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A Two-Year Seasonal Analysis of Wetland Vegetation at the McClintic Wildlife Management Area in Mason County, West Virginia

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A TWO-YEAR SEASONAL ANALYSIS OF WETLAND VEGETATION AT THE MCCLINTIC WILDLIFE MANAGEMENT AREA IN MASON COUNTY, WEST VIRGINIA

By

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Abstract

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Disturbances play a key role in the structure of ecosystems. Most ecosystems are subject to several different disturbance regimes that occur at different temporal and spatial scales. Studying the effects of disturbances can lead to a better understanding of a vegetative community's future productivity. However, in order to understand the effects of disturbance, a vegetative community should first be studied before the disturbance occurs. This study analyzes the composition and seasonal variations of vegetative communities in and around four ponds at the McClintic Wildlife Management Area in Mason County, West Virginia during two growing seasons prior to remediation activities in order to provide a comparison for the effects of the remediation occurring in that area. The objectives of the study were: (1) to characterize aquatic and terrestrial shrubs and herbs over the 1997 and 1998 growing seasons; (2) to observe the monthly patterns of richness, cover and density of the aquatic and terrestrial vegetation; and (3) to compare the vegetation in and around the four ponds where sampling occurred. Species richness, cover and density were used to determine seasonal variations among the species present at each pond. Detrended Correspondence Analysis (DCA) was used to indicate variability among the sampling sites and the influence of certain species during the growing seasons. A wide range of variability occurred among the three vegetative strata and four ponds. In the aquatic stratum, Pond 4 had the most variation among the months and years, where Pond 3 seemed to have the least amount of variation. For the herbaceous stratum, all ponds had some degree of variability mostly occurring between the months in 1997, especially between June and the other two months. The shrub stratum showed mostly overlap between years, indicating a small amount of variability and separation between 1997 and 1998 with most of the variation occurring between months. In general, expected seasonal trends of productivity occurred with a few exceptions which could be attributed to unexpected seasonal trends in precipitation, resource availability and/or interspecific and intraspecific competition. As such, these factors should be considered in evaluating the composition of a community both before and after a disturbance.

Acknowledgements

The completion of this thesis would not have been possible without the efforts, support and patience of a number of individuals. First, I would like to thank Dr. Jeffrey D. May for giving me the opportunity to be a part of this research and for his patience and willingness to allow me to finish this study at the "right time". I also appreciate the support, time and efforts of Dr. Frank S. Gilliam, and Dr. Dan K. Evans for their mentoring and assistance in this study and for accommodating my final attempt in finishing my graduate work. I would like to thank my research partner, Russell Shrader, who, many years ago, accompanied me in this study and assisted in the collection, recording and analysis of the vegetation at the four pond sites at the McClintic Wildlife Management Area.

I would not have been able to complete my graduate work and this thesis without the support and understanding of my employer, Robinson & McElwee PLLC. Specifically, I would like to thank Robert L. Lannan, Esquire, Edward J. George, Esquire, David L. Yaussy, Esquire, and Kim Brown Poland, Esquire, for their constant support and interest in my graduate work and for accommodating my schedule during the last few months of this journey. I would also like to thank Martin H. Berman, who spent many hours and days in formatting and resurrecting crucial files that were essential to this study. Without him, this final document would not have been possible.

Finally, I would like to thank my family. My mother, Elaine Zopp, has been a constant source of inspiration and strength through every challenge in my life, including the completion of this thesis. Without her wise advice and constant support, this challenge would have seemed impossible. Last, but not least, I would like to thank my husband, Andy. We have survived many challenges thus far and have come out stronger and happier each time. Thank you for your humour, patience, loyalty and love, which make all things seem possible.

Dedication

This thesis is dedicated to my father, Henry Hobson Hubbard, II, who taught me to always finish what I start and whose legacy is a constant inspiration for me to challenge myself, to strive to be a better person and to have compassion for others.

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Chapter I

Introduction

Disturbance, productivity, and spatial heterogeneity are major factors regulating species richness in plant communities (Groombridge 1992, Ricklefs and Schluter 1993, Huston 1994, Pollock et al. 1998). Disturbances are also integral features of ecosystems and most ecosystems are subject to several disturbance regimes that occur at different temporal and spatial scales (Holling et al. 1995; Turner et al. 1998; Elmqvist et al. 2001). The disruption of forest structure by natural or human disturbances alters ecosystem processes, which regulate the normal retention and cycling of the elements (Boring and Monk 1981), including plant elemental uptake. Among other causes, this may alter and influence species composition. Gleason (1926), who pioneered the individualistic concept of the plant association, also recognized that disturbances shape the spatial and temporal boundaries of the plant association (Abrams and Scott 1989). Therefore, disturbances can play a powerful role in shaping the characteristics of a vegetative community.

Both human and natural disturbances can affect the ecosystems of terrestrial and aquatic plants in wetland habitats. Studying the effects of these disturbances can lead to a better understanding of a vegetative community’s future productivity and how to better manage such ecosystems. In order to understand the effects of disturbance, the ecological community impacted should also be studied before a disturbance occurs. This process is difficult as ecological systems are continuously changing through natural processes (Dawe et al. 2000). Changes can also occur through the effects of human activities as they interact with the natural variations in systems. It then may become difficult to distinguish the effects of human activities from those of natural variations (Waters and Holling 1990), including seasonal changes, emphasizing the need for a natural variation analysis before a known human disturbance occurs.

Many interactions comprise the natural variations within vegetative communities. A study of the Hubbard Brook Experimental Forest by Bormann et al. (1970) indicated that the vegetation in New England is composed of a system of interacting populations which balance each other. Each vegetation stratum (herbs, shrubs and trees) can play a crucial role in determining the balance of vegetation in other stratum populations. For example, it has been found that variations in understory conditions resulting from different canopy tree species may help influence the distribution and abundance of herbaceous species (Catovsky and Bazzaz 2000; Beatty 1984; Turner and Franz 1986). Most emphasis has been placed on the large, dominant, woody species in which much of the forest biomass is accumulated. However, such species may not characterize ecosystem dynamics as well as understory vegetation, which responds to subtle changes in the stand structure, microclimate, and edaphic factors (e.g., Anderson et al. 1969). Furthermore, information on understory productivity may be critical for understanding processes such as nutrient cycling and animal foraging (Alaback 1986).

Among the understory vegetation, the herbaceous layer is particularly indicative of ecosystem dynamics. Usually defined as all vascular plants < 1-2 m in height (Siccama et al. 1970; Rogers 1981; Gilliam and Christensen 1986), the herbaceous layer is an important and dynamic forest stratum. Although herbaceous vegetation contributes only a small proportion of the total biomass of an ecosystem (Zavitkovski 1976), nutrient dynamics and competitive interactions within this stratum influence the initial success of plants occupying higher strata (Gilliam and Turrill 1993). In turn, herbaceous layer development is strongly affected by canopy characteristics including stand species composition and density (Turrill 1993).

Studies of herbs of the eastern deciduous forests of North America demonstrate that variations in species composition among forest stands are often associated with complex gradients and environmental factors (Beals and Cope 1964; Pregitzer and Barnes 1982; Mann and Shugart 1983; Crozier and Boerner 1984). Bratton (1976) noted that within a forest stand, an herbaceous species may have a preference which is strongly related to its position along certain gradients such as changes in aspect or soil (Aulick 1993). Changes in herb species composition have also been demonstrated among smaller-scale, within-stand gradients (Bratton 1976; Thompson 1980; Crozier and Boerner 1984). These small-scale changes in species abundance may be due to the differences in the dispersal abilities of herbs, which are correlated to different physical features of the forest floor (Crozier and Boerner 1984). Furthermore, the distribution of species is far from even, creating a spatial mosaic of species richness (Rico-Gray et.al., 1997). Not only are species unevenly distributed, their interactions can also vary spatially. Interactions vary in their probability of occurrence along different environmental gradients and under different disturbance regimes (Rico-Gray et.al., 1997), and they vary in their outcome under different ecological conditions (Rico-Gray et.al., 1997).

In addition to varying interactions along different environmental gradients, there are also different interactions among species in different habitats, such as terrestrial and aquatic environments. Differences in interactions in these two habitats can be attributed to competition for different resources. Terrestrial species will compete more for water and less for oxygen when compared to aquatic species. Nutrient and light competition also differs between the two types of species, as their needs vary for both. Outcomes of these interactions under stress will also cause differences in production between terrestrial and aquatic species.

Scientists have posed additional theories on species diversity concerning wetland habitats. They are often described as transitional ecosystems that represent continua between strictly aquatic and strictly terrestrial ecosystems (Brinson 1993). Clements (1916) debated the theoretical differences in the nature of such environmental gradients in ecosystems. He portrayed communities as discrete units with sharp boundaries and a unique organization. Gleason (1926) countered Clements view, finding that the abundance of individual species responds only to the prevailing environmental conditions (Brinson 1993). He believed that a community has no natural limits and that each species is distributed independently of others that co-occur in a particular association. However, due to the absence of well–defined environmental gradients, species diversity in submerged plant communities has often been attributed to interspecific competition (e.g., Hutchinson 1975; Chambers and Prepas 1990), where two or more species compete for limited resources. The absence of moisture gradients, uniformity of water temperatures in the euphotic zone and the vertical constraints to plant growth imposed by water depth also contribute to the potential for interspecific competition in structuring these communities (Chambers and Prepas 1990).

In addition to the many factors which can impact vegetative communities in wetland habitats, stand age and history, particularly, are known to affect species cover, composition, and richness (Albert and Barnes 1987, Gilliam and Turrill 1993). Similar stand age and uses of land can result in comparable species composition. Similar soils and moisture availability also create environments that allow for like species to grow and develop. Observation of these factors is important in evaluation of species composition, along with seasonal studies to compare and analyze monthly patterns of species productivity. As species composition reflects a combination of environmental and historical events at a site, studying species composition changes within a vegetative community can provide a sensitive measure of ecologically relevant changes in the environment (Philippi et al. 1998).

Successional changes in species composition are considered to be important in regulating community attributes such as species diversity (Tilman 1993; Huston 1994; Ikeda 2003). Therefore, observing monthly patterns during a growing season is an important analysis in a vegetative study. When only peak months are observed, activity of early-and late-season species is missed. Intensive, short-term studies such as this are essential for viewing successional steps as they occur and provide a more complete understanding of total ecosystem dynamics (Hockenberry 1996). Seasonal patterns in a two-year study can also show the effects of weather conditions of both growing seasons, which can influence growth conditions.

This study analyzes seasonal variations among both terrestrial and aquatic environments in a wetland habitat. This is one of two studies of a project funded by the U.S. Army Corps of Engineers (COE) to initially assess vegetation in an area that has been exposed to disturbance by groundwater remediation. By studying the affected area before the remediation occurs, this analysis will set a basis of comparison for future observation of the vegetation impacted by the remediation project. The objectives of the study were: 1) to characterize aquatic and terrestrial shrubs and herbs over the 1997 and 1998 growing seasons; 2) to observe monthly patterns of richness, cover and density of aquatic and terrestrial shrub and herbaceous layers; and 3) to compare the vegetation in and around the four ponds where the sampling occurred.

Chapter II

Materials and Methods

Site Description

This study was conducted at the McClintic Wildlife Station (MWS), which occupies approximately one-third of the former West Virginia Ordnance Works (WVOW) in Mason County, WV. On the site, 2,4,6-dinitrotoluene (TNT) was produced from 1941 to 1946. The site contained ten TNT manufacturing areas on the Ohio River, 100 storage magazines, wastewater holding ponds, burning grounds, an administrative area, and employee housing. Prior to the establishment of the TNT manufacturing plant, the major land uses were for crops (approximately 50 percent of the area), forest, pasture, and approximately 30 farm residences.

The MWS area is 1,115 ha in size and is now operated by the West Virginia Department of Natural Resources (DNR). The area has been designated by the DNR to promote a wetland/terrestrial habitat for populations of resident and migratory wildlife. At the close of operations in 1945, an effort was made to decontaminate the WVOW. The site contained red and yellow liquid wastes, which were produced in the manufacturing process of TNT. More than 30 shallow ponds have been constructed since cessation of military activities and used as retention ponds, known as the Red Water Reservoirs and Yellow Water Reservoirs. These were constructed to regulate the discharge of red and yellow water to the river. Surface and subsurface soils and groundwater in areas of WVOW are still contaminated with nitroaromatic residues. A potential also exists for contamination of other areas due to post-operative contamination resettlement.

In May 1981, ranger officials observed seepage of red water adjacent to Pond 13. The DNR and the U.S. Environmental Protection Agency (EPA) investigated this incident. The shallow ground water discharging to Pond 13 was found to be contaminated by hazardous substances pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. §9601 *et seq*. (CERCLA). These findings led to a remedial investigation. A Record of Decision was made regarding sources of contamination and groundwater. Remediation activities have been in process since 1997 and have included groundwater extraction and treatment processes.

The groundwater extraction plan called for monitoring the potential impacts to ponds, and the plant communities they support. Impacts of water withdrawal were anticipated in and around wetlands directly over the withdrawal zones of the Pond 13 and the Yellow Water Area. Initially, the discharge from the groundwater remediation was not meeting water quality standards and the project was stopped. However, following an alternative analysis study, system modifications were made to provide additional effluent treatment and the remediation activities resumed in 2000. This study occurred after the remediation stopped in 1997 and before the remediation activities resumed in 2000.

Site Soils and Precipitation

Many of the similarities and differences among the ponds can be attributed to the soils and history of the area. McClintic Wildlife Station is located near Point Pleasant in Mason County, West Virginia. The history of Point Pleasant dates back to the late 1700's when the first settlements were made after the Indian War. It was not until about 1800, however, that sizable permanent settlements were made in Mason County. Early settlers cleared and farmed bottomlands first and gradually worked back into the hill country. Many of the general farms have been allowed to grow up partially in natural vegetation for the past few decades, as many farmers have accepted employment in nearby industrial plants.

Mason County has a warm temperate climate. Precipitation is well distributed throughout the year. The rainfall in June and July is considerably above the monthly average, while August has about average rainfall. The average growing season, in areas along the Ohio River, is 173 d (April 23 to October 16) according to records at Point Pleasant, where the elevation is 171 m. Growing seasons in the uplands, which are 60 to 90 m higher in elevation, can be expected to be slightly shorter.

There are about 4960 ha of woodland in Mason County. Woodlands are for the most part of the Upshire-Muskinghum and the Muskinghum-Upshire soil complexes and related soils. They are mostly on the southern and western exposures of the steepest land in the county. According to the U.S. Soil Conservation Service (1961), the soils identified along the Ohio River bottomlands and terraces are the Aston, Wheeling, and Lakin Associations. The bottomlands and river terrace deposits consist of alluvial soil, with a thin veneer of recent river silt and clays. Since the pond sites at MWS are located in close proximity to the Ohio River, these bottomland soils will probably be most influential on the vegetation studied. The upland areas can be grouped into the Muskinghum, Upshur, and Vandalia Associations. The upland soils consist of material weathered from the underlying bedrock, mostly sandstone, shales, and siltstone. A third major soil type consists of mixed elements of alluvium and sediment disintegrated from the underlying bedrock. These mixed soils are located on upland terraces and consist of the Wheeling soil type on well-drained areas and the Sciotoville, Ginat, and Chilo soil types on the poorly drained areas. This variety of soils, with a wide range of drainage and permeability could allow for different growing conditions among ponds, resulting in a variety of species and growth patterns.

Field Sampling

Sampling was conducted in plant communities in and around Ponds 3, 4, 13, and 14 (Figure 1). Three of the ponds (3, 13, and 14) were chosen because they were in potential cones of depression (treatment areas). Pond 4 was chosen as a control pond because it was outside the treatment area. Ponds varied in shape, depth, extent of watershed, underlying soils, and disturbance. Permanent transects were established, two per pond, perpendicular to the margin of each pond, for a total of 20 m. Within each transect, four 5-m x 5-m plots were established for assessment of shrubs. Portable 1-m^2 tubing was used to create six plots for analysis of herbaceous layers along each transects line. Transects were also extended into the water for sampling aquatic vegetation using portable 1m^2 tubing.

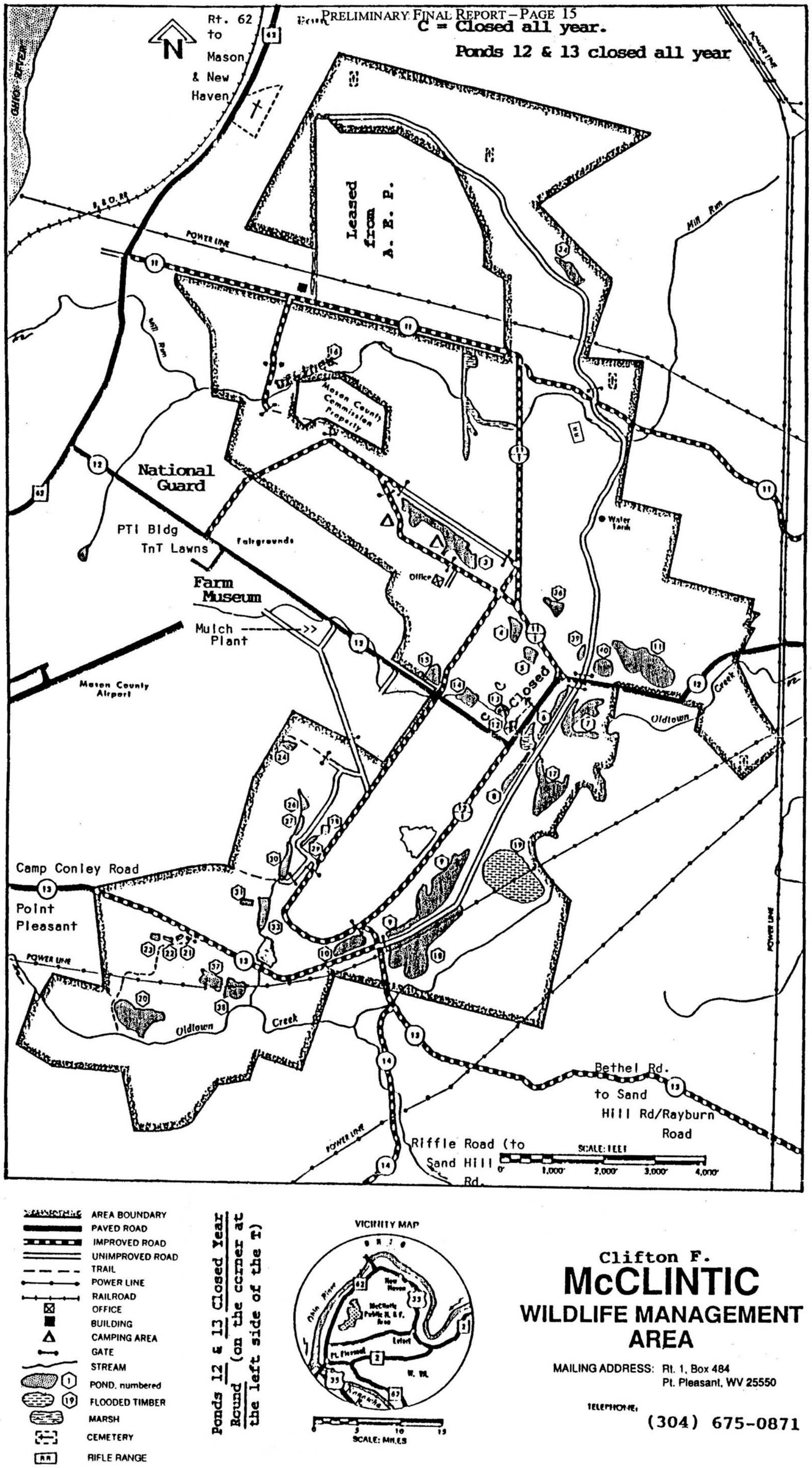
Data Collection

Quantitative measurements were made monthly for each pond during the 1997 and 1998 growing seasons. Height and number of stems were used to determine relative importance values for shrubs (woody plants greater than 1.0 m in height, but less than 2.5 cm DBH (diameter at breast height)). Percent cover was used to quantify herbaceous plants (those less than 1.0 m in height) and aquatic vegetation.

Data Analysis

Data for the herbaceous, aquatic and shrub plants were initially averaged from all plots in both transects from each pond to give mean cover, density and richness totals. These totals were examined for seasonal variation of all species for each month sampled from the 1997 and

Figure 1. Map of McClintic Wildlife Management Area, Mason County, West Virginia.


C = Closed all year.
Ponds 12 & 13 closed all year
Rt. 62 to Mason & New Haven
Leased from A. E. P.
POWER LINE
Mill Run
Mason County Commission Property
National Guard
PTI Bldg
TnT Lawns
Fairgrounds
Office
Farm Museum
Mulch Plant
Mason County Airport
Water Tank
Closed
Oldtown Creek
Camp Conley Road
Point Pleasant
Bethel Rd. to Sand Hill Rd/Rayburn Road
Riffle Road (to Sand Hill Rd.
SCALE: FEET
AREA BOUNDARY
PAVED ROAD
IMPROVED ROAD
UNIMPROVED ROAD
TRAIL
POWER LINE
RAILROAD
OFFICE
BUILDING
CAMPING AREA
GATE
STREAM
POND, numbered
FLOODED TIMBER
MARSH
CEMETERY
RIFLE RANGE
Ponds 12 & 13 Closed Year Round (on the corner at the left side of the T)
VICINITY MAP
SCALE: MILES
Clifton F.
McCLINTIC
WILDLIFE MANAGEMENT AREA
MAILING ADDRESS: Rt. 1, Box 484
Pt. Pleasant, WV 25550
TELEPHONE:
(304) 675-0871

1998 growing seasons. Cover of the aquatic and herbaceous plants that measured >1% of the ground cover of any month in any pond was used to show patterns of variation throughout the two-year sample period. Density (number of stems of each species/plot) was used to show seasonal variation of the shrub plants for each month, from each pond of the 1997 and 1998 growing seasons. Richness (number of species/plot) was calculated for aquatic, shrub, and herbaceous data to show variation in species abundance during the two growing seasons.

Importance values (IV) were calculated for each species from the relative cover of the herbaceous and aquatic species and the average of the relative height and relative density of the shrub species. Importance values were used to indicate the relative dominance of a species within its community stratum, implying its importance in controlling ecosystem dynamics such as the transfer of nutrients and energy. Data were averaged from all plots from the three stratum to arrive at a condensed number of 52 plots for each type of strata, one for each month for each pond. These numbers were used in the multivariate technique Detrended Correspondence Analysis (DCA) to show variability among ponds over the two years. The DCA graphs are based on the importance values of the different species at each pond, which indicates the relative strength of the associations between the species and each pond. This technique analyzed the 52 aquatic, herbaceous, and shrub plots separately, giving 3 matrices to show overall variability between ponds and to determine which species were most responsible for the variation.

Monthly patterns were analyzed of the three types of vegetation from June to November 1997, and April to October 1998. In this analysis, there were 12 matrices used to determine variability among the ponds during the two - year growing season. These data were also separated into the three types of vegetation. The resulting DCA values were used to determine which species were most responsible for causing monthly variability.

Chapter III

Results and Discussion

Overview

A total of 76 species were identified from sampling which occurred from June 1997 to October 1998 at the four pond sites (See Appendix). Of the species identified, 23 species were found in aquatic plots, 68 species were found in the herbaceous plots, and 33 species were found in the shrub plots. Species will be referred to by common name. For reference, the scientific names, acronyms, and authorities for each species will be listed in the Appendix. The data and results of the vegetative study are presented by strata (aquatic, herbaceous and shrub). For each stratum, the overall species composition for that stratum is presented first. Second, data and discussion of the seasonal variations of the vegetation among the four pond sites will be discussed. Finally, the inter-year differences in vegetation will be addressed. In each discussion results will be presented using DCA, species richness, and average cover or density analysis.

Aquatic Vegetation

Species Composition.

Of the species identified, 23 unique species were found in aquatic plots. In 1997, there were 15 different species identified, and in 1998 there were 20 species identified among all four ponds in the aquatic plots. Pond 14 had the highest average monthly species richness of the four ponds in 1997, with 4.5 species per month and Pond 13 had the highest average species richness in 1998, with 6.5 species per month (Table 1).

The average overall aquatic cover increased in 1998 at Pond 13 (Table 1). At Ponds 14, 3, and 4, however, overall average aquatic cover decreased in 1998 compared to 1997 (Table 1).

Table 1. Average cover, density and richness for each pond in 1997 and 1998.

	P13		P14		P3		P4	
Variable	1997	1998	1997	1998	1997	1998	1997	1998
Cover (%)								
Aquatic	13.9	35.9	43.9	26.9	114.4	85.6	32	15.6
Herbs	46.6	78.6	37.2	56.8	28.9	48.5	45.3	74.1
Density (stems/m^2)								
Shrubs	73.5	87.1	107.9	113.2	36.3	47.1	85.4	122.9
Richness (# species)								
Aquatic	4	6.5	4.5	3.7	2	2.4	3.3	3.9
Herbs	11.5	15.4	16.2	20.6	18.8	22.7	21.8	26.1
Shrubs	9.7	11	10.2	11.9	7.2	6.7	9.8	11.7

These were the only plots among the stratum where average cover decreased over the two-year study. Climatic variation undoubtedly affects year to year growth (Dawe et al. 2000). However, since the cover decreased in three of the sties, such decrease could be attributed to site specific conditions, such as a decrease in resource availability for the aquatic plants, including light and nutrient availability.

Species with the ten highest importance values in the aquatic plots were considered dominant compared to the other species present. In the aquatic plots there was some variability in dominant species. Only two dominant species, coontail and mild waterpepper, were present in all four ponds (Table 2). Other dominant species occurred in more than one pond, indicating some degree of similarity among the aquatic plots (Table 2). Examples of these species are least duckweed, marsh purslane, and watermeal (Table 2). Only one of the dominant species existed in just one pond. This species was ground pine and was present only in Pond 4 which contained different surrounding habitat conditions than the other ponds.

In the analysis of the aquatic data, the seasonal variations among the four ponds will be discussed using DCA, species richness, and cover results. Each pond will be discussed separately when using DCA. Discussion of all four ponds will be combined when analyzing species richness and cover so that comparisons can be made. Finally, the inter-year differences of aquatic vegetation will be presented, combining the results from all four ponds in a discussion using DCA, species richness, and cover.

Table 2. Dominant aquatic species based on average importance value for each pond.

Species	Common Name	P13	P14	P3	P4	Mean Importance Value
Ceratophyllum demersum	Coontail	3.8	51.0	23.1	32.9	27.7
Wolffia punctata	Watermeal	-----	-----	55.4	17.3	18.2
Ludwigia palustris	Marsh purslane	14.1	25.7	-----	0.6	10.1
Cephalanthus occidentalis	Buttonbush	9.0	7.3	-----	21.4	9.4
Polygonum hydropiperoides	Mild waterpepper	19.8	5.2	0.2	7.1	8.1
Polygonum persicaria	Ladies thumb	16.1	5.6	-----	-----	5.4
Lemna minor	Least duckweed	-----	0.02	13.3	6.9	5.1
Alnus serrulata	Brookside alder	1.6	1.5	-----	-----	0.8
Lycopodium flabelliforme	Groundpine	-----	-----	-----	1.7	0.4
Panicum sp.	Panic grass	-----	0.01	-----	1.7	0.4

----- = Lower than 10^{th} in importance value

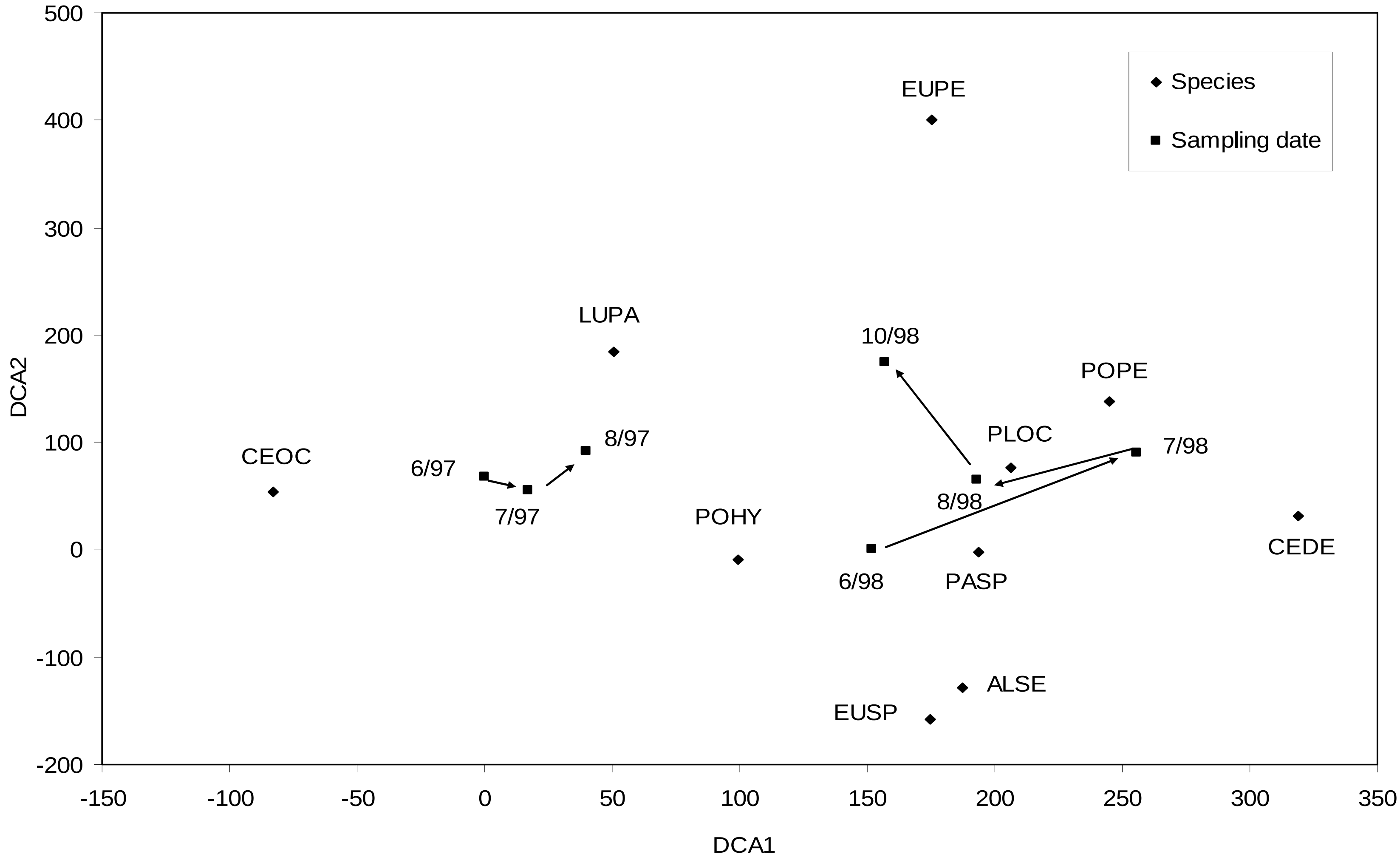
Seasonal Patterns of Aquatic Vegetation

DCA

Seasonal patterns were observed by sampling every month for two growing seasons, June to November 1997 and April to October 1998. In the DCA analysis, data from June, August and October of 1997 and 1998 were utilized to show which species were influential in each of the four ponds. For Pond 13 aquatic species, however, the month of July was added to the analysis due to the lack of vegetation in October of 1997. Influences from each month were shown for each type of stratum by analyzing data by pond and stratum. The ten most important species from each month were used to show variability among the sampling months. The locations of the species on the graph will be associated with their respective influence on distinguishing the vegetation make-up of the ponds in different months. By looking at the location and proximity of a species in relation to a specific month, the influence of that species can be determined. The DCA provides a means of illustrating changes in species composition occurring through time (DeGrandpre and Bergeron 1997). This was illustrated by inserting vectors between the points in time on the graphs.

Pond 13. Overall, Pond 13 had more variation among the months in the 1998 growing season than in the 1997 growing season. The variation between the two years could be due to the increase in species richness and cover of aquatic species in 1998 (Table 1). This increase resulted in higher variability among the individual months in 1998 as well. For the 1997 sampling months, the points representing aquatic species in Pond 13 indicated that June, July and August had little separation among species variation (Figure 2). The proximity of the species' points to the months shows that buttonbush was abundant in June of 1997 and marsh purslane was more abundant in August of 1997 (Figure 2). More species were clustered around the

Figure 2. DCA for Pond 13 aquatic species showing influence of species diversity during the months of June, July, and August 1997 and June, July, August and October of 1998.


Species
Sampling date
EUPE
LUPA
10/98
POPE
PLOC
8/97
7/98
CEOC
6/97
8/98
7/97
POHY
CEDE
6/98
PASP
ALSE
EUSP
DCA2
DCA1
500
400
300
200
100
0
-100
-200
-150
-100
-50
0
50
100
150
200
250
300
350

months June, July, August and October of 1998 (Figure 2) which is consistent with the increase of richness and cover in 1998. Seven species were surrounding these months including mild waterpepper, the most important species of all of the seven months used in the graph (Table 3). Boneset was isolated from all months along the DCA2 axis (Figure 2), indicating that, although it was a more important species at this pond, it had less of an influence on the monthly variability.

Pond 14. Only eight species occurred in Pond 14 during these sampling months (Figure 3, Table 4). In this analysis, months were separated along the DCA1 axis with June 1997 overlapping with the months of 1998 (Figure 3), indicating the similarities in species composition during those months. In 1997, buttonbush and coontail were most abundant in August and October (Figure 3) at the height and end of the growing season. These were the two most important species for Pond 14 (Table 4). Marsh purslane was most abundant in October 1998 (Figure 3). June of 1997 and 1998 and August 1998 were similarly affected by buttonbush and marsh purslane (Figure 3). Species that did not have a large effect on these months were *Panicum* sp., soft rush and least duckweed (Figure 3). These species also had the overall lowest importance values for Pond 14 (Table 4).

Table 3. Aquatic species used in Pond 13 DCA graph and their importance values.

Species	Common Name	Acronym	Importance Value
Polygonum hydropiperoides	Mild waterpepper	POHY	19.8
Polygonum persicaria	Ladies thumb	POPE	16.1
Ludwigia palustris	Marsh purslane	LUPA	14.1
Cephalanthus occidentalis	Buttonbush	CEOC	8.9
Ceratophyllum demersum	Coontail	CEDE	3.8
Eupatorium sp.		EUSP	1.8
Alnus serrulata	Brookside alder	ALSE	1.6
Eupatorium perfoliatum	Boneset	EUPE	1.2
Panicum sp.	Panic grass	PASP	0.5
Platanus occidentalis	Western sycamore	PLOC	0.1

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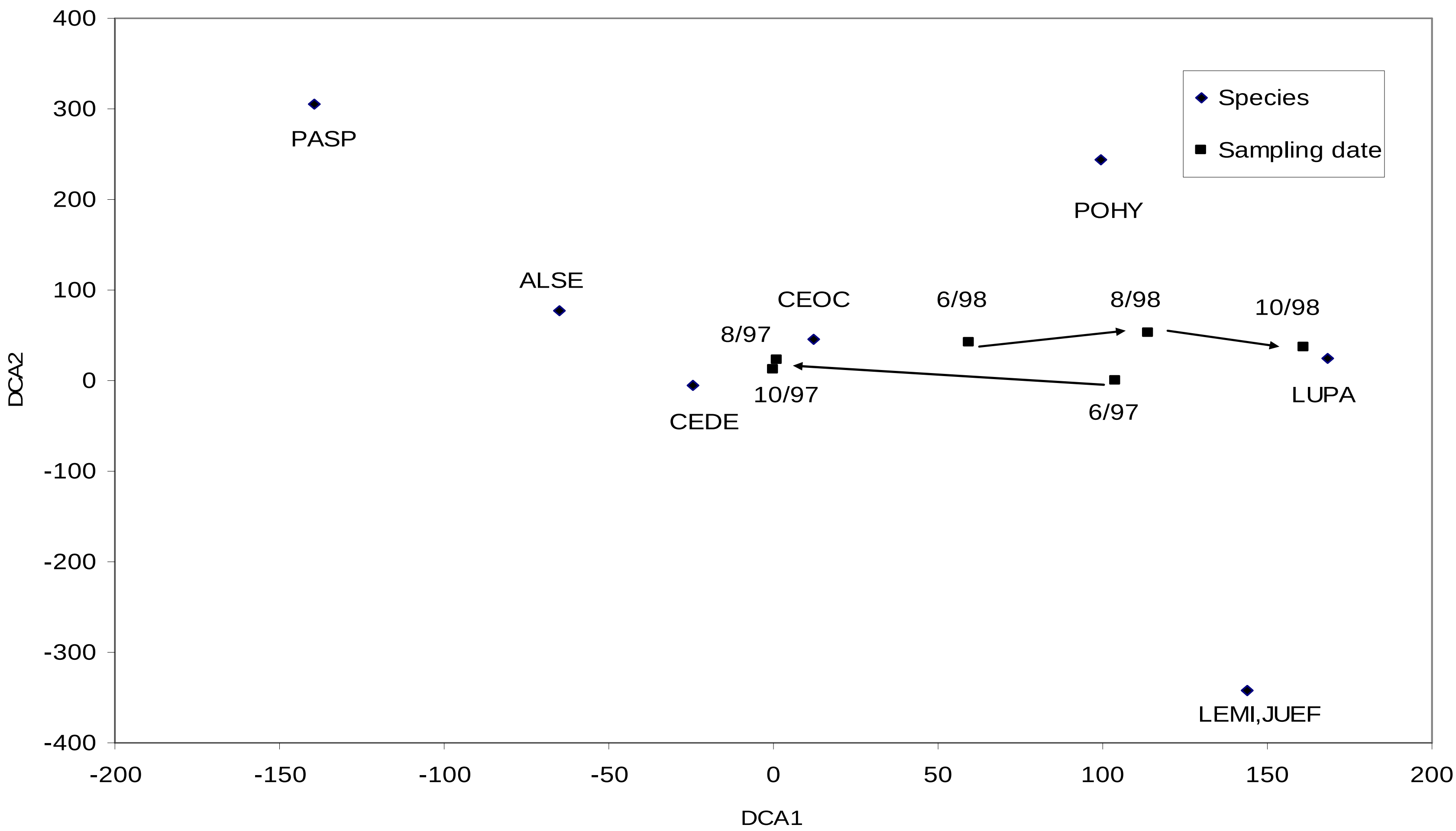
Table 4. Aquatic species used in Pond 14 DCA graph and their importance values.

Species	Common Name	Acronym	Importance Value
Ceratophyllum demersum	Coontail	CEDE	51.0
Ludwigia palustris	Marsh purslane	LUPA	25.7
Cephalanthus occidentalis	Buttonbush	CEOC	7.3
Polygonum hydropiperoides	Mild waterpepper	POHY	5.2
Alnus serrulata	Brookside alder	ALSE	1.5
Juncus effusus	Soft rush	JUEF	0.2
Panicum sp.	Panic grass	PASP	0.1
Lemna minor	Least duckweed	LEMI	0.02

Figure 3. DCA for Pond 14 aquatic species showing influence of species diversity during the months of June, August and October 1997 and June, August and October 1998.



400
300
200
100
0
-100
-200
-300
-400
DCA2
-200
-150
-100
-50
0
50
100
150
200
DCA1
Species
Sampling date
PASP
POHY
ALSE
CEOC
6/98
8/98
10/98
8/97
10/97
CEDE
6/97
LUPA
LEMI,JUEF

Pond 14 showed a different pattern of variability than Pond 13. In Pond 14 there was little to no variability between August and October of 1997, but there was substantial variability among June 1997 and the other months of 1997. June of 1997 had more variation among the other 1997 months than with the months of the 1998 growing season. There were equal amounts of variability among the months of 1998. The similarities of June 1997 with the 1998 months may be due to the strong presence of marsh purslane in the month of June 1997 (Table 5). Overall, the most important species for both years was coontail, which seemed to be most abundant in August and October of 1997 (Table 4, Table 5).

Pond 3. Only four species were found in Pond 3 during June, August and October of 1997 and 1998 (Figure 4). The most important of these species was watermeal, which was most abundant in June 1998 (Table 6). The other three species, coontail, mild waterpepper, and least duckweed seemed to have a similar effect on the other months of the growing season, which formed a cluster in the center of the graph (Figure 4). This suggests little variability among the three months from both years. This may be attributed to the fact that there were only four species present and, therefore, less influence on each of the months due to the low species richness. August of 1998, however, was slightly varied, as shown by a shift towards the right on the graph by the influence of least duckweed (Figure 4). There was more variation among the 1998 months than among the 1997 months. The species richness for 1998 was slightly higher, which may have affected the variation among the three months of 1998 (Table 1).

Pond 4. Pond 4 overall had the most variability among the ponds during the months of the two growing seasons. This variability could be explained by the increase in

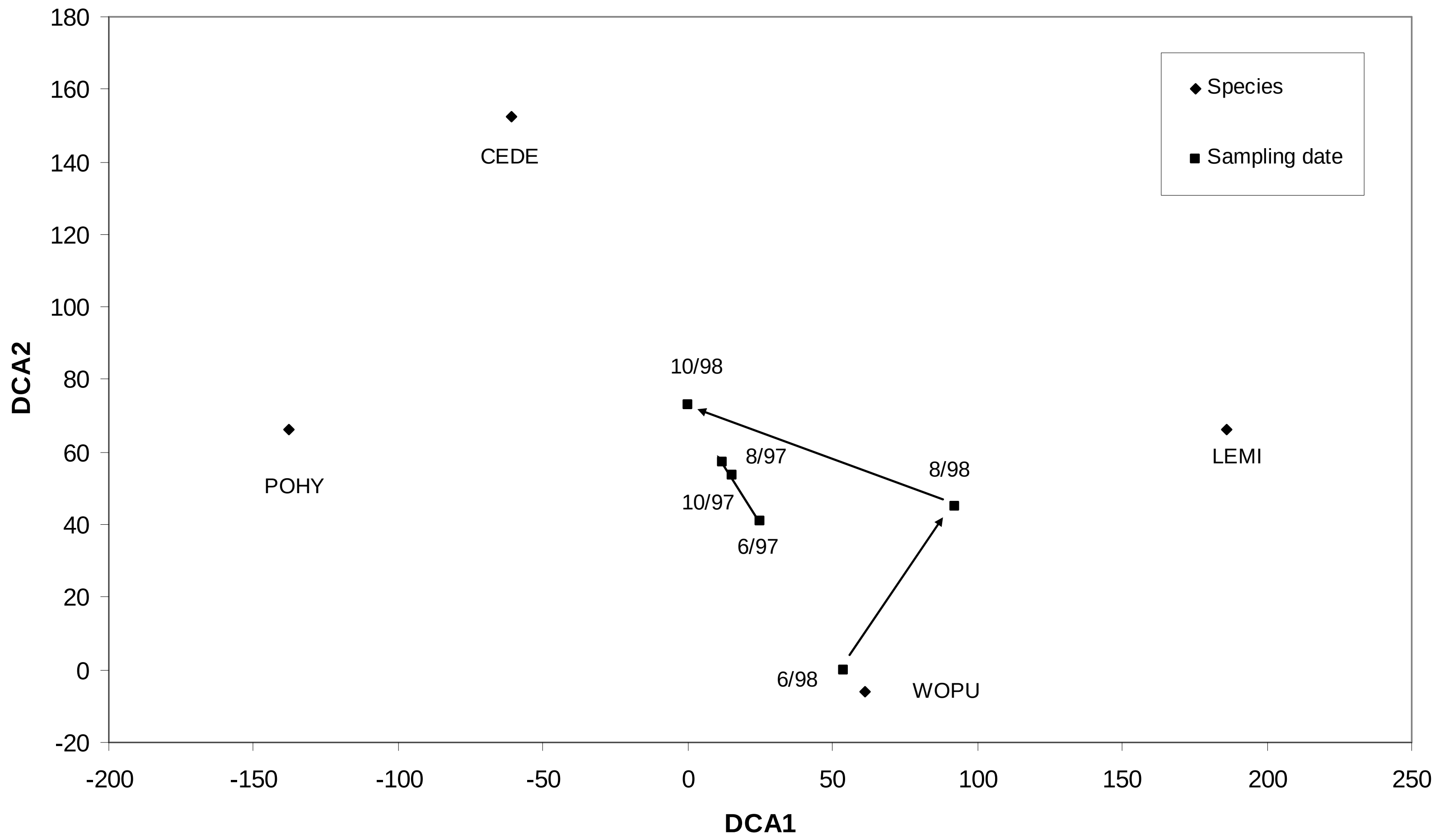
Table 5. The most dominant species (aquatic, herbaceous and shrub) at each pond for each month of the growing season for 1997 and 1998 and their importance values for each month. (See Appendix for acronym).

Ponds	1997 Jun	1997 Jul	1997 Aug	1997 Sept	1997 Oct	1997 Nov	1998 Apr	1998 May	1998 Jun	1998 Jul	1998 Aug	1998 Sept	1998 Oct
AQUATICS													
POND 13	POHY (26.9)	POHY (39.8)	LUPA (45.5)	-----	-----	-----	-----	POHY (51.9)	POHY (43.5)	POPE (63.3)	POPE (35.9)	POPE (39.0)	POPE (48.4)
POND 14	LUPA (40.5)	CEDE (74.9)	CEDE (73.8)	CEDE (77.9)	CEDE (72.0)	CEDE (100)	CEDE (90.3)	CEDE (85.0)	CEDE (42.3)	POPE (73.0)	LUPA (61.2)	LUPA (79.1)	LUPA (92.4)
POND 3	WOPU (70.3)	WOPU (------)	WOPU (60.0)	WOPU (61.3)	WOPU (62.4)	CEDE (69.8)	WOPU (93.5)	WOPU (57.1)	WOPU (95.1)	WOPU (96.4)	WOPU (46.5)	WOPU (94.2)	WOPU (50.0)
POND 4	CEOC (74.6)	CEDE (58.5)	CEDE (74.1)	CEOC (42.8)	CEOC (48.7)	CEDE (100)	WOPU (100)	LEMI (65.8)	WOPU (49.3)	CEDE (50.2)	CEDE (35.4)	HYPU (35.1)	HYPU (100)
HERBS													
POND 13	JUEF (20.9)	LOJA (25.6)	PAQU (21.3)	PAQU (20.9)	LOJA (26.2)	LOJA (30.4)	PAQU (28.5)	POSI (16.1)	RHRA (16.8)	POSI (16.0)	POHY (16.0)	LOJA (20.4)	LOJA (22.2)
POND 14	LUPA (23.8)	LOJA (25.1)	PAQU (20.5)	SAAL (15.6)	DASP (42.5)	DASP (42.8)	DASP (42.6)	DASP (24.7)	DASP (21.5)	DASP (14.4)	LUJA (26.3)	DASP (34.7)	DASP (37.1)
POND 3	LOJA (58.7)	LOJA (55.3)	SPDO (37.9)	SPDO (34.1)	SPDO (39.4)	SPDO (36.9)	SPDO (37.5)	SPDO (26.6)	SPDO (21.1)	PAN1 (26.8)	SPDO (15.1)	SPDO (19.3)	SPDO (9.6)
POND 4	PAN1 (20.9)	LOJA (22.9)	SPHG (31.7)	SPHG (36.7)	SPHG (35.1)	SPHG (52.4)	SPHG (31.5)	PAN1 (27.1)	PAN1 (21.2)	PAN1 (19.9)	PAN1 (28.3)	SPHG (17.2)	SPHG (38.2)
SHRUBS													
POND 13	CAOV (18.1)	CAOV (17.5)	CAOV (16.8)	CAOV (21.0)	RUB1 (19.6)	RUB1 (36.6)	ELUM (35.5)	CAOV (17.2)	CAOV (16.0)	CAOV (17.0)	CAOV (21.5)	CAOV (17.3)	RUB1 (28.7)
POND 14	NYSY (27.1)	CAOV (11.9)	CAOV (16.6)	CAOV (22.1)	QUSP (22.8)	QUSP (32.8)	ELUM (30.4)	CAOV (19.2)	CAOV (18.3)	CAOV (17.9)	CAOV (22.7)	CAOV (20.7)	NYSY (21.6)
POND 3	ACRU (21.0)	ELUM (54.8)	ELUM (33.2)	ELUM (34.2)	ELUM (33.6)	LOJA (39.6)	ELUM (38.1)	ELUM (36.3)	ELUM (32.4)	ELUM (31.0)	ELUM (33.1)	ELUM (35.9)	ELUM (41.3)
POND 4	ASTR (18.6)	LIBE (22.0)	LIBE (19.7)	LIBE (18.9)	LIBE (17.9)	ELUM (33.9)	ELUM (21.3)	COFL (12.9)	LIBE (14.0)	LIBE (15.7)	LIBE (16.8)	LIBE (17.2)	ELUM (21.2)

Table 6. Aquatic species used in Pond 3 DCA graph and their importance values.

Species	Common Name	Acronym	Importance Value
Wolffia punctata	Watermeal	WOPU	55.4
Ceratophyllum demersum	Coontail	CEDE	23.1
Lemna minor	Least duckweed	LEMI	13.4
Polygonum hydropiperoides	Mild waterpepper	POHY	0.2

Figure 4. DCA for Pond 3 aquatic species showing influence of species diversity during the months of June, August and October 1997 and June, August and October 1998.


180
160
140
120
100
80
60
40
20
0
-20
DCA2
-200
-150
-100
-50
0
50
100
150
200
250
DCA1
Species
Sampling date
CEDE
POHY
LEMI
WOPU
10/98
8/97
10/97
6/97
8/98
6/98

richness in 1998 (Table 1). There were also many species present at Pond 4 that were high in importance value and that strongly influenced each month (Table 7). Even though there were many species present, cover for this pond was overall lower than other ponds (Table 1).

The effect of productivity in species richness has almost always given a unimodal, or hump-shaped, relationship between species richness and productivity (Weiher 1999). Under the unimodal theory, species diversity appears to peak at moderate levels of productivity and is lower when productivity is both very low and very high (Stevens 1999). The declining phase of this pattern has left some scientists puzzled where highly productive habitats tend to have fewer species than nearby, less productive habitats (Puerto et al.1990). The interspecific competition theory may explain this phenomenon as it drives down species richness. At highest levels of productivity, resource acquisition and growth by the dominant species reduces growth of less dominant species and eventually excludes them, resulting in a decrease in species richness (Stevens 1999).

Pond 4 was the only one that showed great variability in aquatic plants between the growing seasons. Buttonbush was most abundant in June of 1997 (Figure 5, Table 5). This was also the second most important species for Pond 4, preceded by coontail (Table 7). August of 1997 was pulled away from June by the influence of coontail and October 1997 was affected by mild waterpepper (Figure 5). October 1998 was pulled down the DCA1 axis by St.John's wort, while June and August were influenced by watermeal, ground pine and sensitive fern (Figure 5).

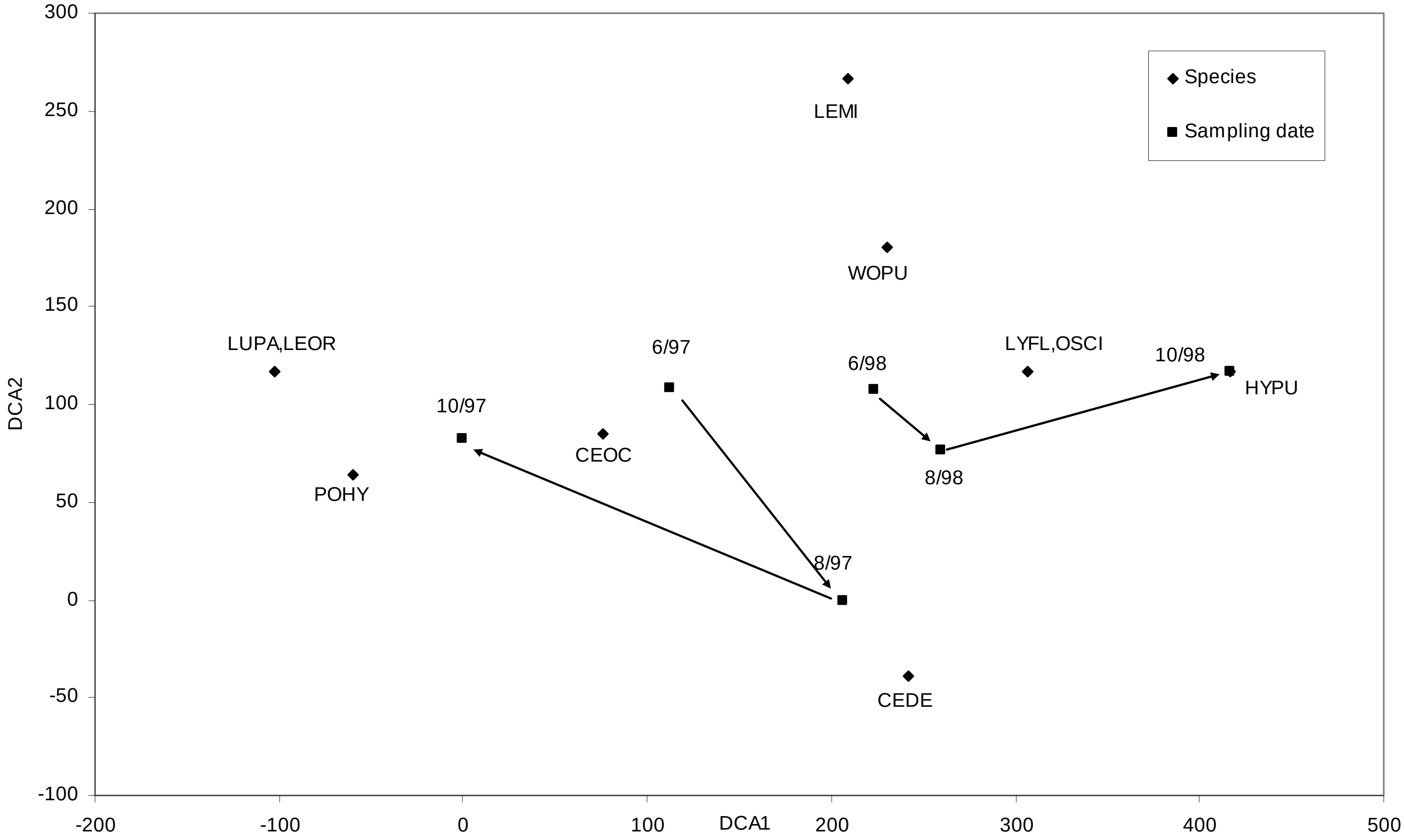
Species richness and cover

Species richness and cover are other important aspects of productivity used in analyzing seasonal changes in vegetation. The ponds are discussed together in this analysis for comparison

Table 7. Aquatic Species used in Pond 4 DCA graph and their importance values.

Species	Common Name	Acronym	Importance Value
Ceratophyllum demersum	Coontail	CEDE	32.9
Cephalanthus occidentalis	Buttonbush	CEOC	21.4
Wolffia punctata	Watermeal	WOPU	17.3
Hypericum punctatum	Dotted St. John's wort	HYPU	11.9
Polygonum hydropiperoides	Mild waterpepper	POHY	7.1
Lemna minor	Least duckweed	LEMI	6.9
Lycopodium flabelliforme	Groundpine	LYPL	1.7
Osmunda cinnamomea	Cinnamon fern	OSCI	1.3
Leersia oryzoides	Rice cut grass	LEOR	1.0
Ludwigia palustris	Marsh purslane	LUPA	0.6

Figure 5. DCA for Pond 4 aquatic species showing influence of species diversity during the months of June, August and October 1997 and June, August and October 1998.


300
250
200
150
100
50
0
-50
-100
-200
-100
0
100
200
300
400
500
DCA1
DCA2
Species
Sampling date
LEMI
WOPU
LUPA,LEOR
6/97
6/98
LYFL,OSCI
10/98
HYPU
10/97
CEOC
POHY
8/98
8/97
CEDE

purposes. Species richness was determined for each pond by of stratum. The richness of each stratum was graphed by month of the growing season to show variability among the four ponds. All ponds were graphed together for the aquatic stratum and an average for each pond was taken for 1997 and 1998.

Overall, the average for the two years showed expected seasonal changes in 1997, except for the decline in richness at Pond 14 in July. In 1997, the average showed that June and August were the peak months for species richness of aquatic plants (Figure 6). This was also the trend for each of the ponds, with November having the lowest number of species present (Figure 6). In 1998, richness was low in April with an increase until August, and then a decline to November. The average showed August as the peak in species richness (Figure 6). This was also the peak month for Pond 13 and Pond 3 (Figure 6). However, there was an unexpected decline in richness for Pond 3 and Pond 13 in July 1998 (Figure 6). This could be due to the decline in precipitation for that month (Figure 7).

A total for average cover was calculated for aquatic species to show seasonal variation among the ponds for 1997 and 1998. Each pond was graphed separately along with the herbaceous vegetation. For the most part, expected seasonal variations in cover occurred among the four ponds. For Pond 13, aquatic vegetation cover peaked in July in 1997 and then disappeared completely in September through November (Figure 8). Aquatic vegetation returned in May of 1998 and peaked in July, with a higher percent cover than in 1997 (Figure 8). Cover decreased seasonally after July through October (Figure 8). At Pond 14 in 1997, aquatic species cover was highest in August (Figure 9). In 1998, August was also the peak month for

Figure 6. Monthly variability of aquatic species richness in 1997 and 1998.

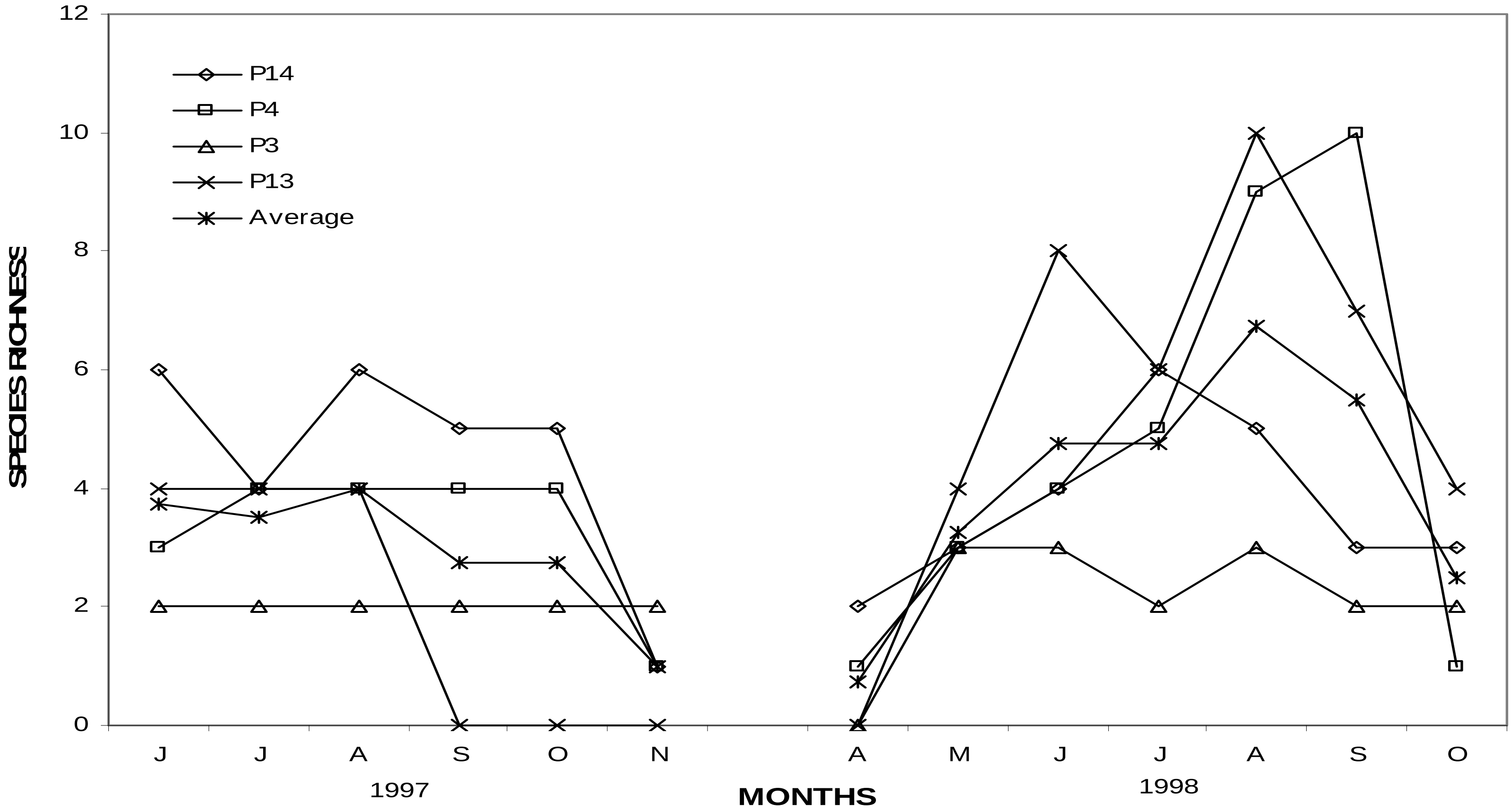

12
10
8
6
4
2
0
P14
P4
P3
P13
Average
SPECIES RICHNESS
J
J
A
S
O
N
A
M
J
J
A
S
O
1997
MONTHS
1998

Figure 7. Changes in monthly precipitation in Mason County from 1997 to 1998.

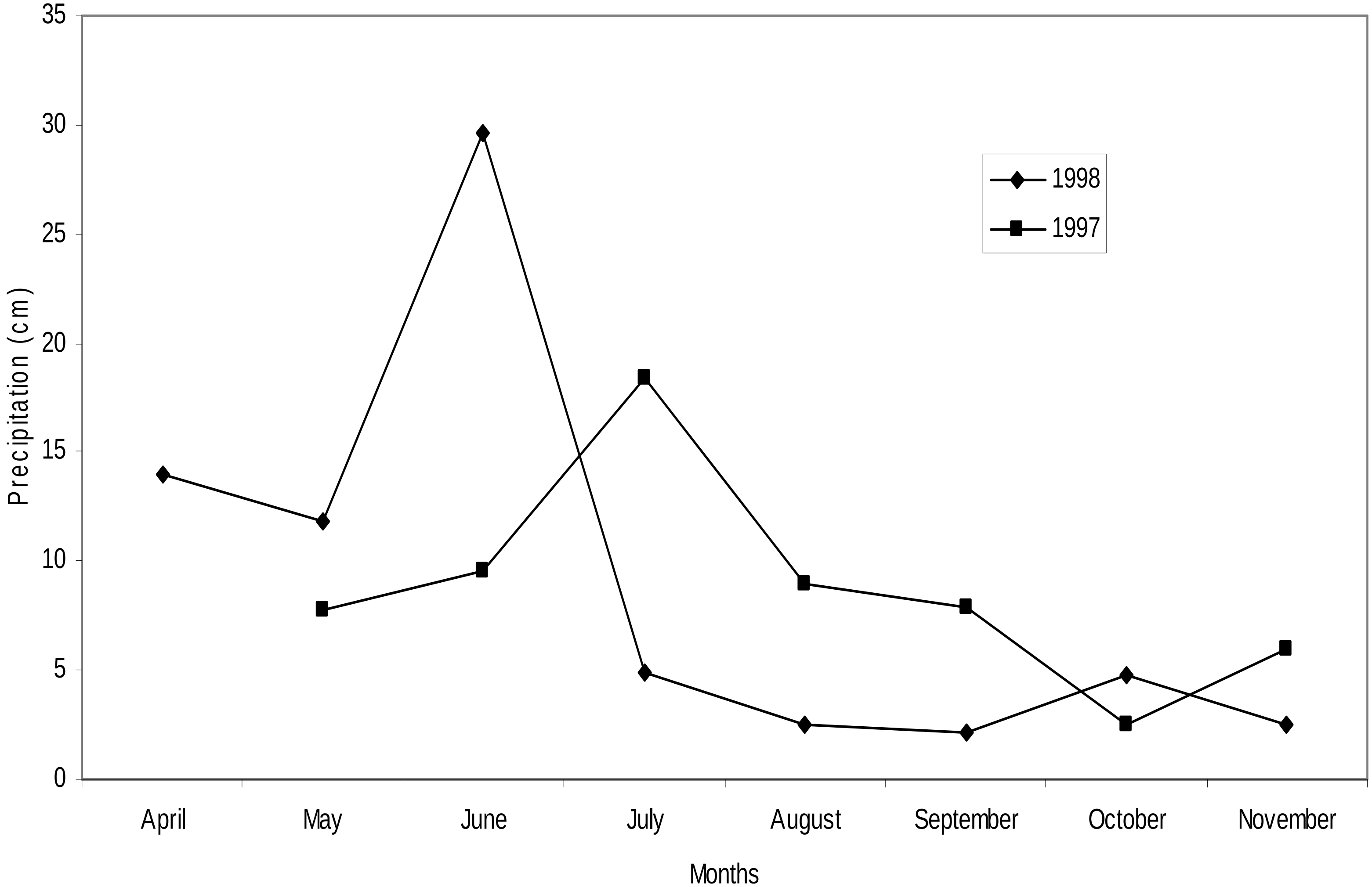
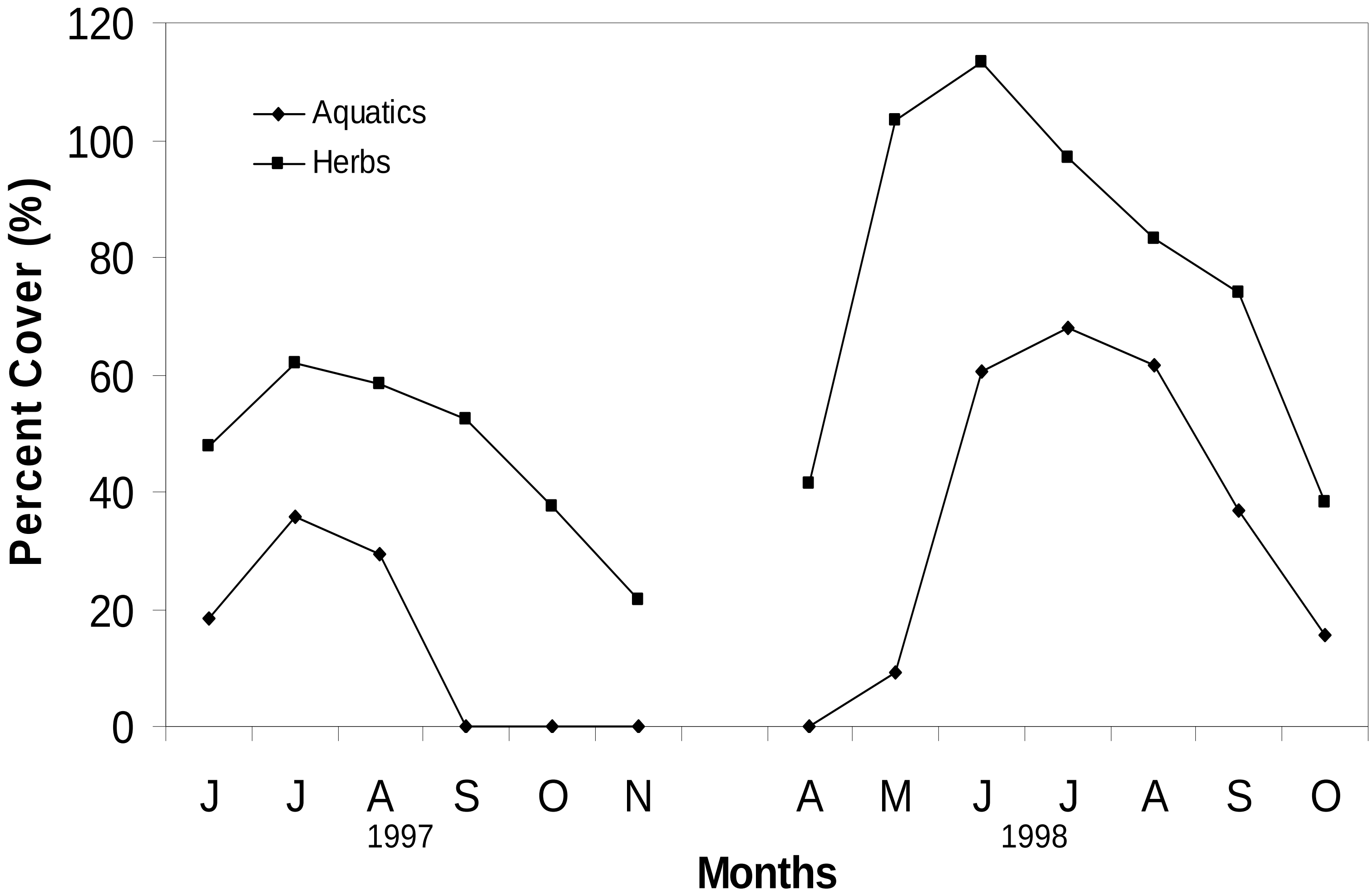
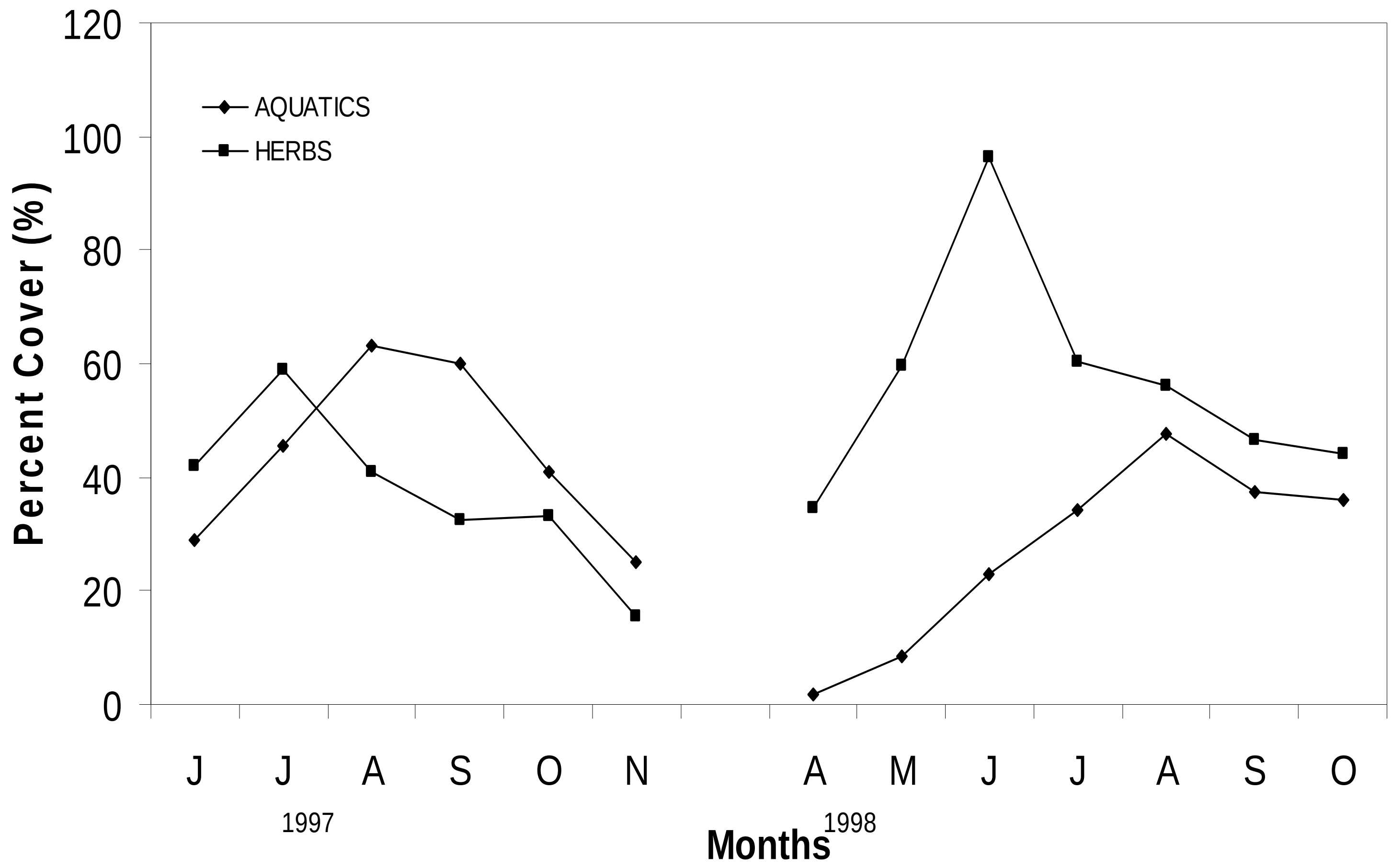

35
30
25
20
15
10
5
0
Precipitation (cm)
1998
1997
April
May
June
July
August
September
October
November
Months

Figure 8. Variability in total cover of aquatic and herbaceous species at Pond 13 for 1997 and 1998.



120
100
80
60
40
20
0
Percent Cover (%)
Aquatics
Herbs
J
J
A
S
O
N
A
M
J
J
A
S
O
1997
1998
Months

Figure 9. Variability in total cover of aquatic and herbaceous species at Pond 14 for 1997 and 1998.


120
100
80
60
40
20
0
Percent Cover (%)
AQUATICS
HERBS
J
J
A
S
O
N
A
M
J
J
A
S
O
1997
1998
Months

aquatics, with a lower percent cover than in 1997 (Figure 9). At Pond 3 in 1997, the aquatic vegetation was highest in cover in August with a slight decrease in September before dropping dramatically (Figure 10). Aquatic species in 1998 also peaked in August, but with a lower percent cover (Figure 10). In 1997, the aquatic species at Pond 4 had the highest percent cover in July (Figure 11). In 1998, the cover peaked in June, decreased in July, then increased in August (Figure 11).

Differences in Aquatic Vegetation Between Years

DCA

In this part of the study, data were examined by comparing results from all sample dates for 1997 and 1998. By using DCA for each type of stratum (aquatic, herbaceous and shrub) data from each pond can be compared by species present at chosen dates. Species with the highest importance values from each stratum were plotted with an average from all of the months sampled in 1997 and 1998. For each year, each pond was represented by a single point. This will show which species affected each pond on spatial and temporal levels. Species were chosen that had high importance values and that had the most influence on the ponds. For each stratum, sample data from both years was analyzed to show overall variation among ponds.

Ten species were shown to have the most effect on the variation of all ponds between 1997 and 1998 (Figure 12, Table 2). Most of the variability was along the DCA1 axis indicating that most of the ponds were quite similar in species composition, with the exception of Pond 3, which was heavily affected by least duckweed and watermeal (Figure 12). The variation at Pond 4 between 1997 and 1998 was due to a species of grass and coontail, the most dominant species among all of the ponds (Table 2). Buttonbush had equal influence on Ponds 4 and 13 in 1997

Figure 10. Variability in total cover of aquatic and herbaceous species at Pond 3 for 1997 and 1998.

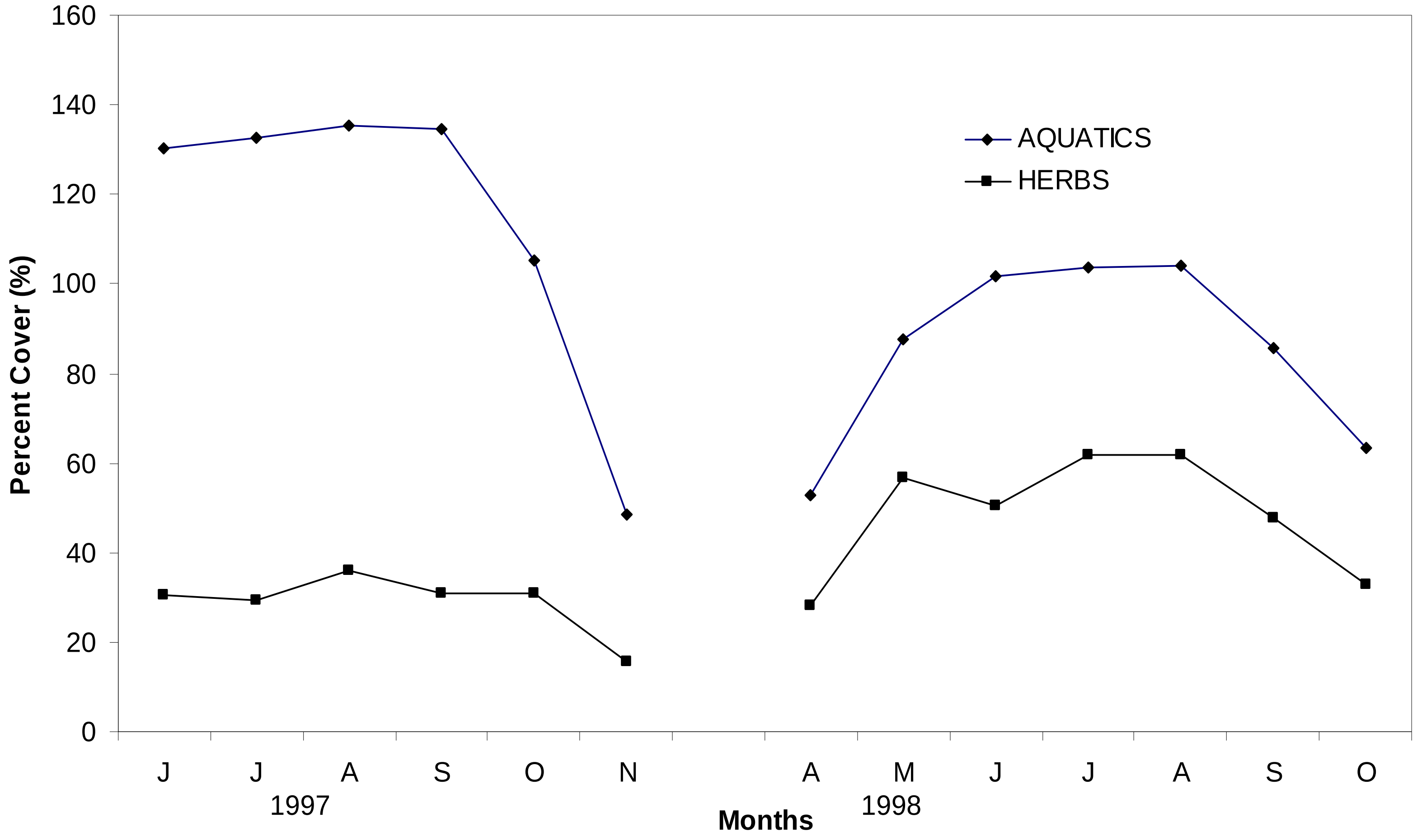

160
140
120
100
80
60
40
20
0
Percent Cover (%)
AQUATICS
HERBS
J
J
A
S
O
N
A
M
J
J
A
S
O
1997
Months
1998

Figure 11. Variability in total cover of aquatic and herbaceous species at Pond 4 for 1997 and 1998.

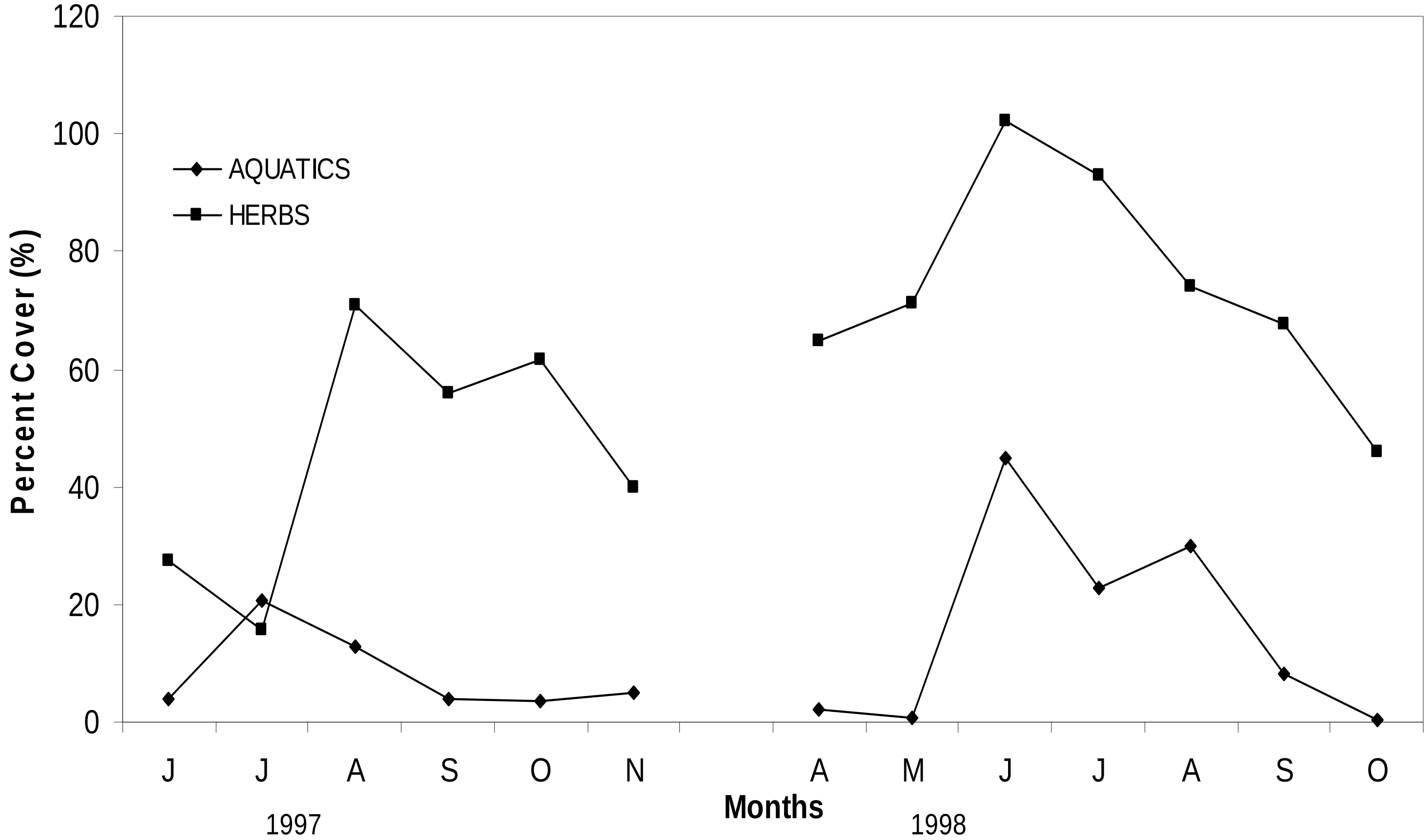
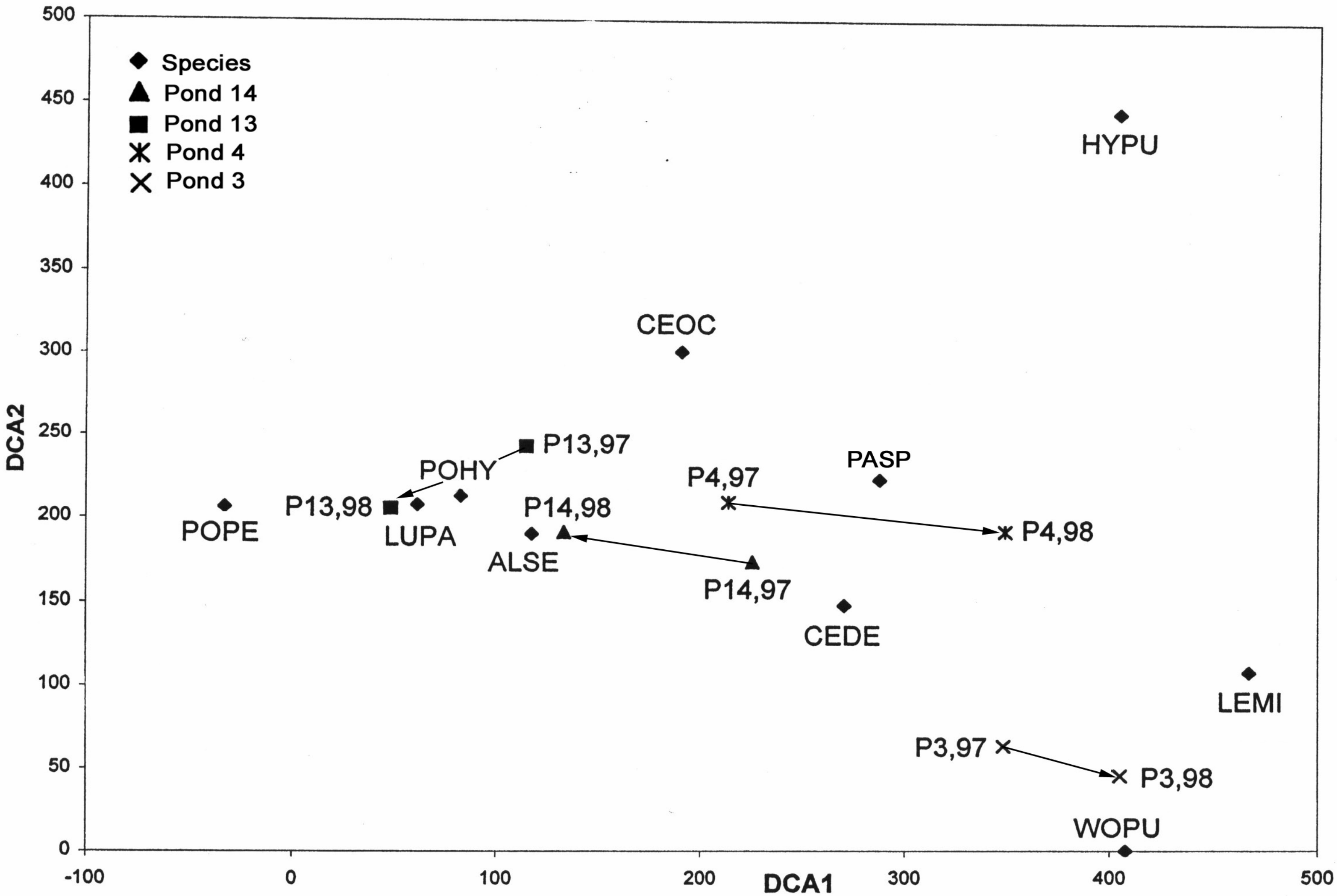

120
100
80
60
40
20
0
Percent Cover (%)
AQUATICS
HERBS
J
J
A
S
O
N
A
M
J
J
A
S
O
Months
1997
1998

Figure 12. DCA showing variation of aquatic species among the four ponds in 1997 and 1998.



Species
Pond 14
Pond 13
Pond 4
Pond 3
DCA2
DCA1
500
450
400
350
300
250
200
150
100
50
0
-100
0
100
200
300
400
500
HYPU
CEOC
P13,97
POHY
P13,98
PASP
P4,97
P14,98
POPE
LUPA
ALSE
P4,98
P14,97
CEDE
LEMI
P3,97
P3,98
WOPU

(Figure 12). The variation in Pond 13 from 1997 to 1998 was caused by three species: mild waterpepper, ladies thumb, and marsh purslane, which were also the most dominant species at Pond 13 (Figure 12, Table 2). Brookside alder was responsible for the shift in Pond 14 from 1997 to 1998 (Figure 12). One species, dotted St. John’s wort, seemed to have little or no effect on the ponds (Figure 12). This species was only present at Pond 4 late in 1998 and it seemed to pull the placement of Pond 4 in 1998 down the DCA1 axis, but had little effect on the placement along the DCA2 axis (Figure 12, Table 5).

Species richness and cover

Species richness and cover were also used to analyze differences between the two years. In the aquatic stratum there was an increase in species richness from 1997 to 1998 at every pond except Pond 14 (Table 1). There was an overall increase in species richness from 15 species in 1997 to 20 species in 1998. Pond 3 had the lowest average aquatic species richness (2) in 1997, which increased to an average of 2.4 species in 1998 (Table 1). Pond 14 had the highest average in species richness in 1997, but with its decrease, Pond 13 contained the most species in 1998 with an average of 6.5 species per month (Table 1). Pond 13 also had the largest increase among the four ponds for aquatic species; numbers increased from 4 average species per month in 1997 to 6.5 average species per month in 1998 (Table 1).

The variability found in the yearly changes of aquatic species richness could be due to fluctuating water levels in the ponds due to weather patterns. Annual precipitation was greater in 1998 than in 1997 (Figure 7). Since these species have rapid relative growth and shorter life cycles, it was expected they would have a significant response to yearly changes among community composition. Furthermore, under the unimodal theory, productivity affects species richness in a unimodal pattern so that variations in productivity between the years would also affect species richness (Stevens 1999).

From 1997 to 1998, aquatic species increased in average cover at Ponds 13 and Pond 4 but decreased at Ponds14 and 3 (Table 1). Pond 3 had a much higher average percent of cover than the other ponds in 1997 (114.5%, Table 1). Even though Pond 3 contained the fewest number of species, the species covered a higher percentage of area within the aquatic plots. This could be due to the interspecific competition exclusion theory, where at high levels of productivity resource acquisition and growth of dominant species exclude subordinate species. The most dominant species at this pond was watermeal, which had the largest importance value of any aquatic species (55.4 species; Table 2). This accounted for the larger percent cover in Pond 3 for both 1997 and 1998 (Table 1) and could be attributed to it excluding less dominant species by its high productivity.

Herbaceous Vegetation

Species Composition

The second type of vegetation analyzed in this study was herbaceous species. The herbaceous plots were located in the terrestrial area adjacent to the pond's edge. Similarities in soils and moisture availability among the four pond sites affected the herbaceous plots, resulting in an overlap in the species present at the four ponds sampled. However, of the four pond sites studied in the herbaceous terrestrial plots, *Sphagnum* sp. was exclusive to the Pond 4 site (Table 8), where growing conditions were conducive for a boggier habitat. As acidic peatlands, bogs are typically dominated by the *Sphagnum* genus (Bedford et al. 1999). Other pond sites showed

Table 8. Dominant herbaceous species based on average importance values for each pond.

Species	Common Name	P13	P14	P3	P4	Mean Importance Value
*Lonicera japonica**	Japanese honeysuckle	17.8	9.4	21.5	5.9	13.7
Sphagnum sp.	Sphagnum moss	-----	-----	-----	24.3	6.1
*Danthonia spicata**	Poverty grass	-----	23.7	-----	-----	5.9
Spiraea douglasii	Hardhack	-----	-----	22.8	-----	5.7
*Juncus effusus**	Soft rush	6.9	10.8	-----	-----	4.4
*Polygonum hydropiperoides**	Mild waterpepper	5.8	-----	3	-----	2.2
Carya ovata	Shagbark hickory	4.1	4.4	-----	-----	2.1
*Smilax rotundifolia**	Common greenbrier	-----	4.9	2.9	-----	1.9
Cornus florida	Flowering dogwood	-----	3.8	3.4	-----	1.8
Onoclea sensibilis	Sensitive fern	-----	-----	2.5	4.2	1.7

----- = Lower than 10th in importance value

* = Occurred at all four ponds

some similarity in overall species composition among herbaceous vegetation, with most of the variability occurring in the richness and cover, as discussed in more detail below.

Of the 76 species, 68 were fond in herbaceous plots. Overall, species diversity was lower for all four pond sites in 1997 with 48 different species present, than in 1998 with 56 species. In 1998, Pond 4 had the highest average of species richness for both years, 26.1 species per month, with Pond 13 in 1997 having the lowest average species richness for both years, 11.5 species per month (Table 1). High values of species richness are characteristic of eastern deciduous forests (Hockenberry 1996). The higher species diversity at Pond 4 could be due to a number of conditions including availability to resources such as water and nutrients or the influence of the productivity rate which, at moderate levels, could increase species richness.

Herbaceous cover increased in 1998 at all pond sites. Pond 13 had the highest average percent cover (78.6%), with Pond 4 only slightly lower (74.1%; Table 1). Pond 3 had the lowest percent cover of the four pond sites. This could be caused by the higher percentage of overstory species around Pond 3 compared to the other ponds. Light availability to the herb layer, important to cover and richness, is generally a function of canopy density (Gilliam and Turrill 1993). In fact, overall cover and biomass of forest understory vegetation increases, often dramatically, with canopy openness (Thomas et al. 1999). Although overstory vegetation higher than shrubs was not included in this study, it was evident that Pond 3 had a larger canopy cover preventing moisture and sunlight from reaching the forest floor, in turn affecting the growth of the understory vegetation at Pond 3.

Five dominant herbaceous species occurred at all four pond sites (Table 8), with one dominant at all ponds, Japanese honeysuckle. One species was exclusive to Pond 4, sphagnum moss. This is attributable to the boggy habitat at Pond 4, which is suited for such species. As such, there are both similarities and differences in overall herbaceous species present among the four ponds.

Seasonal Patterns of Herbaceous Vegetation

DCA

Pond 13 site. The results of the DCA graphs of the four ponds show that all ponds had some spatial and temporal variability among the months of the two growing seasons. Pond 13 seemed to have the most variability in the herbaceous vegetation with all months equally scattered across the graph (Figure 13). Each month was progressively influenced in both years. This could be attributed to the expected seasonal changes in temperature and moisture, which in turn affect the productivity of the vegetation.

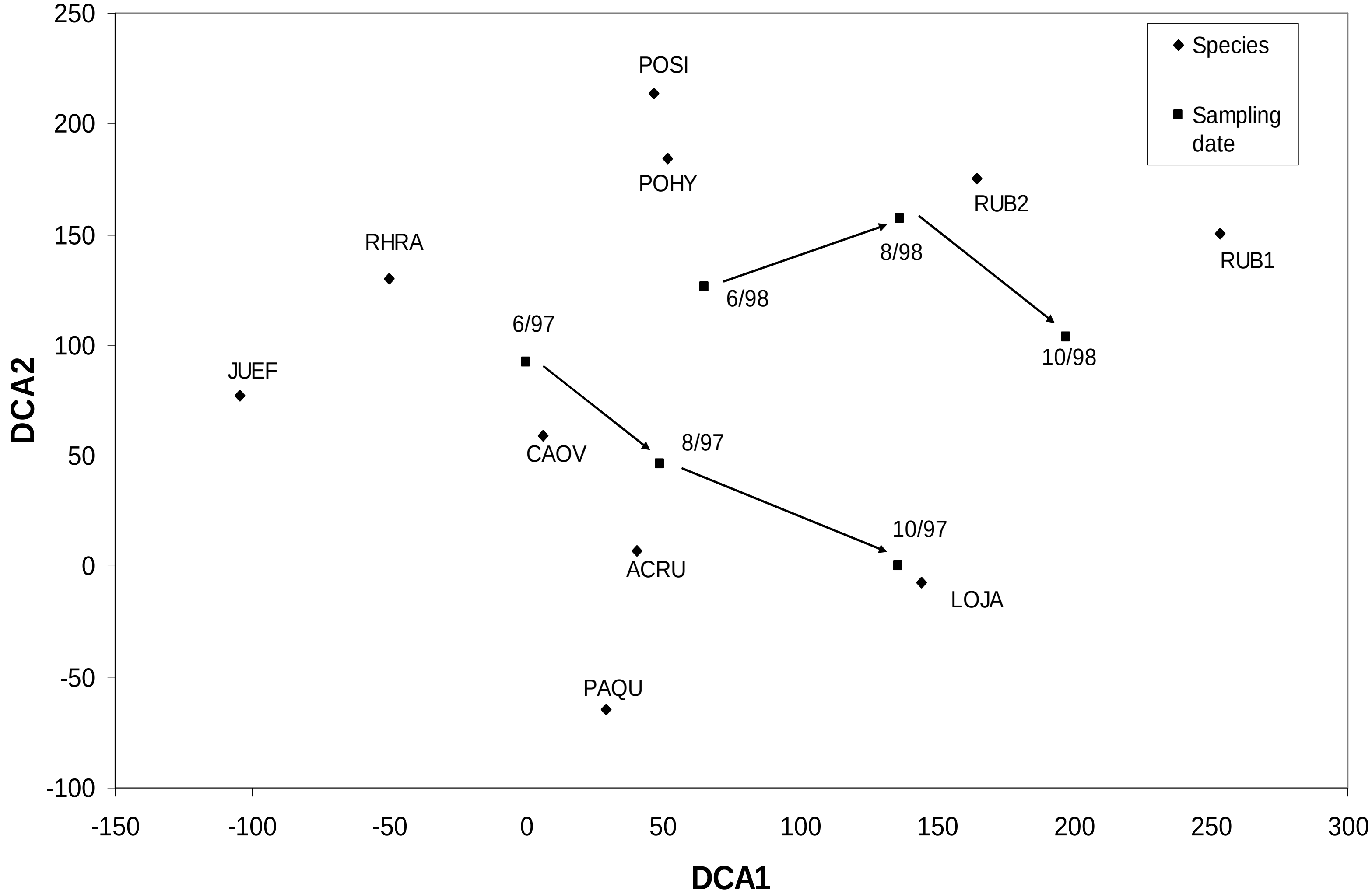
All of the species graphed were also equally separated. This suggests variability among the months and years. The most important species, Japanese honeysuckle, was most abundant at Pond 13 in October of 1997 (Figure 13, Table 9). There was little difference in the effect of shagbark hickory on the months of June and August in 1997 (Figure 13). Examples of dominant species in 1998 are mild waterpepper in June, dewberry in August and blackberry in October (Figure 13).

Pond 14 site. Pond 14 had less variation, with most months appearing closely to the others in the same year, except for October of 1997, which differed greatly from the other months in 1997 and appeared more closely to the months of 1998 (Figure 14). The influence of poverty grass which survives late in the season could be the reason for such overlap (Table 5). Three species were most abundant in June and August of 1997, including Japanese honeysuckle (Figure 14). Poverty grass, the most important species during these months, is most dominant in October of 1997 and 1998, showing that it survives to the end of the growing season (Figure 14,

Table 9. Herbaceous species used in Pond 13 DCA graph and their importance values.

Species	Common Name	Acronym	Importance Value
Lonicera japonica	Japanese honeysuckle	LOJA	17.8
Parthenocissus quinquefolia	Virginia creeper	PAQU	9.0
Rhus radicans	Poison ivy	RHRA	7.9
Potentilla simplex	Common cinquefoil	POSI	7.6
Juncus effusus	Soft rush	JUEF	6.7
Polygonum hydropiperoides	Mild waterpepper	POHY	5.8
Carya ovata	Shagbark hickory	CAOV	4.1
Rubus sp.	Blackberry	RUB1	4.0
Rubus sp.	Dewberry	RUB2	3.0
Acer rubrum	Red maple	ACRU	2.2

Figure 13. DCA for Pond 13 herbaceous species showing influence of species diversity during the months of June, August and October 1997 and June, August and October 1998.


250
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-100
-50
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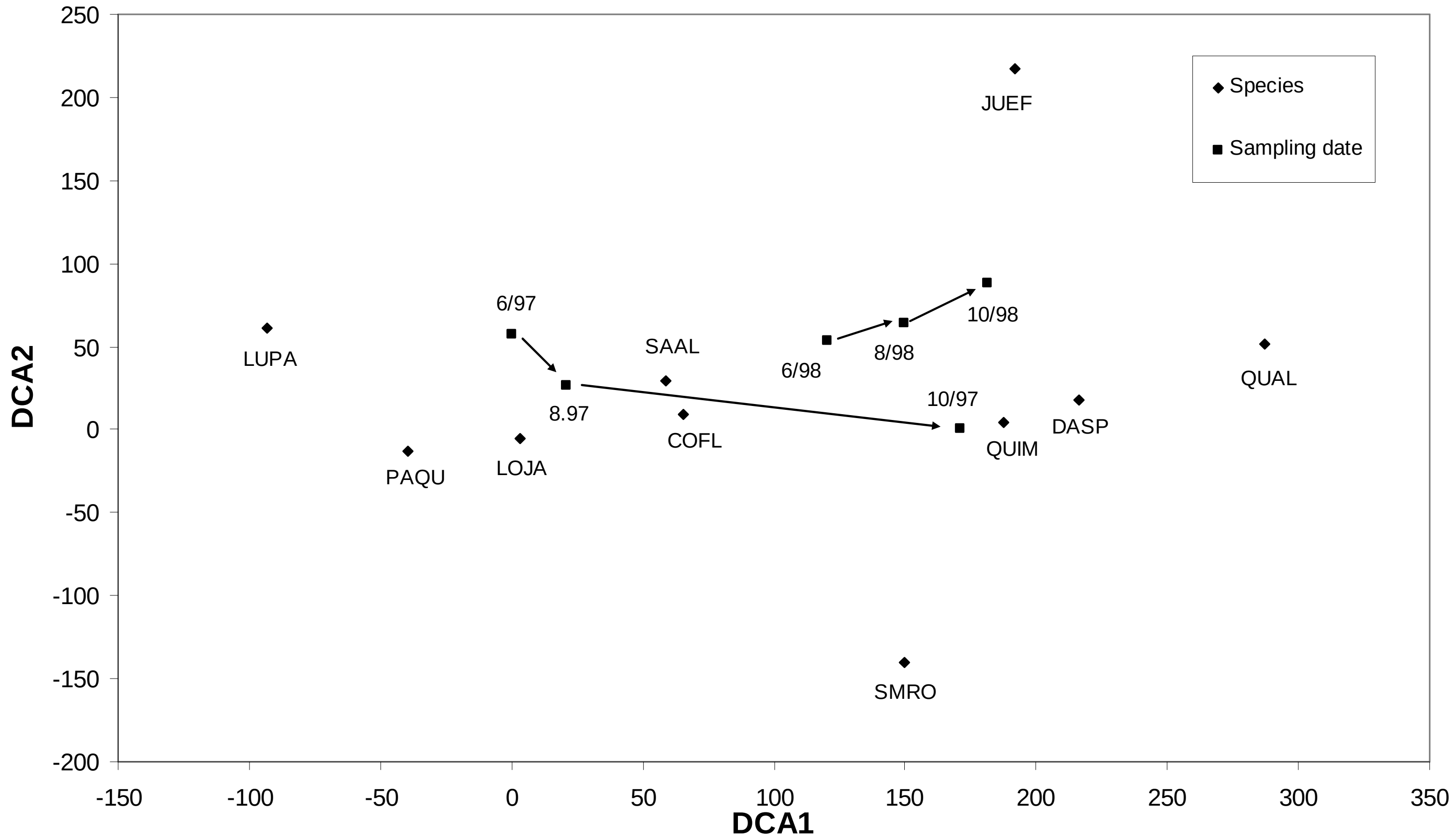
50
100
150
200
250
300
DCA2
DCA1
Species
Sampling date
POSI
POHY
RUB2
RUB1
RHRA
JUEF
CAOV
ACRU
LOJA
PAQU
6/97
8/97
10/97
6/98
8/98
10/98

Table 10. Herbaceous species used in Pond 14 DCA graph and their importance values

Species	Common Name	Acronym	Importance Value
Danthonia spicata	Poverty grass	DASP	23.7
Juncus effusus	Soft rush	JUEF	10.8
Lonicera japonica	Japanese honeysuckle	LOJA	9.4
Sassafras albidum	Sassafras	SAAL	6.1
Quercus alba	White oak	QUAL	5.1
Smilax rotundifolia	Common greenbrier	SMRO	4.9
Parthenocissus quinquefolia	Virginia creeper	PAQU	4.7
Cornus florida	Flowering dogwood	COFL	3.8
Quercus imbricaria	Shingle oak	QUIM	3.1
Ludwigia palustris	Marsh purslane	LUPA	2.3

Figure 14. DCA for Pond 14 herbaceous species showing influence of species diversity during the months of June, August and October 1997 and June, August and October 1998.



250
200
150
100
50
0
-50
-100
-150
-200
-150
-100
-50
0
50
100
150
200
250
300
350
DCA1
DCA2
Species
Sampling date
JUEF
LUPA
6/97
8.97
SAAL
COFL
6/98
8/98
10/98
10/97
QUIM
DASP
QUAL
PAQU
LOJA
SMRO

Table 10). Sassafras was frequent in both August of 1997 and June of 1998 (Figure 14). White oak was responsible for pulling October of 1997 and 1998 along the DCA1 axis showing temporal variability among species from June to October (Figure 14).

Pond 3 site. The variation in Pond 3 occurred mainly in the month of June in 1997 where it was separated from the other months to the left side of the graph (Figure 15). Two species that were more abundant at this time were Japanese honeysuckle, one of the most important species at this pond site, and *Panicum* sp. (Figure 15, Table 11). There were less species present in this earlier month of the growing season, and therefore, these two species were very abundant and had a strong influence on the month of June. The other months of the two growing seasons were relatively close in proximity, due to the increase in species richness.

Although there was little variability among the rest of the ponds for each year, there was some variability among the two years. Multifloral rose and flowering dogwood were a strong influence on the months of 1998, while hardhack and ground pine influenced August and October of 1997 down the DCA2 axis, showing spatial variation from the other months (Figure 15).

Pond 4 site. The Pond 4 analyses indicated variability among June and the other two months of 1997 (Figure 16). Sensitive fern and autumn olive are two species that separated June 1997. The most important species Sphagnum sp. is exclusive to this pond due to its boggy environment (Table 12). This species seemed to have the most effect in October of both years when many other species have already disappeared (Figure 16). Christmas fern and groundberry are most dominant in August and October 1997, indicating that these species live throughout the growing season (Figure 16). In 1998 there was less variability among months. Spicebush appeared to stay dominant throughout all three months of that year (Figure 16).

Table 11. Herbaceous species used in Pond 3 DCA graph and their importance values.

Species	Common Name	Acronym	Importance Value
Spiraea douglasii	Hardhack	SPDO	22.8
Lonicera japonica	Japanese honeysuckle	LOJA	21.5
Panicum sp.	Panic grass, large	PAN2	11.5
Lycopodium flabelliforme	Groundpine	LYFL	5.3
Mentha arvensis	Field mint	MEAR	4.4
Cornus florida	Flowering dogwood	COFL	3.4
Smilax rotundifolia	Common greenbrier	SMRO	2.9
Onoclea sensibilis	Sensitive fern	ONSE	2.5
Panicum sp.	Panic grass, small	PAN1	2.1
Rosa muliflora	Multifloral rose	ROMU	1.9

Figure 15. DCA for Pond 3 herbaceous species showing influence of species diversity during the months of June, August and October 1997 and June, August and October 1998.

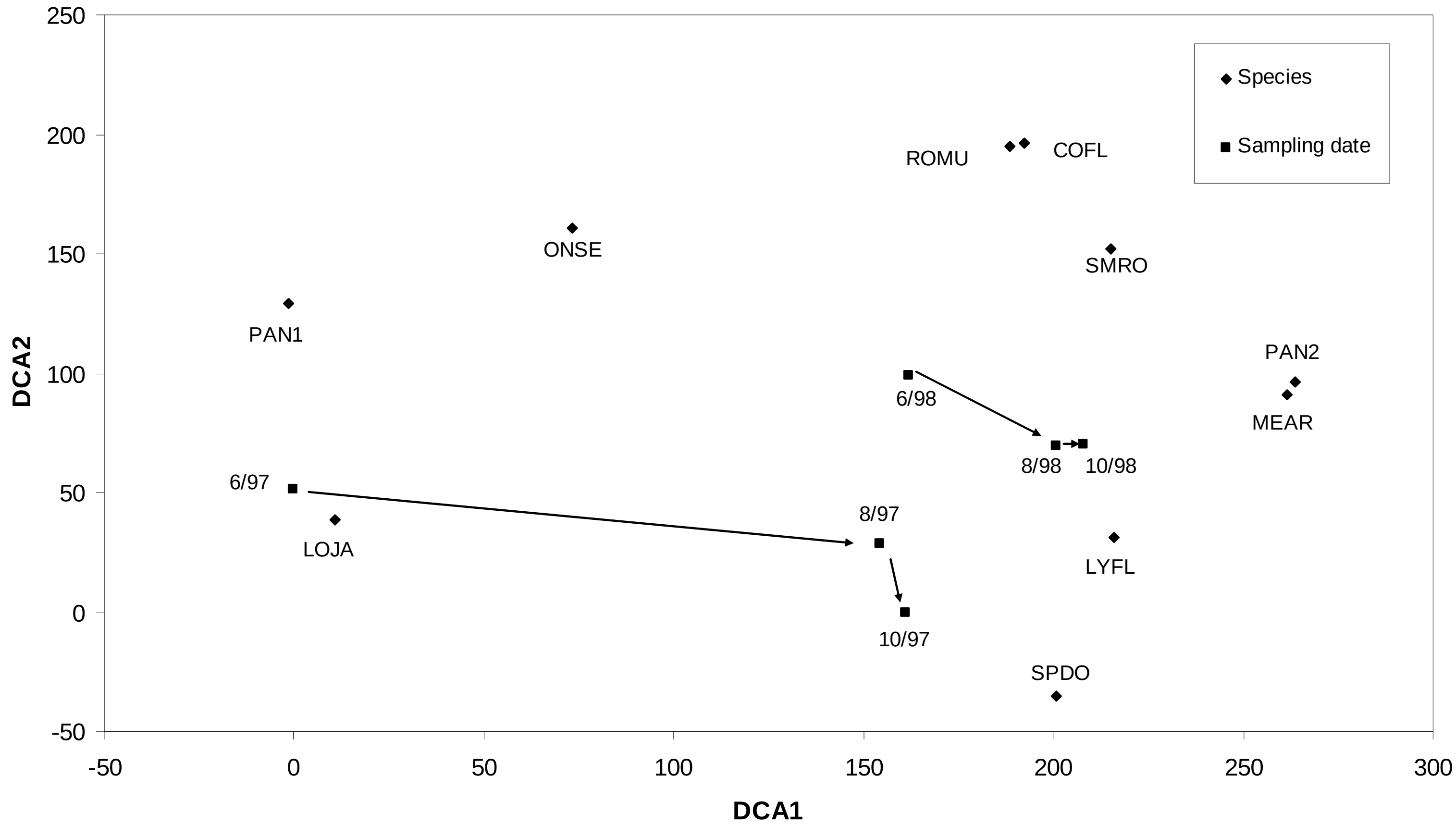
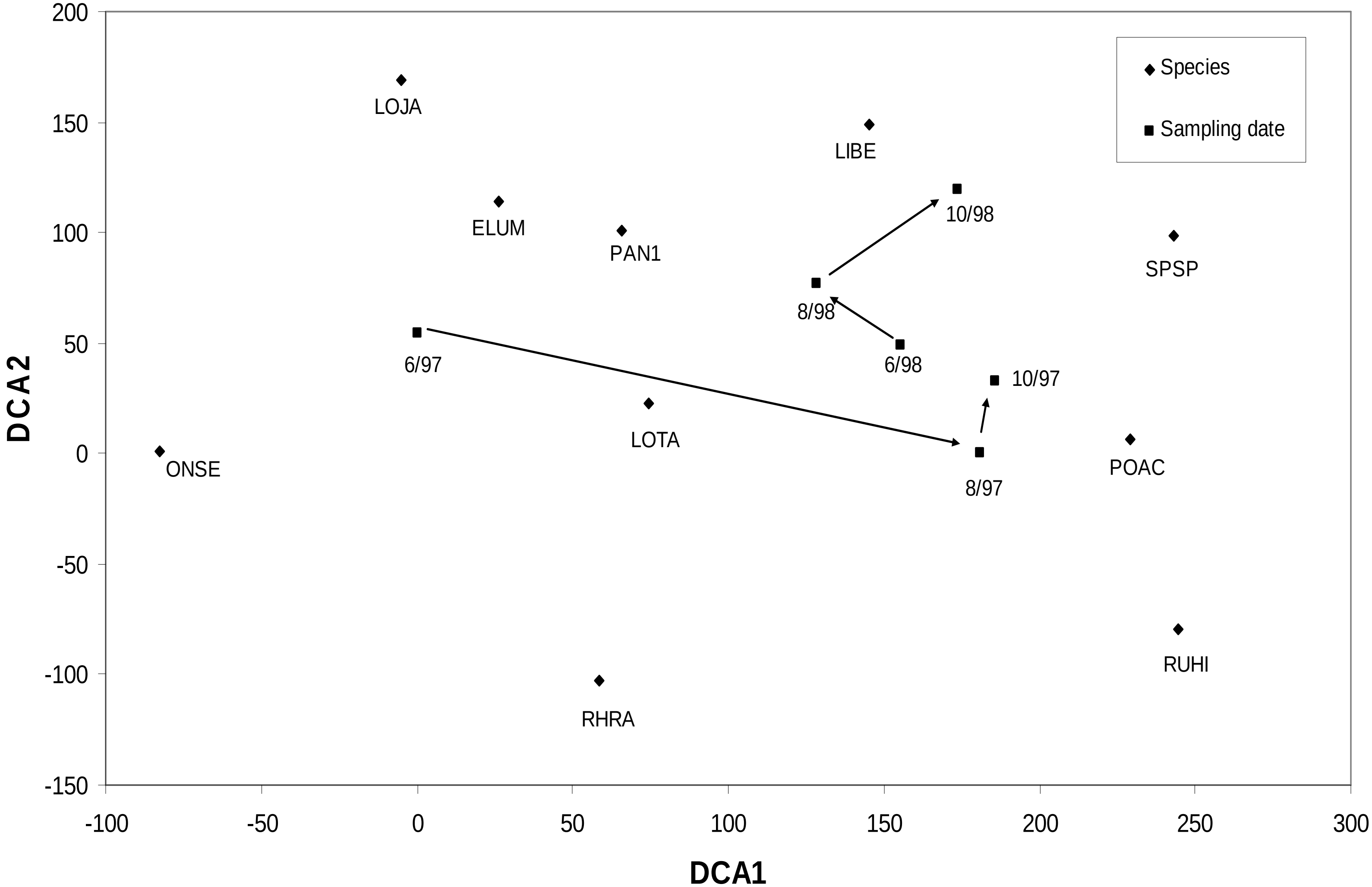

Species
Sampling date
ROMU
COFL
ONSE
SMRO
PAN1
PAN2
MEAR
6/98
8/98
10/98
6/97
8/97
LOJA
LYFL
10/97
SPDO
DCA2
DCA1
250
200
150
100
50
0
-50
-50
0
50
100
150
200
250
300

Table 12. Herbaceous species used in Pond 4 DCA graph and their importance values.

Species	Common Name	Acronym	Importance Value
Sphagnum sp.	Sphagnum moss	SPSP	24.3
Panicum sp.	Panic grass, small	PAN1	14.0
Rubus hispidus	Groundberry	RUHI	11.4
Lonicera japonica	Japanese honeysuckle	LOJA	5.9
Polystichum acrostichoides	Christmas fern	POAC	5.3
Onoclea sensibilis	Sensitive fern	ONSE	4.2
Lindera benzoin	Spicebush	LIBE	4.2
Rhus radicans	Poison ivy	RHRA	2.5
Elaeagnus umbellata	Autumn olive	ELUM	2.4
Lonicera tatarica	Tatarian honeysuckle	LOTA	1.5

Figure 16. DCA for Pond 4 herbaceous species showing influence of species diversity during the months of June, August and October 1997 and June, August and October 1998.



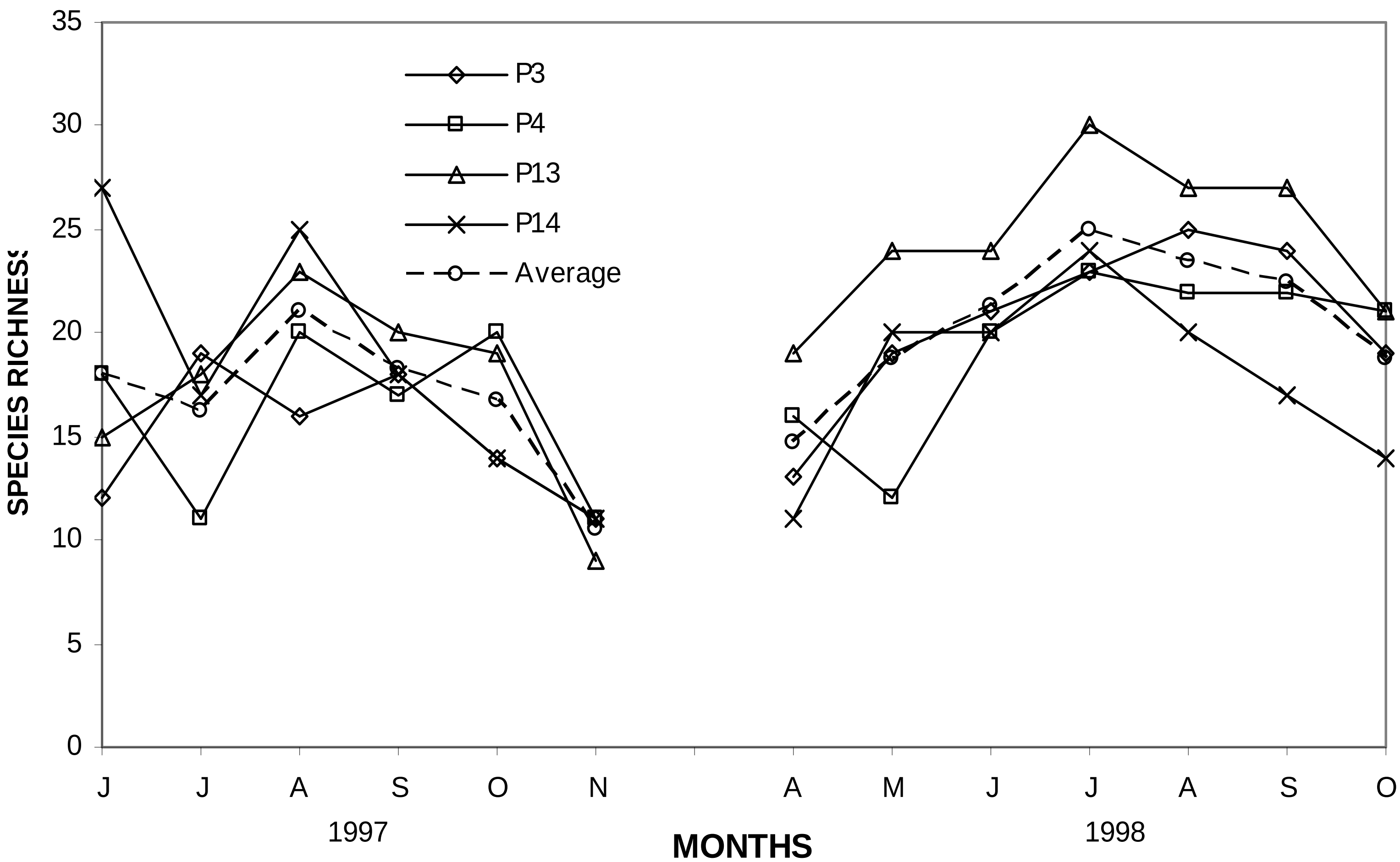
Species
Sampling date
LOJA
LIBE
ELUM
PAN1
10/98
SPSP
8/98
6/97
6/98
10/97
LOTA
ONSE
8/97
POAC
RUHI
RHRA
DCA2
DCA1
200
150
100
50
0
-50
-100
-150
-100
-50
0
50
100
150
200
250
300

Species richness and cover

Species richness was graphed with all four ponds together, including an average of the ponds. Species richness for the herbaceous species varied in 1997. The average of all four ponds showed expected seasonal trends except for a decline in July (Figure 17). Pond 13 and 4 peaked in August, Pond 14 peaked in June, and Pond 3 peaked in July (Figure 17). All ponds showed expected results and declined in species richness after October (Figure 17). Trends in averages of aquatic species and herbaceous species were the same in 1997 with the peak month being August. In 1998, all ponds peaked in species richness in the month of July. This result is not consistent with precipitation results for 1998, where there was a significant decrease in rainfall in July (Figure 6). However, there was significant rainfall in June, which could have affected the growth in July, along with other gradients, such as light and nutrient availability. All ponds had similar trends in growth of richness, decreasing after July with little change from August to September except for Pond 4, which decreased in May. The average in 1998 for the aquatic species differed in the peak month (August) when compared to the average peak month for herbaceous species (July). The variation in seasonal changes in herbaceous species richness in 1997 and 1998 can be attributed to differences in water levels, which could be due to weather conditions, including precipitation.

The herbaceous cover was also varied among the four ponds. This data was graphed along with the changes in cover for the aquatic species, each pond separately. At Pond 13, herbaceous cover was highest in July in 1997, like the aquatic species (Figure 8). In 1998, however, June was the peak month for herbaceous cover. This result is consistent with the rainfall, which was highest in June of 1997. At Pond 14, herbaceous cover differed from the aquatics and peaked in June of both 1997 and 1998, with the cover in 1998 almost doubling the

Figure 17. Monthly variability of herbaceous species richness in 1997 and 1998.



35
30
25
20
15
10
5
0
SPECIES RICHNESS
P3
P4
P13
P14
Average
J
J
A
S
O
N
A
M
J
J
A
S
O
1997
1998
MONTHS

cover in 1997 (Figure 9). The difference in cover from 1997 to 1998, which also occurred at Pond 13 for the herbaceous species and the aquatic species, could be due to migration of species within sample plots and better growth conditions evolving in 1998 (Figure 9).

Herbaceous cover was consistently lower than the aquatic cover at Pond 3 (Figure 10). This could be due to a large canopy cover that affected the terrestrial but not the aquatic plots of Pond 3. Species richness often changes along spatial gradients (Veech 2000) which could also affect the amount of cover. There was little difference among cover for the herbaceous species during the 1997 growing season, peaking in August as the aquatics did (Figure 10). In 1998, herbaceous species cover peaked in July and August, with a small decrease from May to June (Figure 10).

Herbaceous species at Pond 4 in 1997 decreased in cover in July and increased dramatically in August when cover was highest (Figure 11). The trend in 1998 for herbaceous species cover varied, greatly increasing in June, when it was highest, and then decreasing through October (Figure 11). Cover for aquatic and herbaceous species peaked from June to August among the four ponds (Figure 11). The percent cover in 1998 was higher, indicating that growth and migration can increase with time in the absence of disturbance (Figure 11).

Seasonal variation differed among all four ponds for each of the three strata. This could be attributed to a number of causes: the variation of dominant species at each pond, moisture and nutrient availability from each pond, or canopy cover from differences in overstory vegetation.

Differences in Herbaceous Vegetation Between Years

DCA

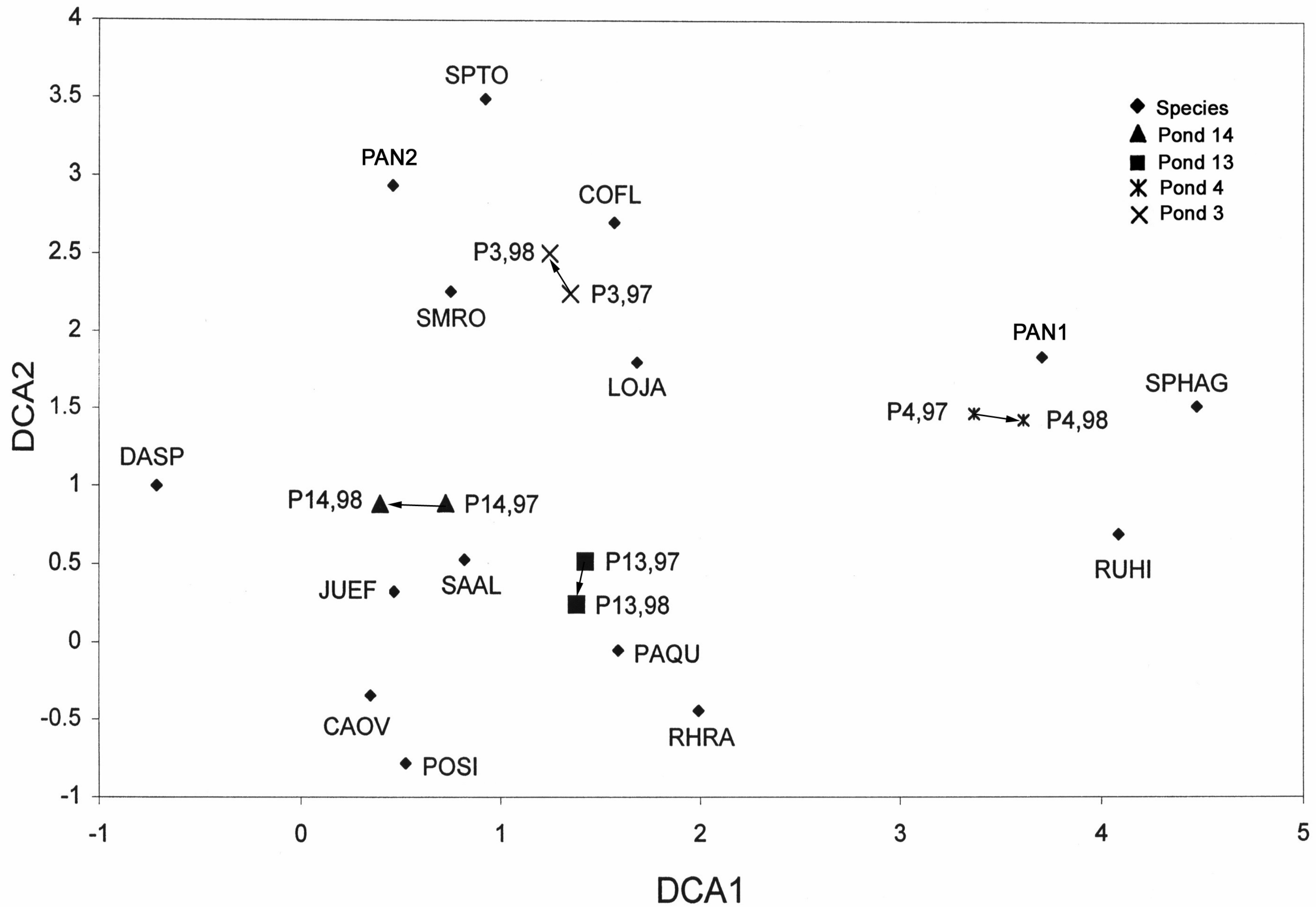
Fifteen species were chosen to show correlation among the ponds in the herbaceous stratum (Figure 18). Each pond seemed to form its own cluster on the DCA graph (Figure 18).

Dominant species that are responsible for the higher percent cover are Japanese honeysuckle and soft rush (Table 8). Pond 3 had the smallest average percent cover for both years with 28.9% in 1997 and 48.5% in 1998 (Table 1). Among ponds, Ponds 13 and 4 had the most similarities in the amount of cover in 1997 and 1998 (Table 1). Ponds 14 and 3 also had similar percent covers in 1997 and 1998 (Table 1). The difference among years could be attributed to weather conditions, including precipitation (which was greater in 1998; Figure 6) and environmental conditions, as it is consistent with the large increasing trend in species richness for 1998.

Overall, the two-year analysis showed a trend of species richness and cover data increasing from 1997 to 1998 with a few exceptions. These results could be due to weather patterns or changing growth conditions such as moisture and light availability. Variability among communities at the ponds could be attributed to the changes in occurrence and abundance of individual species due to interspecific competition. The trend of the increase in cover along with the increase in species richness indicates that species diversity never peaked, which, according to the unimodal theory, would have decreased productivity.

This shows variability among herbaceous species at Ponds 3, 4 and 13, 14 (Figure 18). All ponds remained close in proximity between the two sample years (Figure 18). This shows a small amount of variation between the two years among all ponds. Pond 14 has a very small amount of separation between 1997 and 1998 (Figure 18). Pond 4 is separated from Ponds 13 and 14 along the DCA1 axis (Figure 18). Species that exists around this pond are *Panicum* sp., *Sphagnum* sp. and groundberry (Figure 18). *Sphagnum* sp. has the greatest influence on Pond 4, as it was the most dominant species (Table 8). Pond 4 also had a very small amount of separation between 1997 and 1998(Figure 18). Pond 3 is separated from the other ponds on the DCA2 axis (Figure 18). The five species that separate Pond 3 are Japanese honeysuckle, the

Figure 18. DCA showing variation of herbaceous species among the four ponds in 1997 and 1998.


DCA2
DCA1
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1
0
1
2
3
4
5
Species
Pond 14
Pond 13
Pond 4
Pond 3
SPTO
PAN2
COFL
P3,98
P3,97
SMRO
LOJA
PAN1
SPHAG
P4,97
P4,98
DASP
P14,98
P14,97
RUHI
P13,97
JUEF
SAAL
P13,98
PAQU
CAOV
RHRA
POSI

most dominant herb among all ponds; *Panicum* sp., common greenbrier, flowering dogwood, and hardhack (Figure 18, Table 8).

Species richness and cover

Species richness and cover were also analyzed to show inter-year differences. Herbaceous species underwent a large increase in average species richness from 1997 to 1998 (Table 1). Pond 13 had the smallest average of species in 1997 with 11.50 and also had the smallest average in 1998 with 15.43 average species (Table 1). All ponds increased in average species richness in 1998, but each pond differed in the average number of species present. This high degree of variability among ponds and years can also be attributed to weather, herbivory, nutrient availability, or even interspecific competition. Like aquatic species, herbaceous species have short life cycles and rapid relative growth, which make them susceptible to significant changes from year to year. The cover of herbaceous species largely increased at all ponds in 1998 (Table 1). Pond 13 had the largest average percent cover for both years increasing from 46.6% to 78.6% in 1998.

Shrub Vegetation

Species Composition

Of the 76 species present from June 1997 to October 1998, 33 were found in shrub plots. Average species richness was greatest for both years at Pond 14, and lowest at Pond 3, where average richness actually decreased in 1998 (Table 1). This differed from the trends of the other three ponds where average species richness increased from 1997 to 1998 (Table 1). Shrub density also increased for all ponds in 1998 with Pond 14 having the highest density for 1997 and Pond 3 having the lowest density (Table 1). In the shrub plots there were five species that occurred at all four ponds, with two being dominant at all ponds, autumn olive and spicebush

(Table 13). Paw paw was dominant at only one pond (Table 13). The occurrence of most species at most of the ponds indicates similar growing conditions among the shrub plots.

Seasonal Patterns of Shrub Vegetation

DCA

Pond 13 site. The most obvious characteristic of the data graphed for Pond 13 was the overlap between the points for the 1997 and 1998 months (Figure 19). This suggests that little variability occurred between years, and more among the specific months. Shagbark hickory was abundant in August of 1997 and 1998 and was also the most important species among an average of all months (Table 14). There was some separation between June of 1997 and 1998 (Figure 19). In 1997, sassafras was most abundant in June and in 1998 goldenrod and autumn olive were most abundant in June (Figure 19). Two species were separated from the others, spicebush and common greenbrier (Figure 19). This suggests these species were less influential on the individual months in this graph.

Pond 14 site. For the shrub stratum of Pond 14, there was also an overlap of points in months for 1997 and 1998 (Figure 20). Shagbark hickory was the most important species among these months and was most abundant in August of 1998 (Figure 20, Table 15). White oak occurred frequently in October of 1998 and June of 1997 (Figure 20). These months were also slightly influenced by black gum and flowering dogwood. There was more separation among months in 1997 than in 1998. This could be due to higher variability of species occurring in 1997 than in 1998 for the months of June, August and October. August 1997 was pulled to the left of the graph by influences of shingle oak and goldenrod (Figure 20). October 1997 was influenced by red/black oak (Figure 20).

Table 13. Dominant shrub species based on average importance values for each pond.

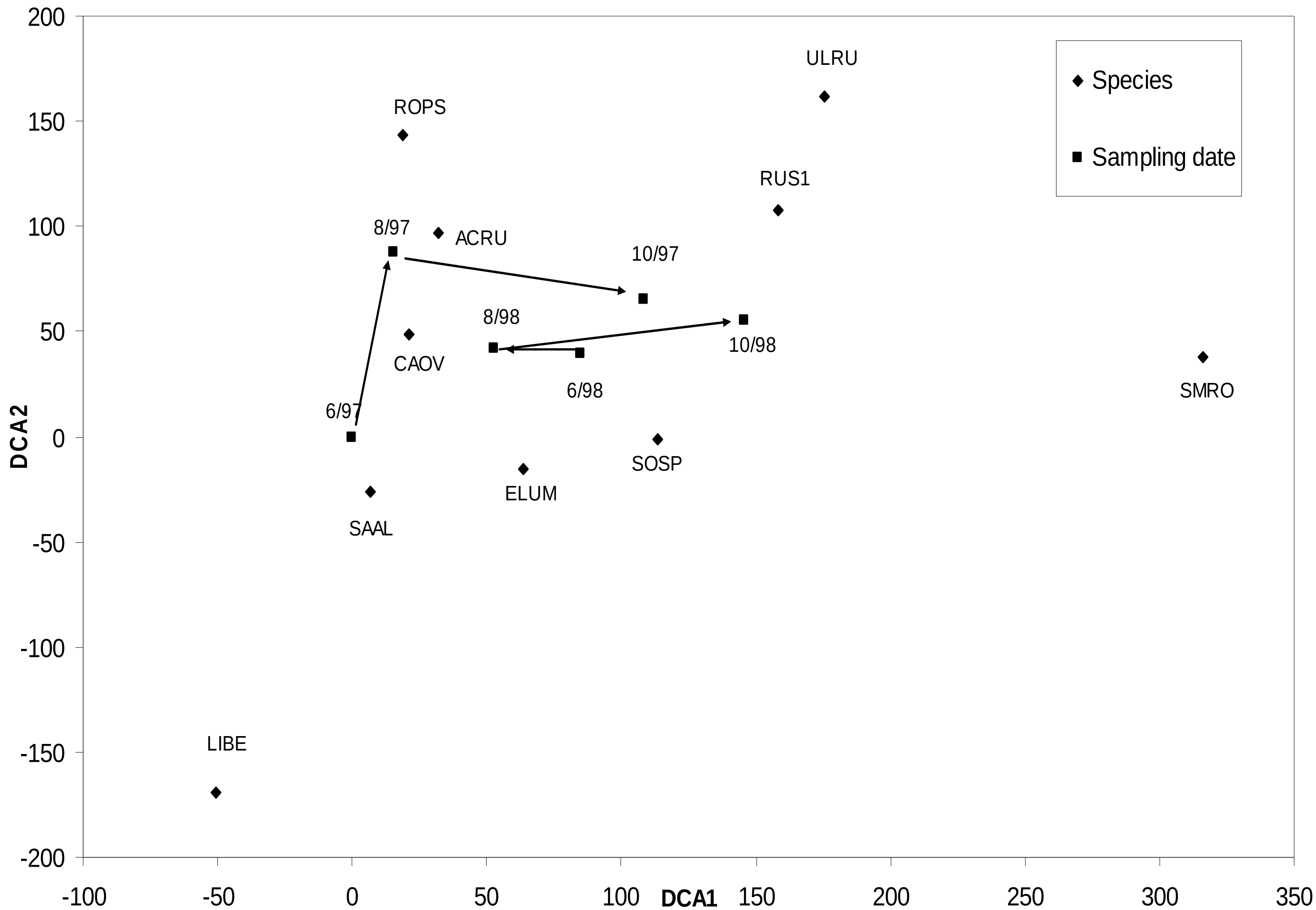
Species	Common Name	P13	P14	P3	P4	Mean Importance Value
*Elaeagnus umbellata**	Autumn olive	10.4	12.6	35.0	13.9	17.7
Carya ovata	Shagbark hickory	16.3	18.2	35.0	-----	17.4
*Lindera benzoin**	Spicebush	3.9	4.2	4.5	15.5	7.0
*Cornus florida**	Flowering dogwood	-----	3.9	6.5	0.6	4.5
*Sassafras albidum**	Sassafras	7.7	5.4	0.5	-----	3.5
*Nyssa sylvatica**	Black gum	-----	10.9	1.9	-----	3.2
Asimina triloba	Paw paw	---	-----	-----	11.1	2.8
Quercus imbricaria	Shingle oak	-----	4.1	1.5	4.6	2.5
Rosa muliflora	Multifloral rose	----	-----	-----	10.0	2.5
Acer rubrum	Red maple	3.4	-----	-----	2.5	1.5

----- = Lower than 10th in importance value
* = Occurred at all four ponds

Table 14. Shrub species used in Pond 13 DCA graph and their importance values.

Species	Common Name	Acronym	Importance Value
Carya ovata	Shagbark hickory	CAOV	16.3
Rubus sp.	Blackberry	RUB1	14.8
Elaeagnus umbellata	Autumn olive	ELUM	10.4
Sassafras albidum	Sassafras	SAAL	7.7
Ulmus sp.	Elm	ULSP	7.2
Solidago sp.	Goldenrod	SOSP	7.1
Smilax rotundifolia	Common greenbrier	SMRO	6.2
Robinia pseudo-acacia	Black locust	ROPS	4.7
Lindera benzoin	Spicebush	LIBE	3.9
Acer rubrum	Red maple	ACRU	3.6

Figure 19. DCA for Pond 13 shrub species showing influence of species diversity during the months of June, August and October 1997 and June, August and October 1998.

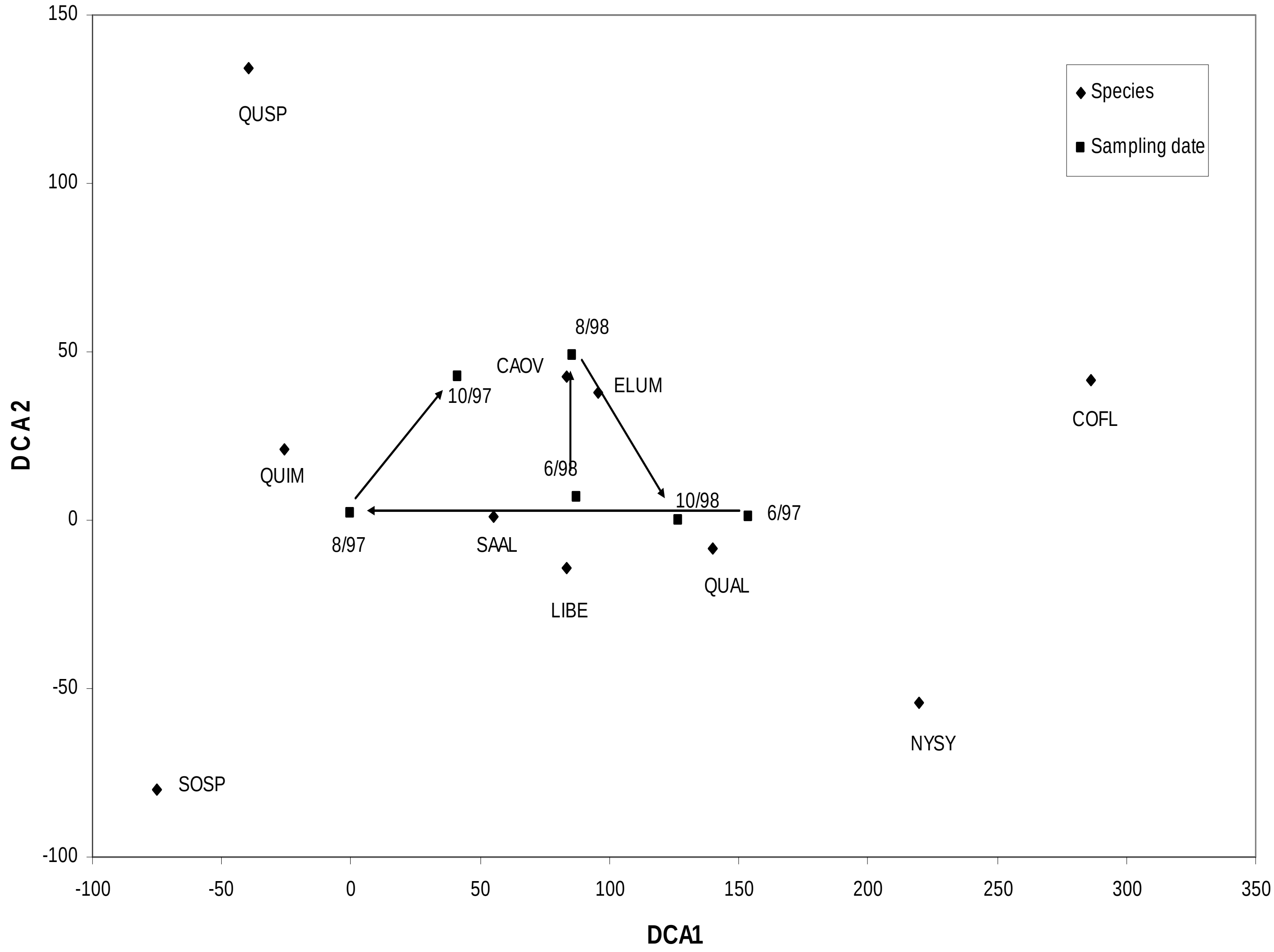


200
150
100
50
0
-50
-100
-150
-200
DCA2
-100
-50
0
50
100
DCA1
150
200
250
300
350
Species
Sampling date
ULRU
ROPS
RUS1
8/97
ACRU
10/97
8/98
10/98
CAOV
6/98
SMRO
6/97
SOSP
ELUM
SAAL
LIBE

Table 15. Shrub species used in Pond 14 DCA graph and their importance values.

Species	Common Name	Acronym	Importance Value
Carya ovata	Shagbark hickory	CAOV	18.2
Quercus sp.	Black/red oak	QUSP	14.5
Elaeagnus umbellata	Autumn olive	ELUM	12.6
Nyssa sylvatica	Black gum	NYSY	10.9
Quercus alba	White oak	QUAL	8.3
Sassafras albidum	Sassafras	SAAL	5.4
Lindera benzoin	Spicebush	LIBE	4.2
Quercus imbricaria	Shingle oak	QUIM	4.1
Solidago sp.	Goldenrod	SOSP	4.0
Cornus florida	Flowering dogwood	COFL	3.9

Figure 20. DCA for Pond 14 shrub species showing influence of species diversity during the months of June, August and October 1997 and June, August and October 1998.



150
100
50
0
-50
-100
-100
-50
0
50
100
150
200
250
300
350
DCA1
DCA2
Species
Sampling date
QUSP
QUIM
SOSP
CAOV
ELUM
SAAL
LIBE
QUAL
COFL
NYSY
8/98
10/97
6/98
10/98
6/97
8/97

Pond 3 site. Unlike the other ponds, all the months graphed for the shrub strata from Pond 3 formed a cluster in the middle of the graph (Figure 21). This suggests little variability among species present at each month of 1997 and 1998. The most important species among these months, autumn olive seemed to be most important during October 1998 and August 1997, along with elm (Figure 21, Table 16). Two species, common greenbrier and paw paw, were in the middle of the cluster suggesting they were the most influential in keeping the low variability among the months (Figure 21).

Pond 4 site. The shrub analysis for Pond 4 indicated variability among both years and months (Figure 22). June 1997 was heavily influenced by spicebush, which was the most important species among all of the months (Table 17). August 1997 was pulled away from June by multifloral rose (Figure 22). Black gum and elm influenced June of 1998 equally and autumn olive and cinnamon fern were two of the species that shifted October of 1998 (Figure 22).

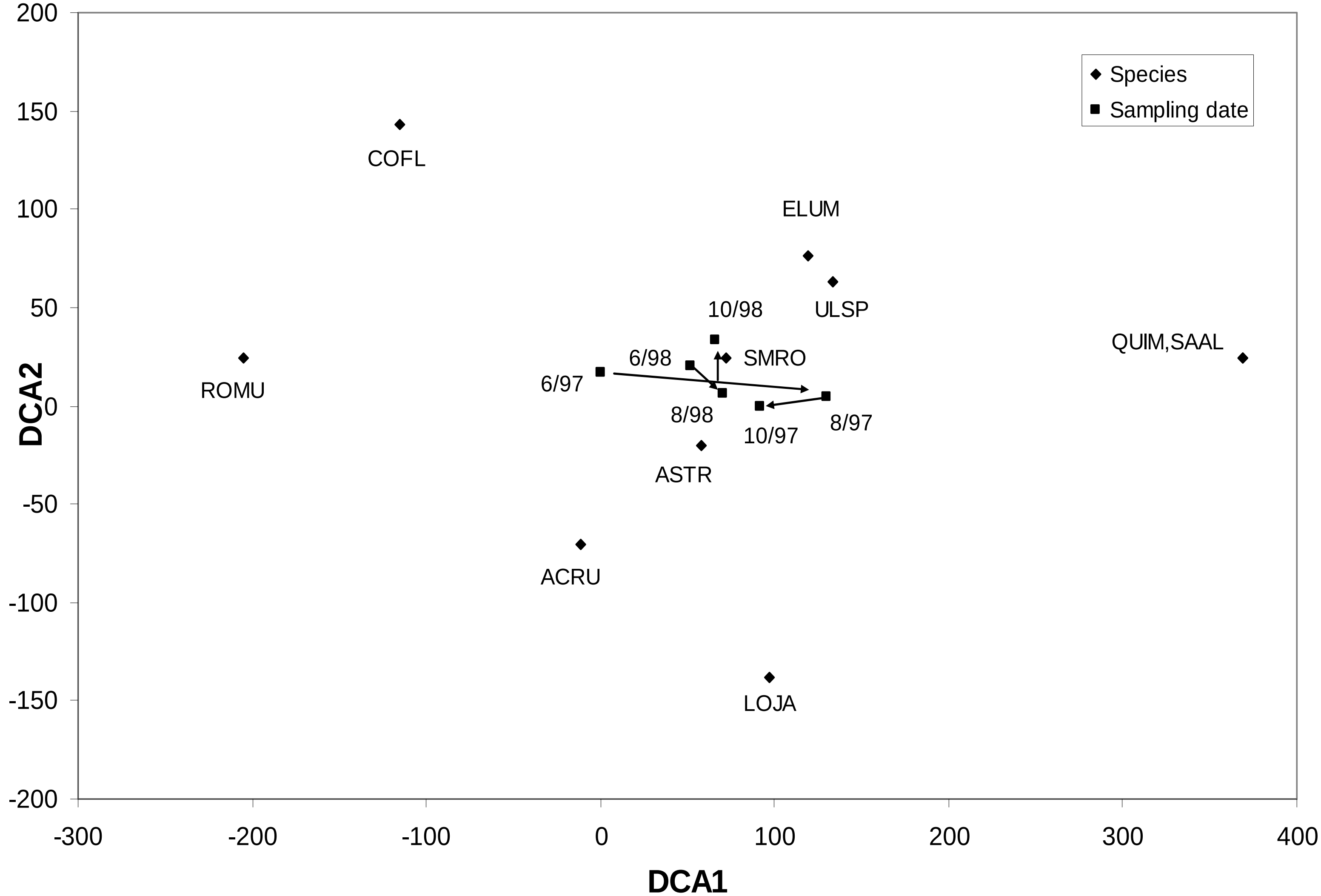
Species richness and cover

The average trends for all strata are consistent in 1997, with a peak in August and expected seasonal decline towards November (Figure 23). The average species richness of the shrub species in 1997 peaked in August (Figure 23). All ponds followed this trend except Pond 14, which peaked in July (Figure 23). Productivity of shrubs at Ponds 4 and 13 decreased in July (Figure 23). In 1998, the average trend peaked in June, earlier than the other strata, which peaked in July and August (Figure 23). The increase in precipitation for the month of June may have had a stronger effect on the shrub vegetation during this month than on the other strata (Figure 6). All ponds had similar trends, showing a decrease in August, which increased in September for Ponds 13 and 3 (Figure 23). As expected, all of the ponds decreased from

Table 16. Shrub species used in Pond 3 DCA graph and their importance values.

Species	Common Name	Acronym	Importance Value
Elaeagnus umbellata	Autumn olive	ELUM	35.0
Lonicera japonica	Japanese honeysuckle	LOJA	17.0
Asimina triloba	Paw paw	ASTR	11.1
Acer rubrum	Red maple	ACRU	8.9
Cornus florida	Flowering dogwood	COFL	6.5
Ulmus sp.	Elm	ULSP	5.3
Smilax rotundifolia	Common greenbrier	SMRO	4.5
Quercus imbricaria	Shingle oak	QUIM	2.4
Rosa multiflora	Multifloral rose	ROMU	2.3
Sassafras albidum	Sassafras	SAAL	0.6

Figure 21. DCA for Pond 3 shrub species showing influence of species diversity during the months of June, August and October 1997 and June, August and October 1998.



Species
Sampling date
COFL
ELUM
ULSP
10/98
QUIM,SAAL
ROMU
6/98
SMRO
6/97
8/98
10/97
8/97
ASTR
ACRU
LOJA
DCA2
DCA1
200
150
100
50
0
-50
-100
-150
-200
-300
-200
-100
0
100
200
300
400

Table 17. Shrub species used in Pond 4 DCA graph and their importance values.

Species	Common Name	Acronym	Importance Value
Lindera benzoin	Spicebush	LIBE	15.5
Elaeagnus umbellata	Autumn olive	ELUM	13.0
Asimina triloba	Paw paw	ASTR	11.1
Rosa multiflora	Multifloral rose	ROMU	10.0
Lonicera japonica	Japanese honeysuckle	LOJA	7.7
Cornus florida	Flowering dogwood	COFL	7.6
Osmunda cinnamomea	Cinnamon fern	OSCI	6.7
Acer rubrum	Red maple	ACRU	3.6
Ulmus sp.	Elm	ULSP	2.2
Nyssa sylvatica	Black gum	NYSY	1.6

Figure 22. DCA for Pond 4 shrub species showing influence of species diversity during the months of June, August and October 1997 and June, August and October 1998.

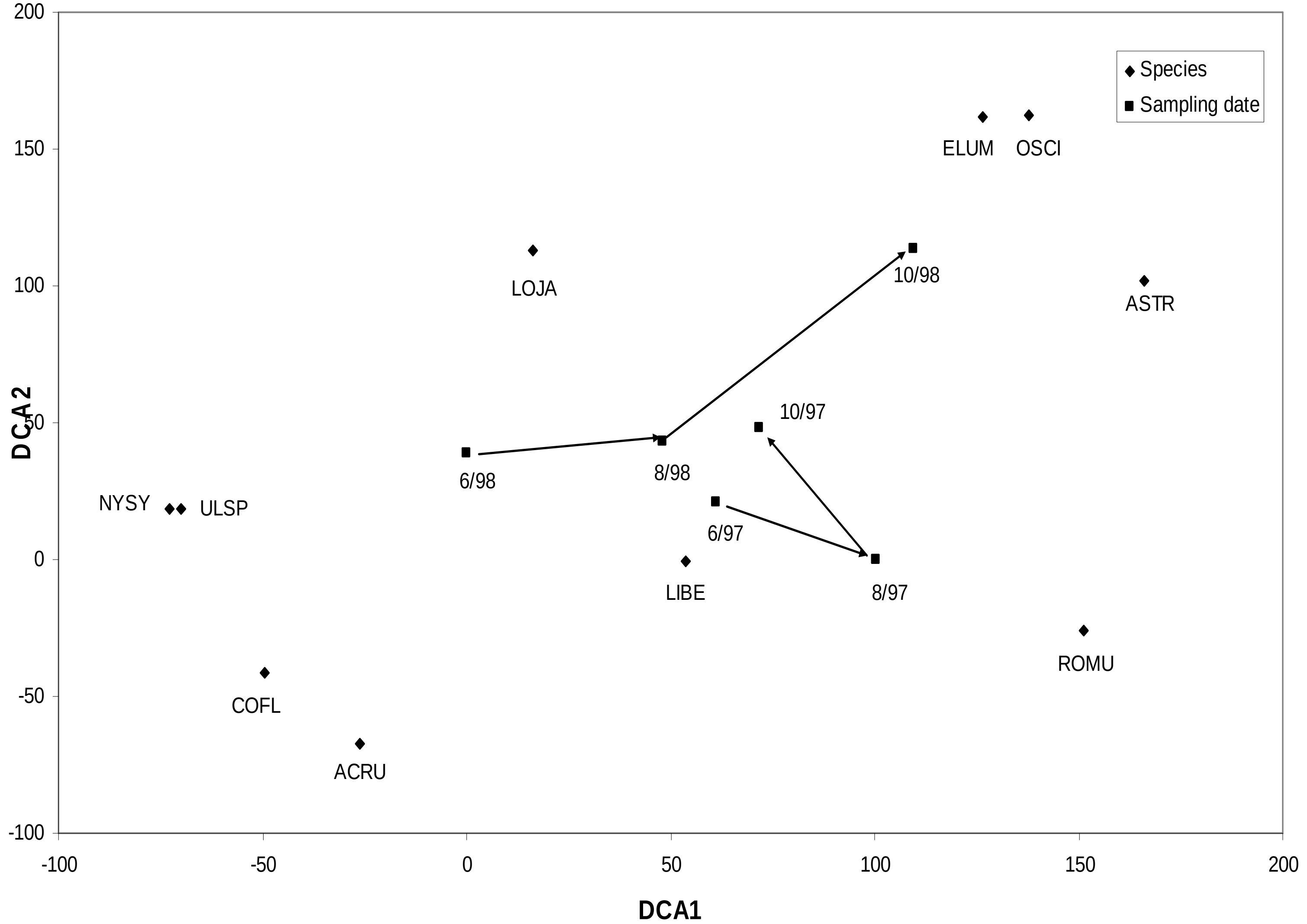
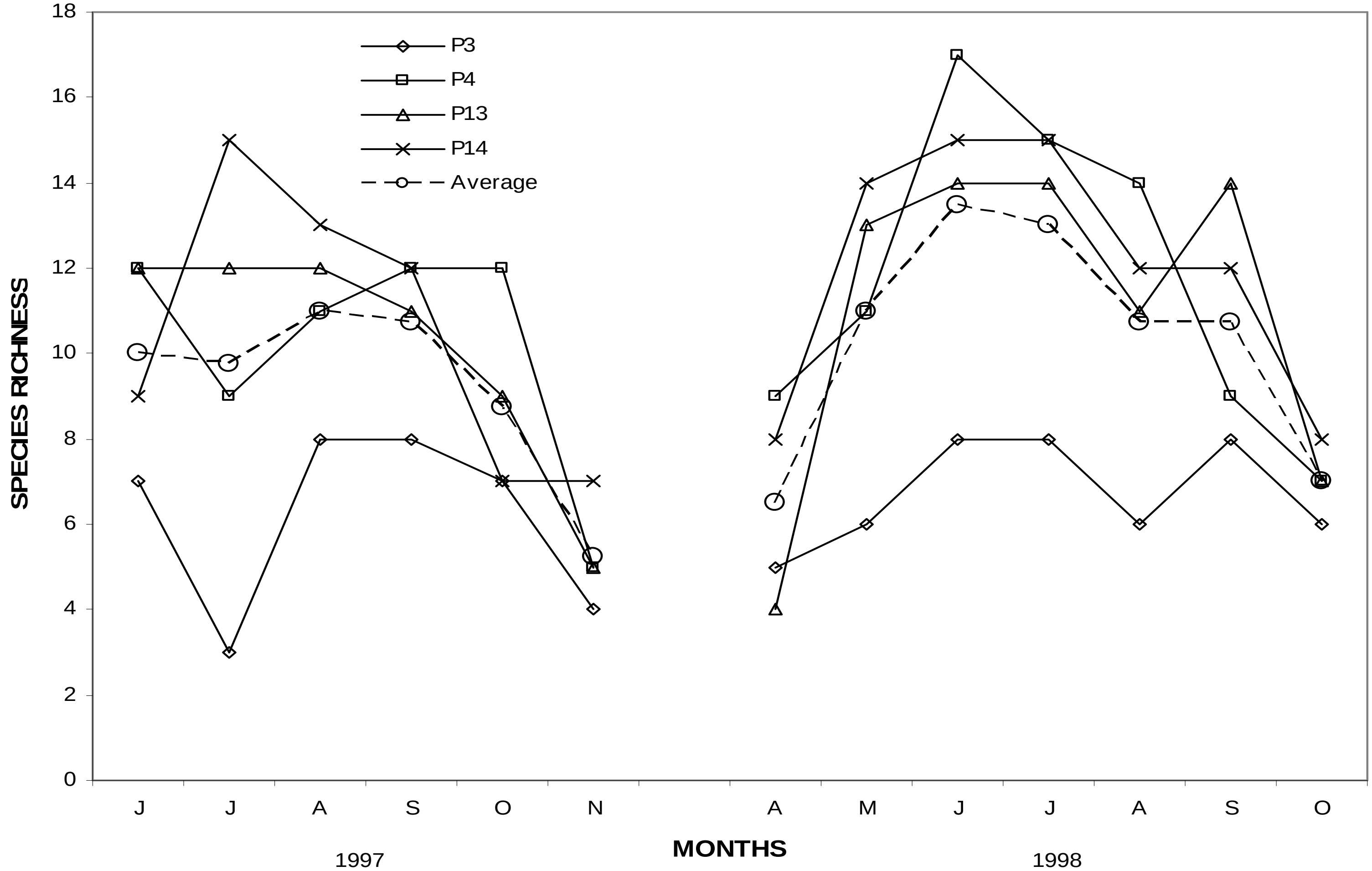

Species
Sampling date
ELUM
OSCI
LOJA
10/98
ASTR
10/97
6/98
8/98
NYSY
ULSP
6/97
LIBE
8/97
ROMU
COFL
ACRU
DCA 2
DCA1
200
150
100
50
0
-50
-100
-100
-50
0
50
100
150
200

Figure 23. Monthly variability of shrub species richness in 1997 and 1998.



P3
P4
P13
P14
Average
SPECIES RICHNESS
MONTHS
1997
1998
J
J
A
S
O
N
A
M
J
J
A
S
O
0
2
4
6
8
10
12
14
16
18

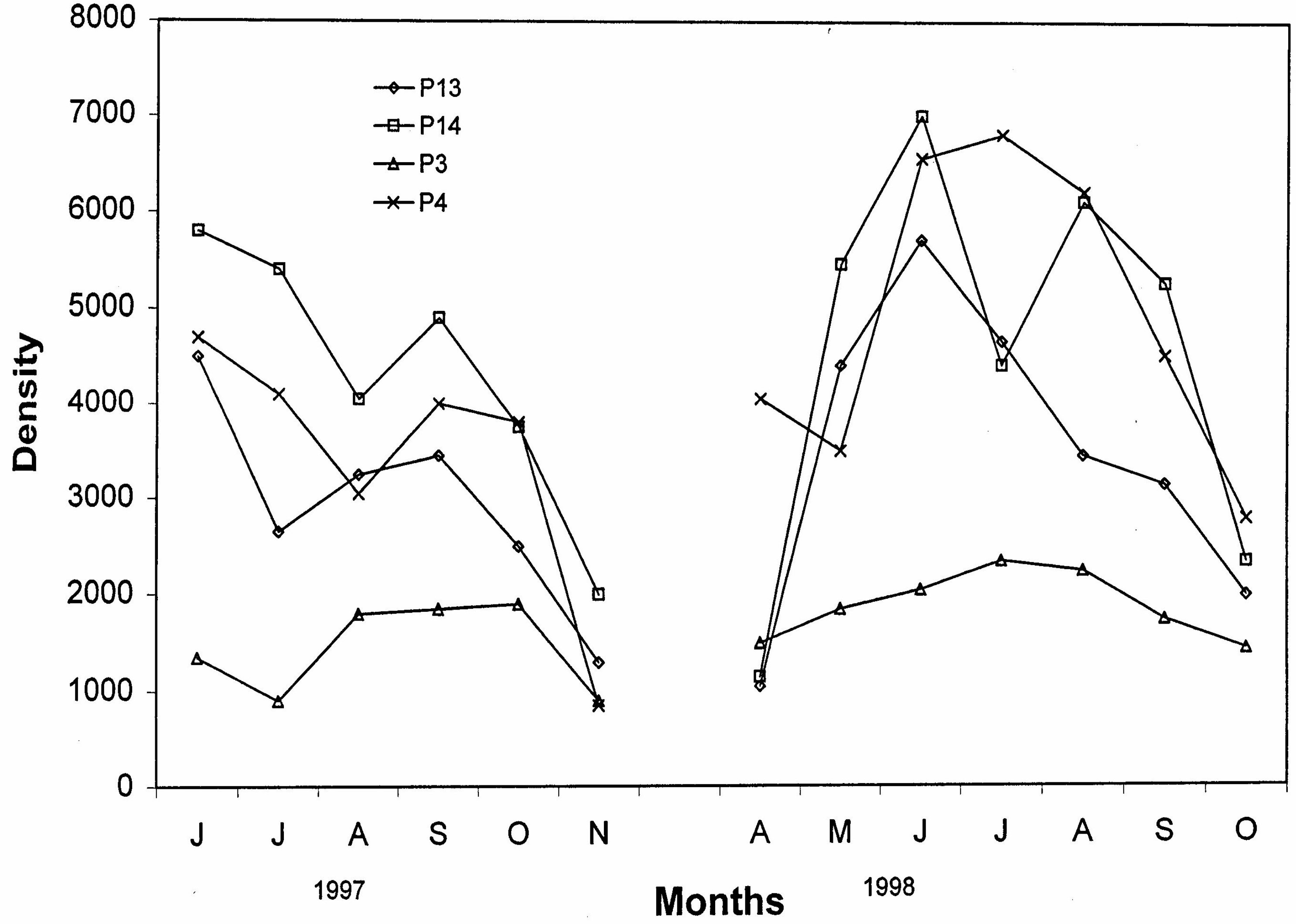
September to October (Figure 23). As with the herbaceous strata, differences in 1997 and 1998 for the shrub species richness could be due to precipitation differences (Figure 6).

Total density was calculated for the shrub species to show seasonal variation among the 1997 and 1998 growing seasons (Figure 24). Density, like percent cover of aquatic and herbaceous species, differed in peak months during the growing seasons among the four ponds. These woody species could also be affected by the canopy cover created by the overstory vegetation, causing differences in total density among the months sampled. The dominant species that occupied each pond may have also affected patterns of density by being early or late-season species. In turn, the density of the shrub layer affects the cover of the herbaceous layer, by regulating light and moisture availability.

Pond 14 had the highest total density in 1997 (Figure 24). This trend peaked in June and contained an unseasonable decrease in August before increasing again in September (Figure 24). The precipitation may have had a strong influence on the density pattern of the shrub vegetation. Rainfall was greatest in July and then decreased through August (Figure 6). Pond 14 also had the highest total density in 1998 in the month of June (Figure 24). There was an unseasonable drop in density in 1998 as well. However, it occurred in the month July - - not August - - as in 1997 (Figure 24). This was also consistent with the drop in rainfall in July of 1998 (Figure 6).

Pond 3 had the lowest density in 1997 and 1998 (Figure 24). It peaked in the month of October in 1997 and in the month of July in 1998 (Figure 24). The late seasonal peak in 1997 could be due to a decrease in canopy cover towards the end of the growing season, which would allow for greater light availability (Figure 24). Ponds 13 and 4 peaked in the month of June in 1997 (Figure 24). In 1998, Pond 13 also peaked in June, but Pond 4 peaked in July (Figure 24).

Figure 24. Monthly variability of shrub species density in 1997 and 1998.



8000
7000
6000
5000
4000
3000
2000
1000
0
Density
P13
P14
P3
P4
J
J
A
S
O
N
A
M
J
J
A
S
O
1997
Months
1998

Differences in Shrub Vegetation Between Years

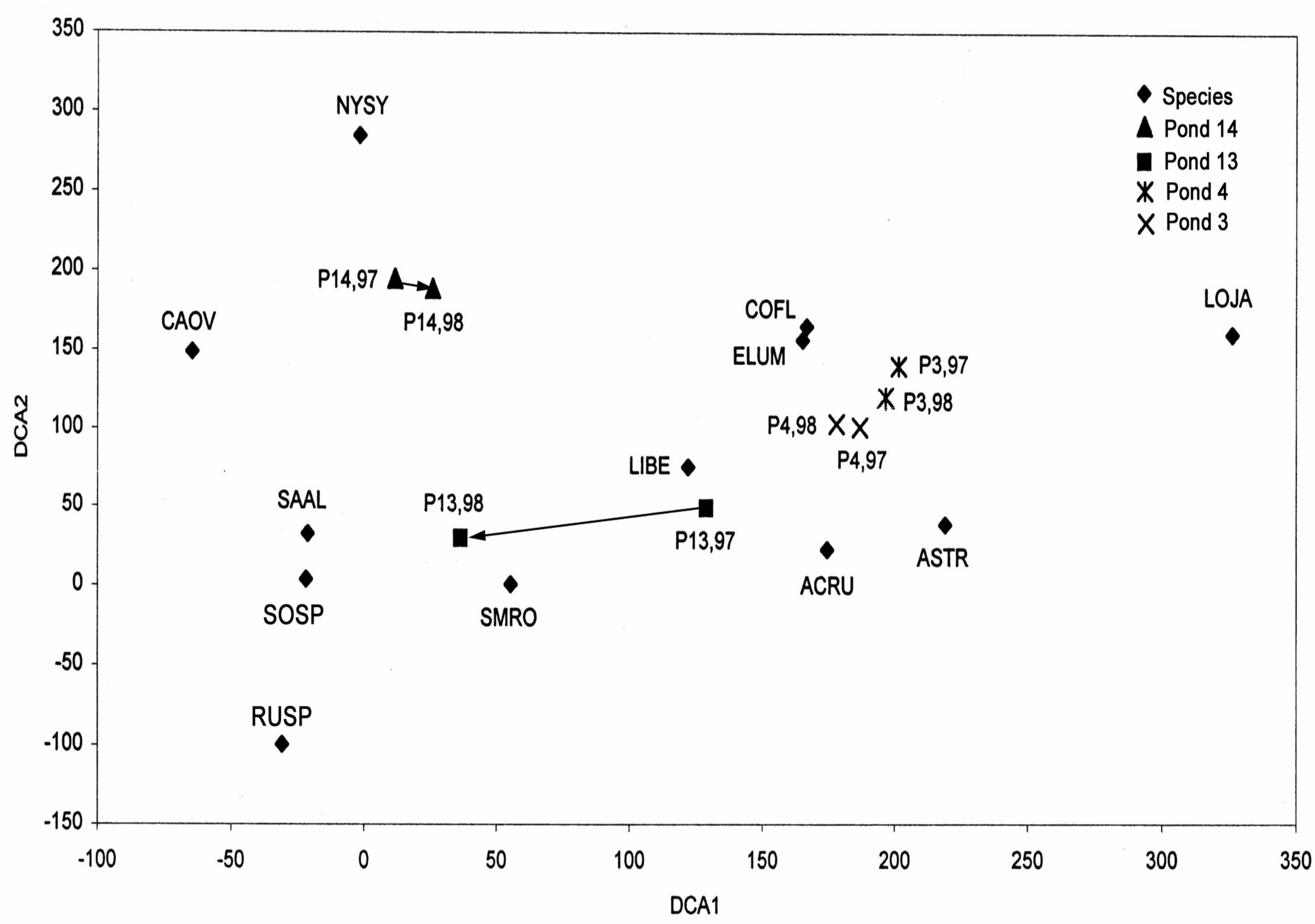
DCA

For the shrub stratum, twelve species were used to show variation among the four ponds (Figure 25). There are three main clusters among the four ponds for 1997 and 1998 (Figure 25). Pond 3 and 4 make up one cluster, while Ponds 13 and 14 have some separation along the DCA2 axis (Figure 25). Two species, paw paw, which is more dominant in these two ponds, and Japanese honeysuckle, which is most dominant at Pond 3 in late 1997, caused Ponds 3 and 4 to be pulled down the DCA1 axis (Figure 25, Table 5, Table 13). Two other species that also have affect on Ponds 3 and 4, equally, are flowering dogwood and autumn olive, the most dominant shrub among all ponds (Figure 25, Table 13). Pond 13 in 1998 was diverted away from 1997 by common greenbrier, sassafras, goldenrod and blackberry (Figure 25). The most influential species on Pond 13 in 1998 was shagbark hickory, where it was more dominant in 1998 than in 1997 (Table 5). Pond 14 had very little separation between 1997 and 1998. The two species that were common for both years were shagbark hickory and black gum, two of the most dominant species at Pond 14 (Figure 25, Table 13).

Species richness and cover

Average richness among the shrubs increased at all ponds in 1998 (Table 1), except for Pond 3, where average richness decreased from 7.17 to 6.71. In 1997, Ponds 4 and 13 contained a similar average of richness, 9.8 and 9.67 respectively (Table 1). However, in 1998 Pond 4 had a larger increase to 11.71 average species compared to the increase at Pond 13 to 11 average species (Table 1). Pond 14 contained the highest number of species in 1997, 10.3, and continued to have the most species in 1998 as well with 11.9 species (Table 1). Pond 3 had the fewest number of species for both 1997 and 1998.

Figure 25. DCA showing variation in shrub species among the four ponds in 1997 and 1998**.**


Species
Pond 14
Pond 13
Pond 4
Pond 3
NYSY
P14,97
P14,98
CAOV
COFL
ELUM
LOJA
P3,97
P3,98
P4,98
P4,97
LIBE
SAAL
P13,98
P13,97
ASTR
ACRU
SOSP
SMRO
RUSP
DCA2
DCA1
350
300
250
200
150
100
50
0
-50
-100
-150
-100
-50
0
50
100
150
200
250
300
350

Density was used to show growth trends in the shrub strata since cover was not an adequate means of measuring changes in the woody species. Trends among each pond remained consistent between 1997 and 1998 (Table 1). All ponds increased in average density from 1997 to 1998 (Table 1). This result may be due to the increase in annual precipitation in 1998 (Figure 6). Pond 14 had the highest average species density in 1997 and in 1998 (Table 1). The most dominant species at this pond was shagbark hickory with an importance value of 18.2. This was also the most important species at Pond 3 along with autumn olive, with an importance value of 35. Pond 3 had the lowest average density among the ponds for 1997 and 1998 (Table 1). This trend was also consistent with the species richness trends for the shrub strata, where Pond 14 had the highest species richness and Pond 3 had the lowest species richness. Like the herbaceous species, productivity increased along with species richness, indicating that diversity had not peaked which would have decreased productivity under the unimodal theory.

Chapter IV

Conclusions

The purpose of this study was to provide an analysis of aquatic, herbaceous, and shrub species during two growing seasons in and around four ponds at MWS before remediation activities occurred. Once remediation is completed, vegetative conditions can be compared to the pre-disturbed conditions for evaluations of the effects of the disturbance. Evaluating pre-disturbed conditions for future comparisons post disturbance can be a challenging task as many natural occurrences can alter "normal" conditions (Dawe et al. 2000). In evaluating the effectiveness of the study, it is important to understand the results and what may have caused any unseasonable or unexpected occurrences.

Changes in species dominance among the ponds were evaluated using importance values for each type of stratum. The herbaceous stratum had the highest turnover, changing dominant species six times in 1998 at Pond 13. This is to be expected in the herbaceous layer, where species are smaller and more sensitive to environmental changes. Pond 13 also had the highest species richness for aquatic species, which would allow for a higher turnover rate. The aquatic and shrub species had fewer changes in dominant species from month to month than the herbaceous species. Pond 3 in 1998 had no change in species dominance for both shrubs and aquatic vegetation. This was expected since Pond 3 had the lowest species richness of both 1997 and 1998.

In examining seasonal patterns using DCA, a relative comparison was given of each stratum with the months of the two growing seasons. This information will be useful in future analyses by knowing what species have historically had the most influence during the months of the growing seasons. It is evident that a wide range of variability occurred among the three strata and four ponds. In the aquatic stratum, Pond 4 seemed to have the most variation among the months and years, where Pond 3 seemed to have the least amount of variation. For the herbaceous stratum, all ponds had some degree of variability mostly occurring between the months in 1997, especially between June and the other two months. The shrub stratum showed mostly overlap between years, indicating a small amount of variability and separation between 1997 and 1998 with most of the variation occurring between months.

Differences in seasonal variation among ponds for all three types of strata can be due to differences in water level and canopy cover for each pond. Each of the ponds varied in its light and water availability due to canopy cover and fluctuating pond levels. A large percentage of canopy cover, which was evident at Ponds 3 and 4, could result in decreases in herbaceous and shrub species richness in an otherwise peak month of a growing season. This occurred in the month of July 1997, for Pond 4 of the aquatic species, Ponds 4 and 3 of the shrub species and Ponds 4 and 14 of the herbaceous species. In 1998, Ponds 13 and 3 decreased in July for the aquatic species and Pond 4 decreased in shrub species richness.

Overall, the results were indicative of expected seasonal changes in vegetation, with a few exceptions. By analyzing all three strata, it is evident how each stratum influences the others in productivity. In using this study as a comparison, future research may be more accurate with the knowledge of what to expect in seasonal and inter-year growth patterns of the vegetation that occurs at the four pond sites at MWS. However, it is also important to observe unexpected seasonable changes in environmental gradients such as precipitation, light and nutrient availability, and competition for those resources which may allow for deviations in production from expected seasonal norms.

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Appendix. List of all species encountered at all four ponds during the 1997 and 1998 growing seasons listed by acronym, common name, scientific name and authority.

Acronym	Common Name	Scientific Name
ACRU	Red maple	*Acer rubrum* L.
ACSA	Sugar maple	*Acer saccharum* Marsh.
AESP	Buckeye	*Aesculus* sp.
AIAL	Tree of heaven	*Ailanthus altissima* (Mill.) Swingle
ALSE	Brookside alder	*Alnus serrulata* Willd.
ASPL	Ebony spleenwort	*Asplenium platyneuron* (L.) Oakes
ASTR	Paw paw	*Asimina triloba* (L.) Dunal
ATPY	Glade fern	*Athyrium pycnocarpon* (Spreng.) Tidestr.
CAFR	Sedge	*Carex frankii* Kunth
CAOV	Shagbark hickory	*Carya ovata* (Mill.)K.Koch
CASP	Sedge	*Carex* sp.
CEDE	Coontail	*Ceratophyllum demersum* L.
CEOC	Buttonbush	*Cephalanthus occidentalis* L.
COAM	Hazlenut	*Corylus Americana* Walt.
COFL	Flowering dogwood	*Cornus florida* L.
CRSP	Hawthorne	*Crataegus* sp.
DASP	Poverty grass	*Danthonia spicata* (L.) Beauv.
ELUM	Autumn olive	*Elaeagnus umbellata* Thunb.
EUPE	Boneset	*Eupatorium perfoliatum* L.

Acronym	Common Name	Scientific Name
EUSE	Late flowering thoroughwort	*Eupatorium serotinum* Michx.
EUSP		*Eupatorium* sp.
FAGR	American beech	*Fagus grandifolia* Ehrh.
HISP	Hawkweed	*Hieracium* sp.
HOSP	Bluet	*Houstonia* sp.
HYPU	Dotted St. John's wort	*Hypericum punctatum* Lam.
ILMO	Mountain holly	*Ilex montana* T.&C.
JUEF	Soft rush	*Juncus effusus* L.
LEMI	Least duckweed	*Lemna minor* L.
LEOR	Rice cut grass	*Leersia oryzoides* (L.) Sw.
LIBE	Spicebush	*Lindera benzoin* (L.) Blume
LOJA	Japanese honeysuckle	*Lonicera japonica* Thunb.
LOTA	Tatarian honeysuckle	*Lonicera tatarica* L.
LUPA	Marsh purslane	*Ludwigia palustris* (L.) Ell.
LYAM	Water hoarhound	*Lycopus americanas* Muhl.
LYFL	Groundpine	*Lycopodium flabelliforme* Blanchard
MEAR	Field mint	*Mentha arvensis* L.
MOAL	White mulberry	*Morus alba* L.
NYSY	Black gum	*Nyssa sylvatica* Marsh
ONSE	Sensitive fern	*Onoclea sensibilis* L.
OSCI	Cinnamon fern	*Osmunda cinnamomea* L.
PAN1	Panic grass, small	*Panicum* sp. Thunb.

Acronym	Common Name	Scientific Name
PAN2	Panic grass, large	*Panicum* sp. Thunb.
PAQU	Virginia creeper	*Parthenocissus quinquefolia* (L.) Planch
PLOC	Western sycamore	*Platanus occidentalis* L.
POAC	Christmas fern	*Polystichum acrostichoides* (Michx.) Schott.
POHY	Mild waterpepper	*Polygonum hydropiperoides* Michx.
POPE	Ladies thumb	*Polygonum persicaria* L.
POPR	Kentucky bluegrass	*Port pratensis* L.
POSA	Tearthumb	*Polygonum sagittatum* L.
POSI	Common cinquefoil	*Potentilla simplex* Michx.
PRSE	Wild black cherry	*Prunus serotina* Ehrh.
QUAL	White oak	*Quercus alba* Michx.
QUIM	Shingle oak	*Quercus imbricaria* Michx.
QUPA	Pin oak	*Quercus palustris* Muenchh.
QUSP	Black/red oak	*Quercus* sp.
RHRA	Poison ivy	*Rhus radicans* L.
RHVE	Poison sumac	*Rhus vernix* L.
ROMU	Multifloral rose	*Rosa multiflora* Thunb.
ROPS	Black locust	*Robinia pseudo-acacia* L.
RUB1	Blackberry	*Rubus* sp.
RUB2	Dewberry	*Rubus* sp.
RUHI	Groundberry	*Rubus hispidus* L.

Acronym	Common Name	Scientific Name
SAAL	Sassafras	*Sassafras albidum* (Nutt.) Nees
SALA	Arrowhead	*Sagittaria latifolia* Willd.
SCSP	Bullrush	*Scirpus* sp. L.
SEFA	Foxtail	*Setaria faberi* Herrm.
SMRO	Common greenbrier	*Smilax rotundifolia* L.
SOSP	Goldenrod	*Solidago* sp.
SPSP	Sphagnum moss	*Sphagnum* sp.
SPDO	Hardhack	*Spiraea douglasii* L.
ULSP	Elm	*Ulmus* sp.
VIPR	Black haw	*Viburnum prunifolium* L.
VIRE	Smooth arrowhead	*Vibernum recognitum* Fernald
VISP	Grape	*Vitis* sp.
VOSP	Violet	*Viola* sp.
WOPU	Watermeal	*Wolffia punctata* Griseb.

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