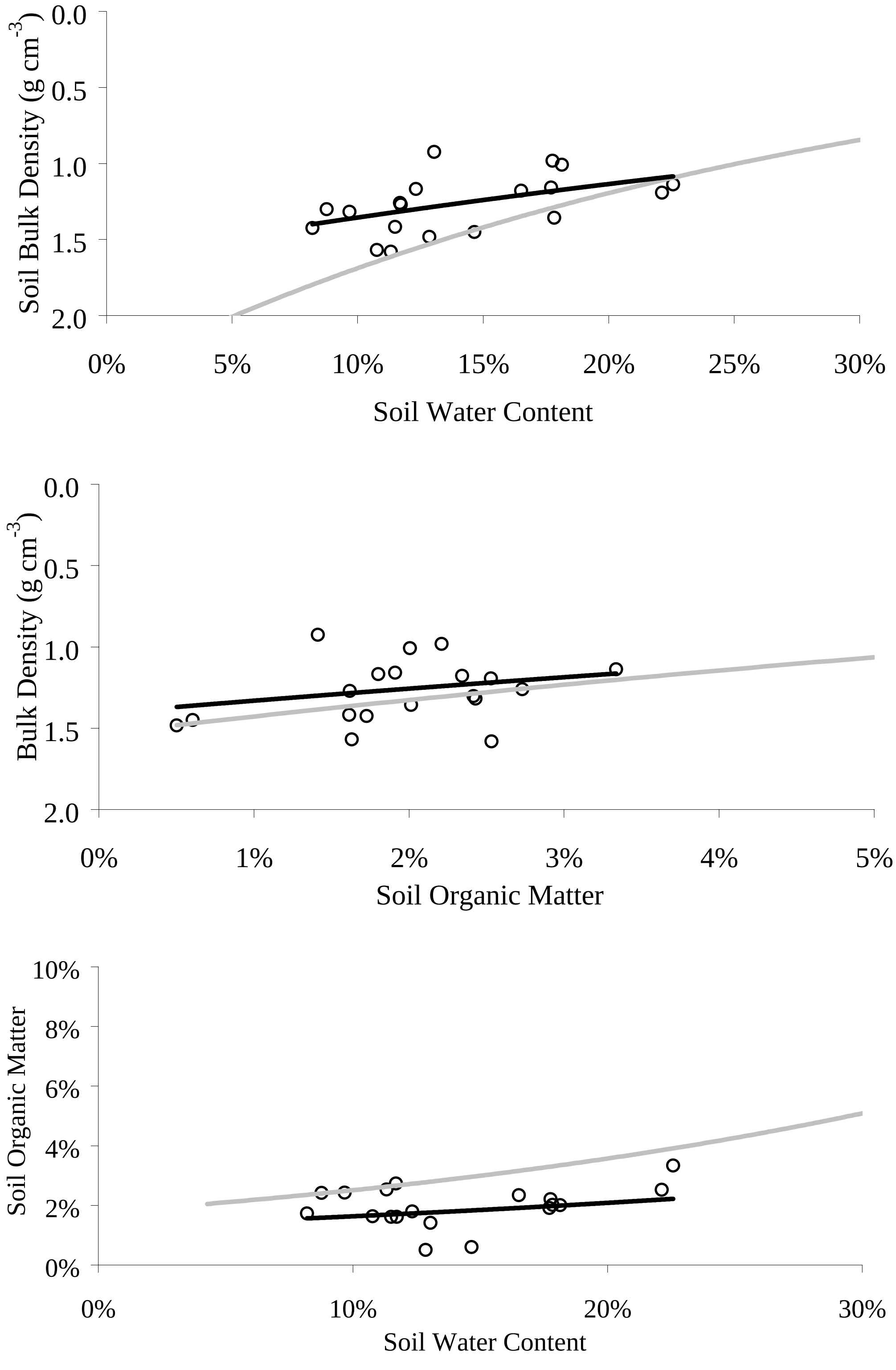


Figure 7.34. Soil Relationships at CO7984, a Five-Year-Old Constructed Forested Wetland. Gray Line Represents the Composite Value for All Sites. Circles and Black Line Are from CO7984 Only.

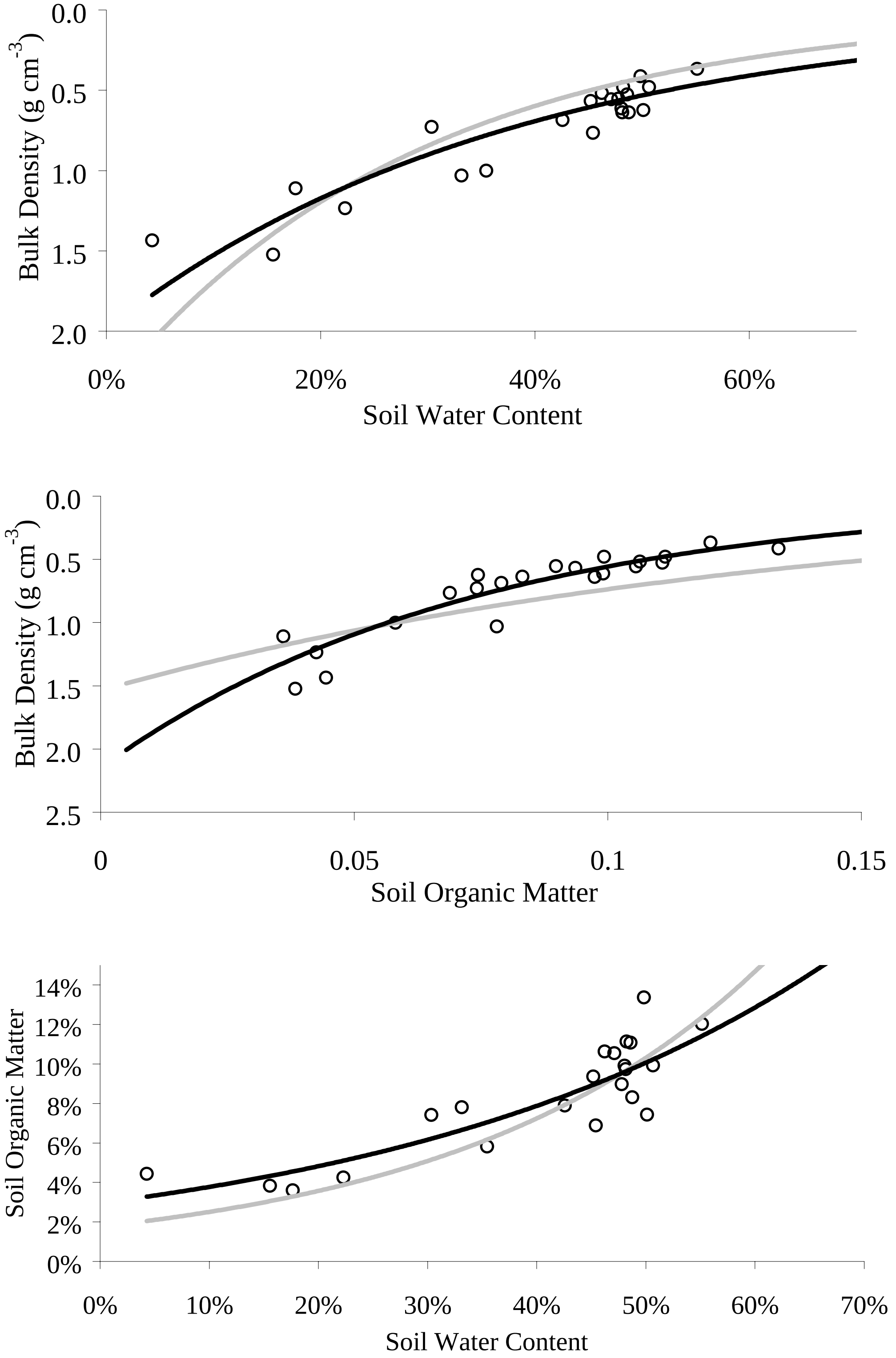


Figure 7.35. **Soil Relationships at East Lobe, a Ten-Year-Old Constructed Forested Wetland. Gray Line Represents the Composite Value for All Sites. Circles and Black Line Are from East Lobe Only.**

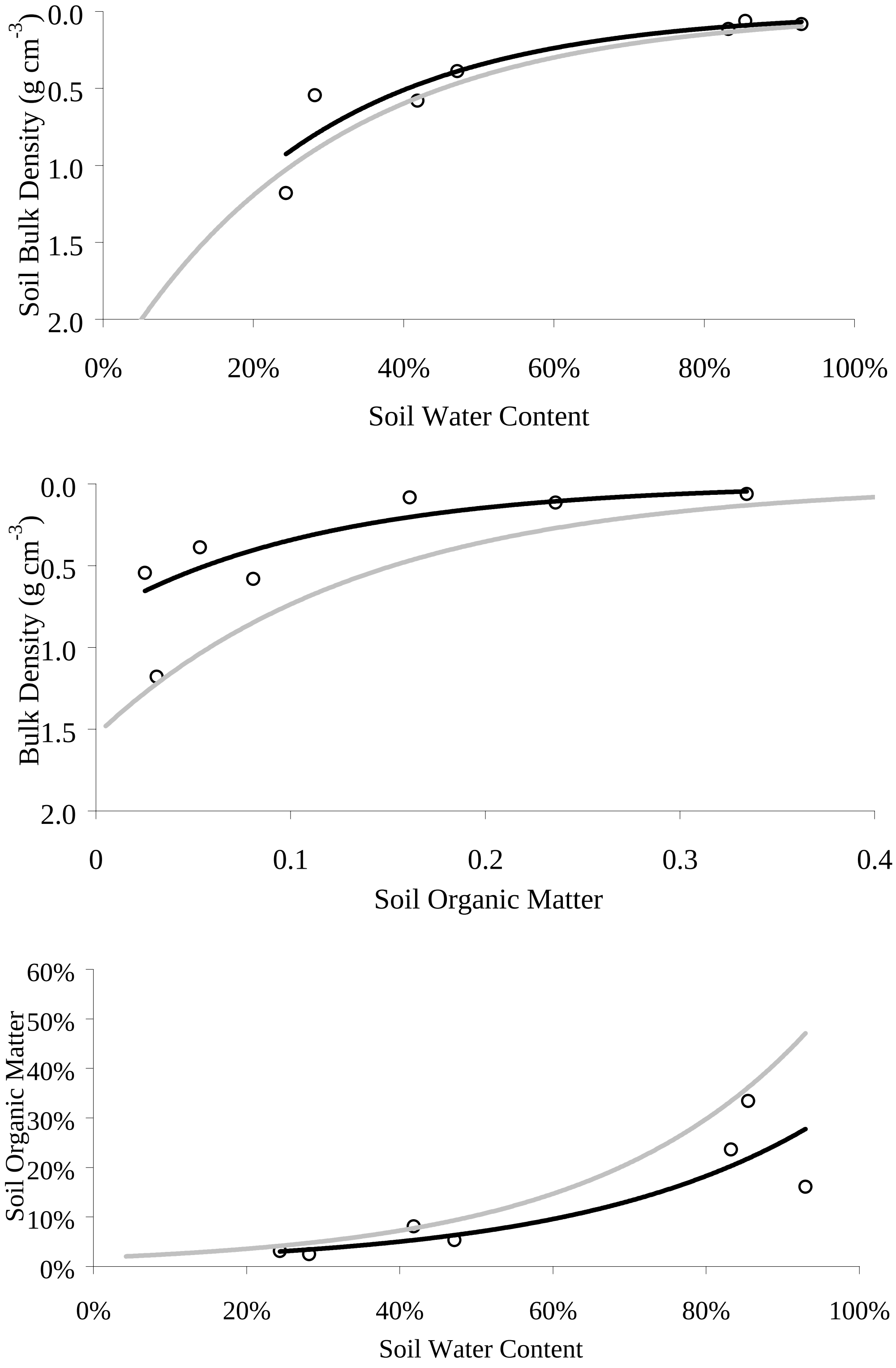


Figure 7.36. Soil Relationships at Guy Branch, a Fifteen-Year-Old Constructed Forested Wetland. Gray Line Represents the Composite Value for All Sites. Circles and Black Line Are from Guy Branch Only.

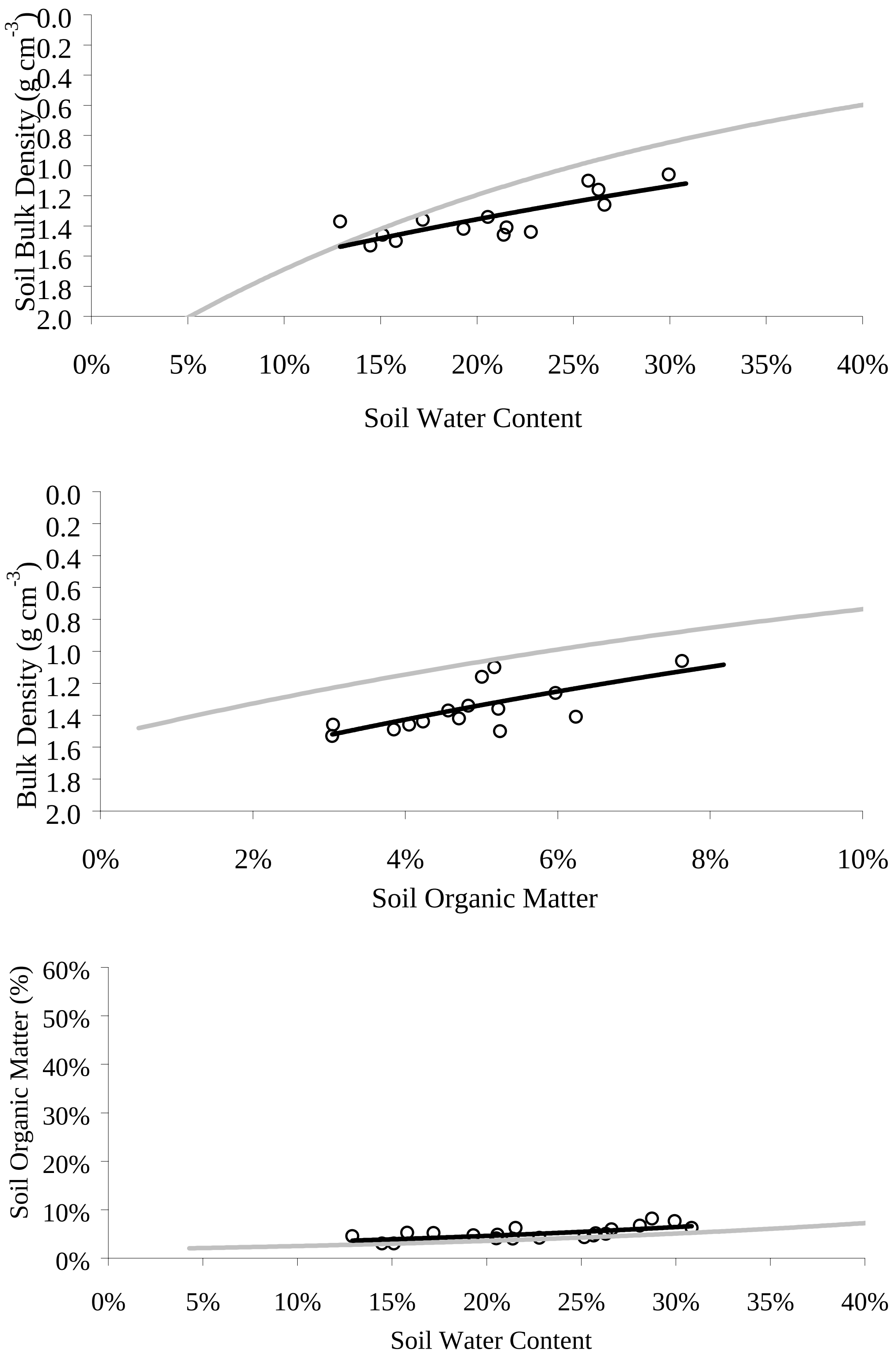


Figure 7.37. Soil Relationships at Parcel B, a Nineteen-Year-Old Constructed Forested Wetland. Gray Line Represents the Composite Value for All Sites. Circles and Black Line Are from Parcel B Only.

In Figure 7.34, a five-year-old site shows the beginning of development of wetland soils. The variation in bulk density attributed to soil water content and soil organic matter is below the mean. And, the percent soil organic matter attributed to soil water content is below the average. The slope of regression suggests that there has been little change from the drier to the wetter parts of the system. The community wetland status of this site falls below the mean. This site shows potential for developing into a wetland, but determining if it can be a forested wetland will require information on tree growth.

Both Figures 7.35 and 7.36 depict sites where wetland soil development is noticeable. Comparing Figure 7.35 or 7.36 with Figure 7.37, it is apparent that more than time is required to develop wetland soils. Although the site depicted in Figure 7.37 is 19 years old, the conditions at this site have resulted in lower levels of soil development. Soil water content and soil organic matter are lower, and bulk density is higher in this site, than in the 10 and 15 year old sites. This does not necessarily mean that the 19-year-old site is not a wetland. It is suggested that rate of development is slower and the slower rate of development is in some way attributable to site hydrology and vegetative productivity.

CONCLUSIONS

It is relatively easy to deem a constructed wetland unsuccessful if it doesn't maintain an appropriate density of the trees originally planted. But, tree survival and density of mature trees, although necessary for success, do not necessarily reflect future success or indicate a self-sustaining ecosystem. In fact, documenting successful seed production of trees alone is not in itself an adequate indicator of success. Many plant species exhibit increased sexual and asexual reproduction under conditions of stress, presumably a means for dispersing offspring into a less stressful environment. Both seed production by mature individuals and establishment of offspring must be documented and provide a better indication of sustainability than seed production alone. Diameter at breast height, frequency distributions of tree size classes and community basal area provide these measures because they reflect tree growth and recruitment.

Wetland ecosystems organize around their driving energies. There is an energy signature associated with forested wetlands, which includes hydrological energies associated with depth, duration and frequency of flooding, light energy and energies associated with soil parameters. The appropriate combination of these driving energies results in a functioning forested wetland. Typically, assessment of wetland health or restoration success focuses on the biotic component of a wetland rather than the abiotic driving energies that give rise to conditions that foster forested wetlands. This is done presumably because the biotic component of an ecosystem integrates the driving energies, and therefore, is an adequate indicator of the presence of appropriate driving energies and ecosystem functions.

In addition to the emphasis on the biotic component of wetland ecosystems, previous efforts at assessing the success of constructed wetlands have focused on the directional change of individual components of the ecosystem, rather than emerging properties, which integrate even further the driving energies and ecosystem functions into easily measurable parameters.

Several easily calculated soil parameters show promise in establishing trajectories for assessment. If appropriate hydrology and vegetation have been restored, organic matter should increase, and bulk density should decrease over time. Increasing the number of sites sampled will determine the applicability of this method.

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