This is to certify that the
dissertation entitled

RELATIONSHIPS BETWEEN COASTAL WETLAND
HABITAT AND YOUNG OF THE YEAR FISH COMMUNITY
CHARACTERISTICS, DISTRIBUTION, AND GROWTH

presented by

SHARON SCHAPEL

has been accepted towards fulfillment
of the requirements for the

Ph.D. degree in Fisheries and Wildlife and
Ecology, Evolutionary Biology, and Behavior

Major Professor's Signature

4 Nov. 2003

Date

RELATIONSHIPS BETWEEN COASTAL WETLAND HABITAT AND YOUNG OF THE YEAR FISH COMMUNITY CHARACTERISTICS, DISTRIBUTION, AND GROWTH

By

Sharon Schapel

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Fisheries and Wildlife
Ecology, Evolutionary Biology, and Behavior Graduate Program

2003

many

young

charac

two spa

charact

differen

includin

fish grow

habitat

oxygen,

perch, a

experim

different

in wetlar

Habitat

abundar

vegetatio

ABSTRACT

RELATIONSHIPS BETWEEN COASTAL WETLAND HABITAT
AND YOUNG OF THE YEAR FISH COMMUNITY CHARACTERISTICS,
DISTRIBUTION, AND GROWTH

By

Sharon A. Schapel

Although wetlands are important habitat for the early life history stages of many fish species, little is known about how wetland habitat characteristics affect young of the year (YOY) fish. This study examines the effect of wetland habitat characteristics on YOY fish community composition, distribution, and growth at two spatial scales. At the macrohabitat scale, relationships between habitat characteristics (e.g. habitat complexity, wetland area, and percent cover of different vegetation types) and characteristics of the YOY fish community, including fish abundance, species richness, diversity, species composition, and fish growth, were examined. At the microhabitat scale, relationships between habitat characteristics (e.g. vegetation type and density, water depth, dissolved oxygen, and turbidity) and the distribution of YOY bluegill, banded killifish, yellow perch, and spottail shiners were examined. Additionally, two enclosure experiments were conducted to evaluate the growth of YOY bluegill under different microhabitat conditions. Young of year fish were responding to changes in wetland habitat characteristics at the macrohabitat and microhabitat scale. Habitat characteristics that had the largest influence on YOY fish included the abundance and type of wetland vegetation, and water depth. The amount of vegetation influenced species richness, diversity, community composition, and

fish gro
the pre
growth
wetlanc
bluegill
of the f
depth v
that sh
comple
microh
correla
distribu
quality
both m
subme
zoopla
habita
type c
subme

fish growth at the macrohabitat scale. The type of vegetation present influenced the presence or absence of banded killifish, and the presence or absence and growth of bluegill at the microhabitat scale. Wetlands that had areas of deeper wetland habitat had a higher diversity of YOY fish, and faster growth rates of bluegill. Within wetland areas, the presence or absence of YOY fish from three of the four fish species examined was positively correlated with increasing water depth within the 0 to 100 cm range sampled. Other macrohabitat characteristics that showed strong relationships with the YOY fish community included habitat complexity and the presence of islands, sand bars, or gravel bars. At the microhabitat scale, the presence or absence of resident wetland species was correlated with changes in the physical structure of the habitat, while the distribution of transient wetland species was correlated with changes in water quality. Results of the enclosure experiments indicated that YOY bluegill fed on both macroinvertebrates and zooplankton when confined to emergent vegetation, submersed vegetation, or open water habitats; however they consumed more zooplankton and less macroinvertebrates in open water than in vegetated habitats. Bluegill growth was influenced by the density of YOY fish as well as the type of vegetation present, growing faster at low densities, and in areas of submersed vegetation.

I

guidanc

thank D

me. I al

member

impleme

I

graduat

and Eco

Michiga

Laborat

the Mich

T

undergra

Kovacs,

Aaron S

greatly a

Fish Lab

lots of th

and sup

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Tom Coon for all of his time, guidance, and patience with me over the past four years. I would also like to thank Dr. Dan Hayes for the use of his lab, and for all the advice he has given me. I also appreciate the help of Dr. Tom Burton and Dr. Mary Bremigan, who as members of my graduate committee, provided valuable insights into the design, implementation, and analysis of my research.

I would also like to thank those organizations that provided funding my graduate education and research, including: Cooperative Institute for Limnology and Ecosystems Research, International Association of Great Lakes Research, Michigan Sea Grant College Program, Great Lakes Environmental Research Laboratory, Department of Fisheries and Wildlife, Michigan State University, and the Michigan State University Distinguished Fellowship Program.

This research was conducted with the assistance of numerous undergraduate and fellow graduate students, including Amy Morgan, Cory Kovacs, Vern Moore, Kelly DeGrandchamp, Matt Klungle, Alfred Thomson, Aaron Shultz, and Randy Schapel. Their help in the field and laboratory is greatly appreciated. I would also like to thank my fellow members of the MSU Fish Lab, for their assistance and humor over the past four years. Finally, I send lots of thanks to my husband Randy Schapel for always being so encouraging and supportive of my desire to "play with the fishes."

TABLE OF CONTENTS

LIST OF TABLES

Table 3.1

Table 3.2

Table 3.3

Table 3.4

Figure 1.1

Figure 1.2

Figure 1.3

Figure 1.4

Figure 1.5

Figure 1.6

Figure 1.7

Figure 1.8

Figure 1.9

Figure 2.1

Figure 2.2

LIST OF FIGURES

Cov

component

role in shor

important f

Over 75% c

their life cy

habitat for e

provide qua

submersed

places to h

larger pred

macrophyte

allows for a

serve as fo

Wetl

estimated 6

agriculture,

up to 75% c

in these are

enrichment,

INTRODUCTION

Covering approximately 1,209 km^2, coastal wetlands are an important component of the Great Lakes ecosystem. These wetlands play an important role in shoreline stabilization, sedimentation, and nutrient dynamics. One of the important functions of Great Lakes coastal wetlands is providing habitat for fish. Over 75% of Great Lakes fish species utilize coastal wetlands for some portion of their life cycle. For many of these species, coastal wetlands serve as important habitat for early life history stages. There are several reasons why wetlands provide quality habitat for young fish. Wetlands are areas with abundant submersed and emergent vegetation. This vegetation provides small fish with places to hide from potential predators, and also reduces the maneuverability of larger predatory fish. Wetlands are also very productive habitats, with abundant macrophyte, phytoplankton, and periphyton communities. This high productivity allows for abundant populations of zooplankton and macroinvertebrates which serve as food for many young fish.

Wetland losses have been considerable in all of the Great Lakes, with an estimated 60-80% of the Great Lakes wetlands having been lost as a result of agriculture, land filling, residential, and industrial development. In some regions, up to 75% of coastal wetlands have been destroyed, and the remaining wetlands in these areas are heavily degraded due to development pressures, nutrient enrichment, watershed changes, and pollution inputs. These activities have altered the t

characteristi

alterations o

determine th

This

young of the

because the

their overwi

Past

uniform wit

is known a

diversities

and growth

should cho

because g

increase li

between th

efficiency i

choose the

maximizing

The

characteris

survival of

altered the total amount of habitat available to young fish as well as the characteristics of the remaining habitat. In order to quantify the impact of habitat alterations on fish populations, there is a need to identify habitat attributes that determine the use of Great Lakes wetlands by fishes.

This study focuses on the use of Great Lakes coastal wetland habitat by young of the year (YOY) fish. Young of the year fish were chosen for study because the growth rate of fish in their first year of life is critical in determining their overwinter survival and ultimately year class strength.

Past research has demonstrated that the distribution of YOY fish is not uniform within wetland areas or among different wetland environments. Yet, little is known about which habitat characteristics lead to higher abundances and diversities of young of year fish, or how habitat influences species composition and growth rates of YOY fish. Optimal foraging theory predicts that YOY fish should choose habitat patches that maximize energy intake per unit time, because growth rates, particularly in the first year, must be maximized to increase likelihood of survival to breeding age. But there is often a trade-off between the increased protection from predation and decreased foraging efficiency in areas of increased habitat structure. As a result, a fish should choose the environment that allows it to minimize its risk of predation while maximizing foraging success.

The overall goal of this project is to assess how wetland habitat characteristics at two different spatial scales affect the distribution, growth, and survival of YOY fish in the Laurentian Great Lakes. By increasing understanding of which habitat characteristics influence the distribution, abundance, diversity, and growth of young fish, managers will be better informed to make decisions concerning the protection, restoration, or alteration of Great Lakes coastal habitat and the Great Lakes fisheries that depend on these habitats.

CHAPTER 1: EFFECT OF COASTAL WETLAND MACROHABITAT CHARACTERISTICS ON THE YOUNG OF THE YEAR FISH COMMUNITY IN SAGNINAW BAY, LAKE HURON

ABSTRACT

Wetland loss and degradation have been extensive throughout the Great Lakes, impacting wetland habitat conditions and fish populations. The goal of this study was to examine relationships between wetland habitat and the young of year (YOY) fish community, including fish abundance, species richness, diversity, and species composition. Additionally, relationships between habitat characteristics and the growth rates of YOY fish were examined. Study sites included fifteen wetland areas in Saginaw Bay, Lake Huron. At each site, habitat characteristics including location, percent cover of vegetation types, maximum water depth, habitat complexity, wetland area, and proximity to other geographical features such as rivers and islands were recorded. Gear used to sample the YOY fish community included seines, minnow traps, Breder traps, throw traps, and trapnets. Habitat characteristics that explained the greatest variation in the YOY fish community included the percent cover of submersed vegetation or open water, the presence of islands and other land features, and water depth. Percent cover of submersed vegetation was positively correlated with species richness and the growth of yellow perch and banded killifish, while the amount of open water had a negative relationship with species diversity, and impacted species composition. The presence of sand bars, gravel bars or islands was positively correlated with fish abundance, and species richness, and impacted fish community composition. Greater species diversity and faster

individual growth rates of YOY bluegill were found in wetlands with areas of deeper water. Regional factors such as distance to the outer Bay did not have significant relationships with fish abundance, species diversity, evenness or fish growth; however they did impact fish community composition.

INTRODUCTION

Covering approximately 1,209 km^2 (Herdendorf et al. 1981), coastal wetlands are an important component of the Great Lakes ecosystem. These wetlands play an important role in shoreline stabilization, sedimentation, and system productivity (Jude and Pappas 1992). Great Lakes coastal wetlands also serve as important habitat for various life stages of fish (Liston and Chubb 1985, Chubb and Liston 1986, Jude and Pappas 1992, Leslie and Timmins 1994, Minns et al. 1994, Brazner 1997, Brazner and Beals 1997). A high percentage of Great Lakes fish species (>75%) depend upon coastal wetlands for some part of their life cycle (Stephenson 1990, Whillans 1992).

Wetland losses have been considerable in all of the Great Lakes, with an estimated 60-80% of the Great Lakes wetlands having been lost as a result of agriculture, land filling, residential, and industrial development (Comer et al. 1995). In some regions, up to 75% of coastal wetlands have been destroyed, and the remaining wetlands in these areas are heavily degraded due to development pressures, nutrient enrichment, watershed changes, and pollution inputs, compromising their ecosystem value (Jude and Pappas 1992, Krieger et al. 1992). For example, the alteration of habitat within coastal wetlands affects the abundance and composition of fish populations that use these habitats (Poe et al. 1986, Leslie and Timmins 1994, Minns et al. 1994, Brazner 1997, Brazner and Beals 1997, Johnson et al. 1997).

Among the important but poorly defined values of coastal wetlands is their role as habitat for the early life history stages of a number of fish species (Jaworski and Raphael 1978). Coastal wetlands provide spawning habitat for some species (e.g., *Esox* spp., *Lepomis* spp.) and habitat for early life history stages of these and other species (e.g., *Perca flavescens*, *Micropterus* spp.) (Chubb and Liston 1986, Herdendorf et al. 1981, Stephenson 1990, Petering and Johnson 1991, Jude and Pappas 1992, Brazner et al. 1998). In order to evaluate the impacts of wetland loss and degradation on fishery resources throughout the Great Lakes, more research is needed on the fish community structure within coastal wetlands, and the function of wetlands as spawning areas and habitat for early life history stages of fish.

Potential benefits of coastal wetlands for juvenile fish include the high primary productivity of these environments, reduced risk of predation, and rich zooplankton and benthos food sources that wetlands provide (Jude and Pappas 1992). Macrophytes are a key component of the habitat of Great Lakes coastal wetlands, providing young of the year (YOY) fish with refuge from predation by serving as protective cover that reduces the visibility of YOY fish and the maneuverability of adult piscivores (Savino and Stein 1982, 1989, Werner et al. 1983, Mittelbach 1986, Gotceitas and Colgan 1987, Werner and Hall 1988, Gotceitas 1990a,b, Heck and Crowder 1991). Vegetation also plays a role in determining the quality and quantity of invertebrates within wetlands (Turner 1988, Cardinale et al. 1997, Cardinale et al. 1998).

The abundance, growth, and survival of juvenile fish are not uniform within a single wetland or among wetlands within the same lake or geographic area (Chubb and Liston 1986, Bryan and Scarnecchia 1992, Baltz et al. 1993, Brazner 1997, Brazner and Beals 1997, Weaver et al. 1997, Duffy and Baltz 1998, Jackson and Jones 1999). Many fishes segregate within and among habitats along gradients of distance from shore, vegetation structure, temperature, and depth (e.g., Keast and Harker 1977, Werner et al. 1977, Johnson and Stein 1979, Brandt et al. 1980, Keast 1984; Killgore et al. 1989, Bryan and Scarnecchia 1992, Michaletz 1998, Pierce et al. 2001). Understanding the spatial distribution of organisms in ecosystems is of crucial importance for understanding ecosystem functioning (Hayes et al. 1996). In order to determine the impact of habitat alterations on fish populations, there is a need to identify habitat attributes that affect the use of Great Lakes wetlands by fishes (Brazner and Beals 1997).

This study builds upon previous efforts to identify linkages among habitat attributes and fish communities, by examining not only community characteristics and species composition, but also relationships between wetland habitat and YOY fish growth. Additionally, this study was carried out within a single aquatic system, Saginaw Bay, Lake Huron, thereby minimizing potential effects of differences in adult fish community characteristics among lake systems.

The goal of this study was to examine relationships between habitat characteristics of wetland environments and the YOY fish community. Specifically, relationships between wetland habitat characteristics and attributes of the YOY fish community such as fish abundance, species richness, species diversity, and species evenness were examined. Additionally, I sought to identify which habitat characteristics may play an important role in determining the species composition of the YOY fish community in different wetland areas. Finally, because the growth rates of freshwater fish within their first year of life are of critical importance in determining their likelihood of winter survival and ultimately year-class strength (Houde 1994), this study also examined the influence of wetland habitat characteristics on the success of YOY fish from four different species as measured by their growth rates.

Stud

Con

with

al. 1

silt

of t

tow

Pa

exc

sho

5.5

in

20

ap

are

sm

da

win

METHODS

Study Site Description

My study sites were located within Saginaw Bay, Lake Huron, USA. Compared to the rest of Lake Huron, Saginaw Bay is a eutrophic embayment with high productivity (Jude and Pappas 1992, Skubinna et al. 1995, Cardinale et al. 1998). The Saginaw River flows into the southern portion of the Bay, carrying silt and nutrients, and thereby affecting water quality along the eastern portions of the Bay. Conditions gradually improve from the mouth of the Saginaw River toward Lake Huron, creating gradients in environmental conditions (Jude and Pappas 1992). Several other smaller tributaries flow into Saginaw Bay. With the exception of urban and industrial landuses near Bay City on the southwestern shore of the Bay, the surrounding land use is primarily agricultural.

Saginaw Bay is relatively shallow; eighty percent of its volume is less than 5.5 m deep (Beeton et al. 1967). Water levels within the Great Lakes are cyclical in nature, with alternating periods of high and low water (Geis 1979, Boutin 2000). Water levels in Saginaw Bay during the study years averaged approximately 0.5 m below the long term mean (Figure 1.1). There are extensive areas of gravel and sand beds scattered throughout the Bay, as well as several small islands. These structures may help to shelter the coastal wetlands from damaging wind and wave energy as strong southwesterly and northeasterly winds are common within Saginaw Bay (Schelske and Roth 1973).

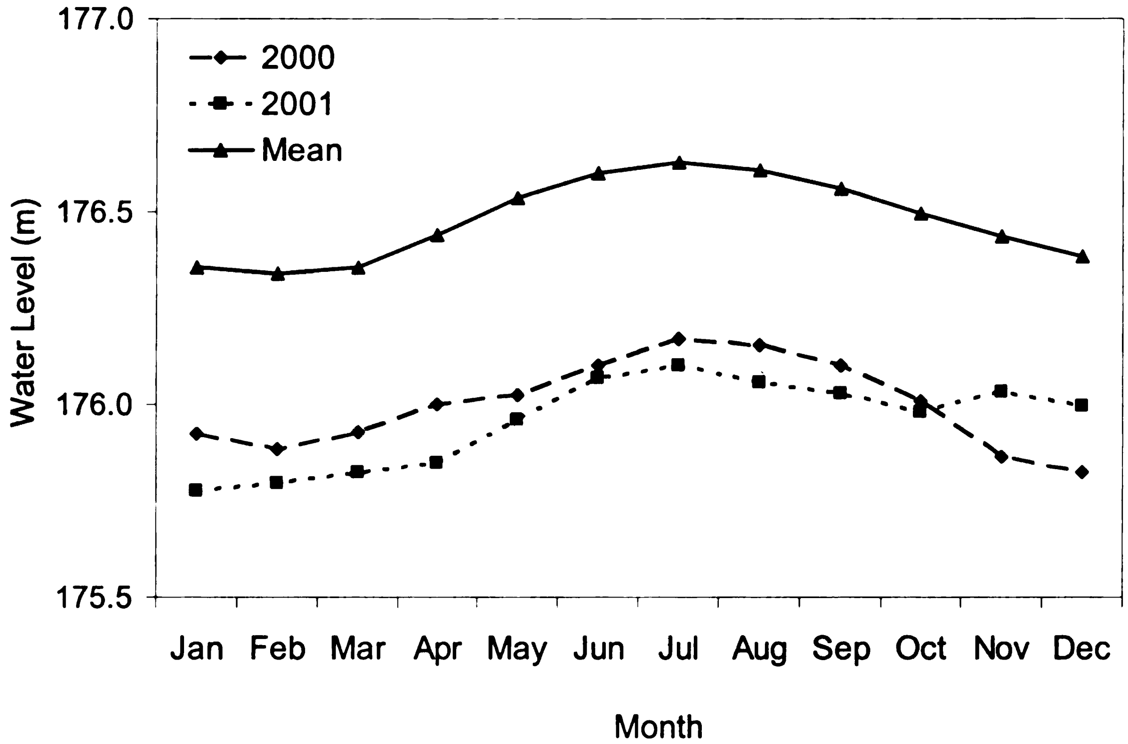


Figure 1.1: Water levels (m IGLD 1985) recorded by NOAA Essexville Station #9075035 in Saginaw Bay, Lake Huron in 2000 and 2001 compared to long term mean (1918-2000).

A great diversity of coastal habitats exists within Saginaw Bay. There are large and extensive wetlands with emergent vegetation communities dominated primarily by *Scirpus pungens* and *Typha angustifolia*. Submersed plant beds are dominated by *Myriophyllum spicatum, Valisineria americana, Potamogeton spp.* and *Chara globularis.*

Fifteen different wetland areas located throughout the Bay were selected as study sites and sampled in the summer of 2000 (Figure 1.2). Due to lower water levels in 2001, only twelve of these wetlands were sampled in 2001 (Au Gres, Essexville, and WigWam were not sampled). All of the wetlands sampled were at least 1.5 hectares in size, and separated by at least 10 km. Seven of these sites are located along the western shore of Saginaw Bay, while eight sites are located along the eastern shore of Saginaw Bay. Study sites varied in habitat characteristics, with some wetland areas being rather small and contained within distinct boundaries (e.g., Bayport), while other wetlands were a portion of continuous vegetated habitat along the coast that stretched on for many kilometers (e.g., Pinconning). The wetlands also varied in the presence of a structure such as islands, sand bars, or gravel bars that may offer protection from wave action.

Fish Collection

A variety of gear types was used to sample fish in 2000 (Table 1.1). As the size of YOY fish increased and vegetation growth became more prolific, it

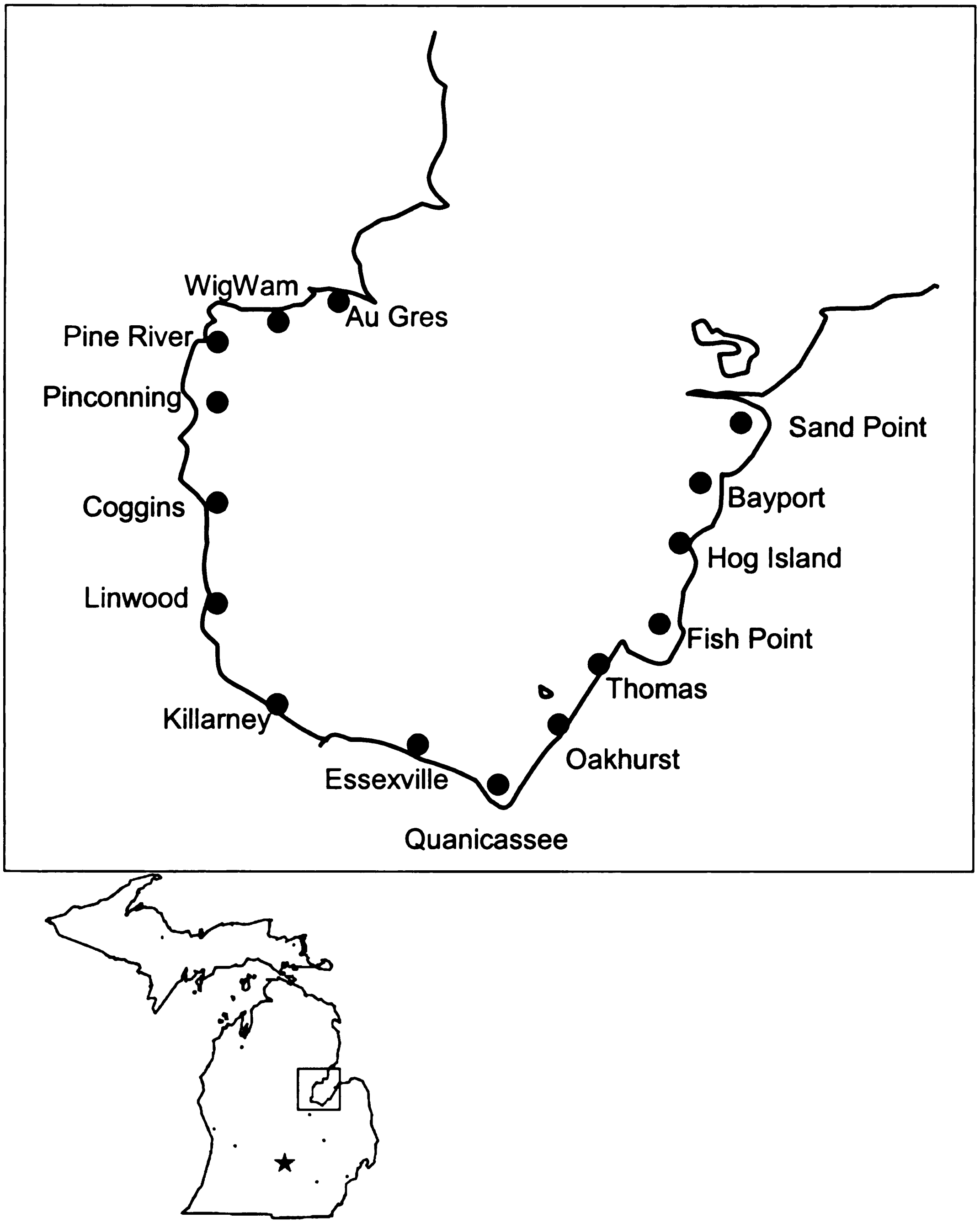


Figure 1.2: Map of approximate locations of study sites in Saginaw Bay, Lake Huron.

Table 1.1: Summary of fish collection methods used in 2000 and 2001.

	# Wetlands Sampled	# Samples Taken per wetland	Start Date	End Date
Seine	15	5	6/12/2000	6/28/2000
Minnow trap	15	20	7/6/2000	7/13/2000
Breder trap	15	10	7/25/2000	8/14/2000
Throw trap	15	10	7/25/2000	8/14/2000
Throw trap	12	10	9/1/2000	9/4/2000
Trapnet	12	4	7/23/2001	8/10/2001

wa

tak

site

eac

sei

tra

20

we

Ple

5m

bo

Re

to

we

an

Fr

Th

to

to

was necessary to switch sampling gears. The same number of samples was taken at each of the fifteen wetlands with each gear type. For each gear type, all sites were sampled within a three week period, for a total of five sample events in each wetland over a 15-week period in 2000.

A 5 m beach seine (3mm mesh) was used in May 2000, and five 15 m seine hauls were conducted at each site.

Minnow traps were used to sample fish in early June 2000. A total of 20 traps were set overnight in each wetland in water less than 1 m deep. Ten of the 20 traps were baited with saltine crackers.

Ten modified Breder traps (Breder 1960) were set overnight in each wetland in late July thru early August 2000. These traps were constructed of Plexiglas, with dimensions of 32 cm x 17 cm x 17 cm, and 46 cm long wings. A 5m long lead made of 5 mm mesh nylon netting with lead weights and fishing bobbers for floats was attached to each trap to increase catch (Figure 1.3). Rebar placed through holes drilled through the trap was used to attach the lead to the trap and fasten the other end into the sediment.

A modified throw trap (Figure 1.4) was used to sample fish within the wetlands in late July thru September 2000. Throw traps have been shown to be an effective method of sampling YOY fish in vegetated wetlands (Kushlan 1981, Freeman et al. 1984, Dewey 1992, Baltz et al. 1993, Raposa and Oviatt 2000). The throw trap used was designed with an angle iron base, weighted with lead, to cause the trap to sink rapidly. A PVC (4 cm diameter) frame was used for the top of the trap, which would float on the water's surface. Three mm mesh nylon

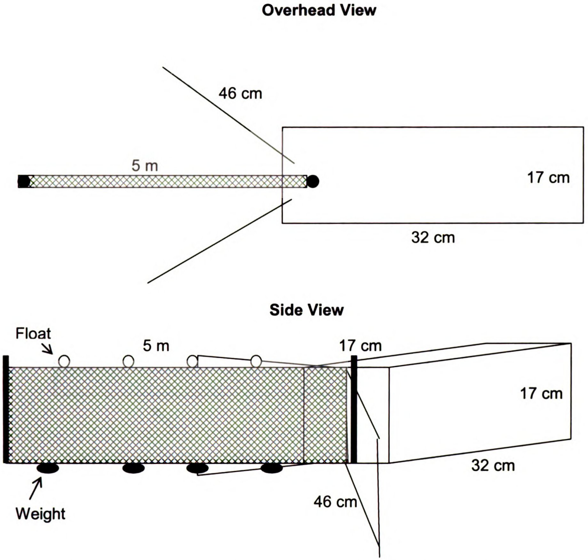


Figure 1.3: Illustration of modified Breder trap used to catch YOY fish.

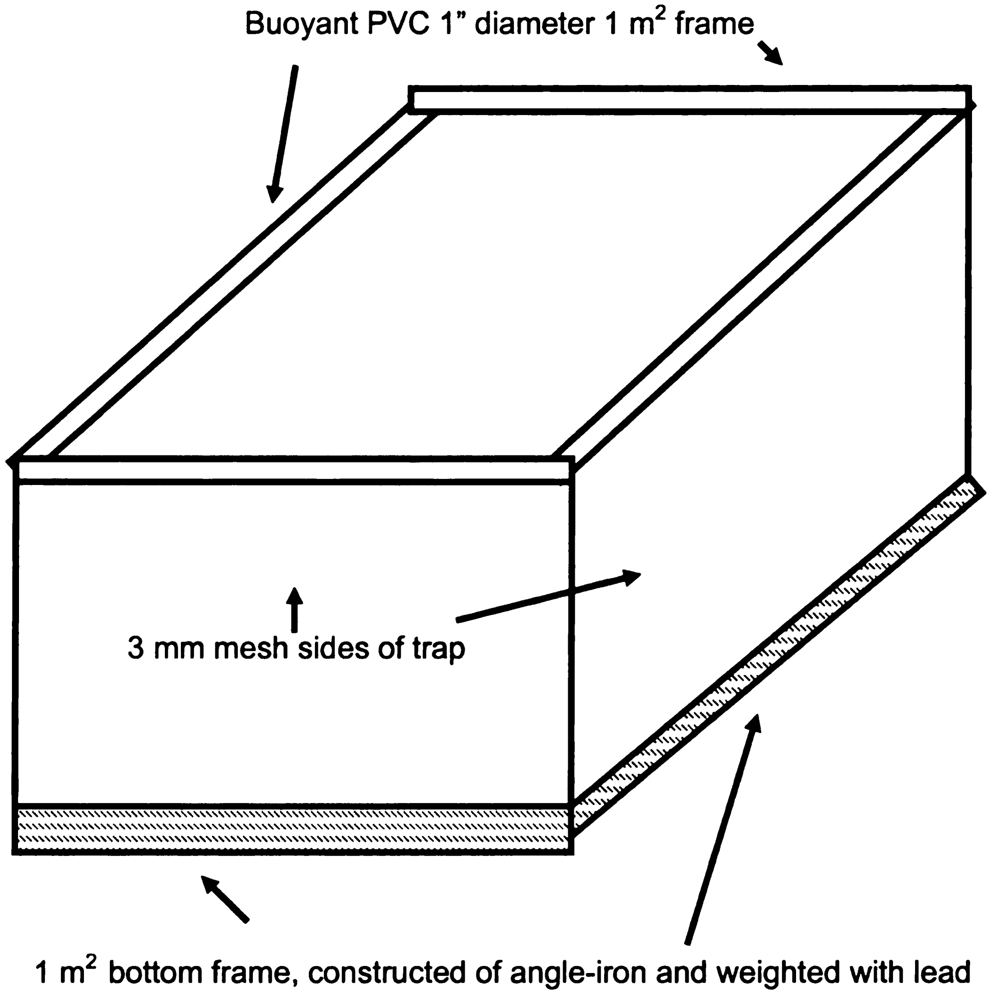


Figure 1.4: Design of 1 m^2 throw trap used to sample YOY fish in wetlands in late July thru September of 2000.

netting was used for the sides of the throw trap. The trap sampled 1 m^2 of wetland habitat up to 1 m in depth. The net was deployed by two people tossing the frame into the water. Pihl and Rosenberg (1982) found that animals generally did not exhibit an avoidance response to throw traps until moving people were within 1.5 m, and our throws typically covered a distance of three to four meters. The trap was deployed ten times in each wetland habitat. After deployment, the bottom of the frame was pushed into the sediment. A 5 mm mesh seine was used to remove fish from the trap. Seining continued until six consecutive seine hauls resulted in no additional fish being captured.

Trapnets (Figure 1.5) were used to sample fish in late July and August of 2001. Four traps were deployed overnight in each of the twelve wetland areas. The traps consisted of a PVC frame measuring 100 cm x 50 cm x 35 cm. The PVC was filled with a sand and gravel mix to cause the trap to sink and increase rigidity. Mesh netting (3 mm) was used for the sides and funnel of the trap. The funnel had a round opening of 11.5 cm. Wings constructed of 5 mm mesh netting were attached to the traps. Each wing was 7.5 m in length, with lead weights and plastic floats.

With all gear types, a stratified random sampling procedure was used to select sample locations. Effort was made to sample the diversity of habitat conditions available to YOY fish within a given wetland in proportion to the availability of that habitat type. All fish collected were identified to species, and counted. At each sample location, the standard length of five to ten individuals of each species was recorded. A minimum of ten individuals per species were

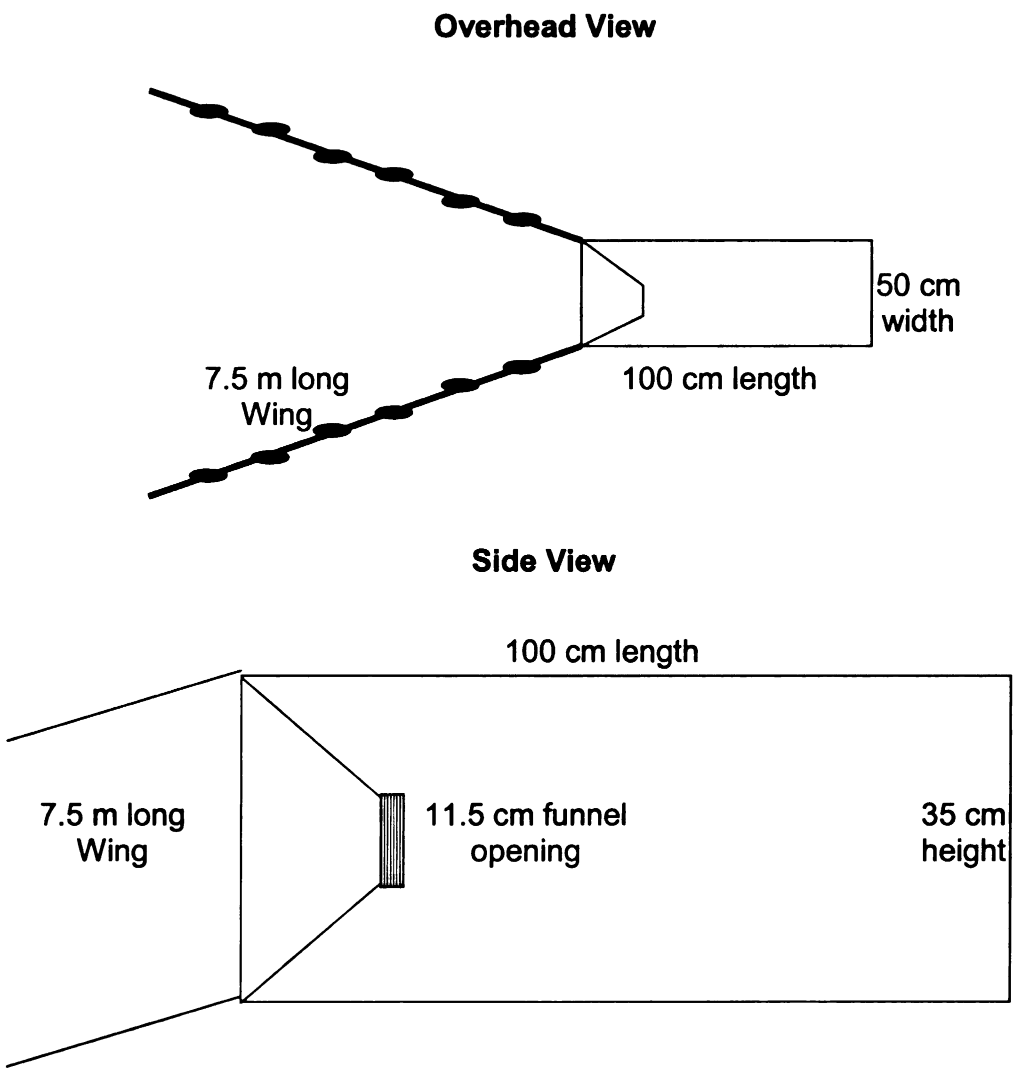


Figure 1.5: Design of trapnet used to sample YOY fish in wetlands in 2001.

preserved in a 90% ethanol solution, for otolith analysis of growth rates. An Optimas imaging system was used to measure the total radius of the otolith, and the radius of the otolith before the last seven rings were deposited. Growth rates of fish over the week preceding their capture were calculated according to procedures for the body proportional hypothesis outlined in Francis (1990).

Habitat Measurements

The location of each sample was recorded in the field using a hand held Garmin GPS unit. The presence of gravel bars, sand bars, islands or other structures that may serve to shelter the wetland from wave energy was also recorded.

Five 200 m transects were established within each wetland to sample characteristics of the vegetation community. Random locations were selected along the shore for the starting point of each transect, with the criteria that all transects were located at least 20 m apart. Transects ran perpendicular from shore into the wetland. Water depth was measured every five meters along each transect. Additionally, the presence of open water, submersed, emergent, or floating leaf vegetation was recorded every five meters. These data were used to determine the percent cover of open water, submersed vegetation, emergent vegetation, and floating leaf vegetation, habitat complexity, and the maximum water depth along the transects for each wetland.

Black and white aerial photographs from 1998 were obtained from the Michigan DNR website. The MrSID GeoViewer software program was used to measure the area of each wetland and the distance from each wetland area to the nearest river. These photographs were also used to measure the size of islands, sand bars, or gravel bars adjacent to the wetlands sampled.

USGS topographic maps were used to determine the distance from each wetland to the Saginaw River and to the outer Bay. The outer Bay was defined as water northeast of a line connecting Au Gres Point on the western bank of Saginaw Bay to Sand Point on the eastern bank of Saginaw Bay (Figure 1.2). USGS maps were also used to categorize each wetland as on the eastern or western bank of Saginaw Bay, with the Saginaw River being used as the dividing line (Figure 1.2).

Data Analysis

Analysis of Covariance (ANCOVA, forward selection procedure, $\alpha = 0.05$) was used to relate fish abundance, species richness, species diversity, and species evenness to habitat characteristics of each wetland. Only the twelve wetlands that were sampled in both 2000 and 2001 were used for this analysis.

Principal Coordinate Analysis (PCoA, city block distance measure) was used to compare the YOY fish communities in each of the twelve wetlands sampled in 2000 and 2001. A matrix was constructed containing information on the presence / absence of all species collected within the wetlands. Species that were found in only one of the twelve wetlands sampled were dropped from this analysis. Jaccard's similarity index was used to measure similarity of the YOY fish communities among wetlands. ANCOVA analysis was used to examine relationships between the PCoA scores of each wetland for the first two PCoA axes and habitat characteristics of those wetlands.

The mean weekly growth rate of four fish species, yellow perch, *Perca flavescens*, spottail shiner, *Notropis hudsonius*, banded killifish, *Fundulus diaphanous,* and bluegill, *Lepomis macrochirus,* over the week preceding their capture was compared among wetlands. To minimize the variability in growth rates due to time, fish size, fish age, and year, only fish collected over the 3-week sampling period in 2001 were used for this analysis. Approximately 20 to 30 fish of each species per wetland were used in this analysis. Growth rates were calculated according to the body proportional hypothesis model outlined in Francis (1990). ANCOVA was used to examine relationships between mean fish growth rates in different wetland sites and the habitat characteristics of those sites.

RESULTS

General Catch Characteristics

A total of 3,800 young of the year fish was collected in the fifteen wetland areas throughout the study period. Fish sampling in 2000 resulted in a capture of 2,768 YOY fish, while 1,032 fish were collected from the twelve wetland areas sampled in 2001 (Table 1.2). In 2000, total catch of fish ranged from a low of 10 at WigWam to 684 at Bayport. In 2001, total YOY catch ranged from 8 at Killarney to 396 at Linwood. The number of fish species caught at a single wetland in 2000 or 2001 ranged from two to eighteen (Table 1.2).

Young of year fish from 36 different species were collected throughout the two-year study period. WigWam had the lowest species richness, with only two species collected (Table 1.3). The highest number of species was collected at Linwood, where young of year fish from 21 species were collected. Common carp (*Cyprinus carpio*) was the only species found in all fifteen wetland areas. Other common fish species included quillback (*Carpiodes cyprinus*), banded killifish, bluegill, spottail shiner, largemouth bass (*Micropterus salmoides*), and yellow perch. Twelve fish species were collected in only one of the fifteen wetland areas (Table 1.3).

Table 1.2: Summary of overall fish catch, and number of species of young of year fish captured at each study site in 2000 and 2001.

	Total Fish Caught		# Species Caught	
	2000	2001	2000	2001
Au Gres	382	-	5	-
WigWam	10	-	2	-
Pine River	20	82	7	6
Pinconning	195	82	4	2
Coggins	96	14	5	4
Linwood	160	396	18	11
Killarney	304	8	11	3
Essexville	105	-	7	-
Quanicassee	29	22	5	5
Oakhurst	132	28	10	5
Thomas	36	14	4	3
Fish Point	213	34	6	8
Hog Island	389	247	8	6
Bayport	684	55	13	3
Sand Point	13	50	3	6

Table 1.3: List of young of the year fish species sampled indicating wetlands where each was collected; where, A = Au Gres, B = Bayport, C = Coggins, E = Essexville, F= Fish Point, H = Hog Island, L = Linwood, O = Oakhurst, P = Pinconning, R = Pine River, Q = Quanicassee, S = Sand Point, K = Killarney, T = Thomas, W = WigWam.

Scientific name	Common	A	W	R	P	C	L	K	E	Q	O	T	F	H	B	S
Ambloplites rupestris	rock bass						X	X								
Ameiurus natalis	yellow bullhead													X		
Ameiurus nebulosus	brown bullhead			X			X								X	
Amia calva	bowfin			X			X									
Carassius auratus	goldfish						X		X				X			
Carpiodes cyprinus	quillback	X				X	X	X	X		X		X		X	X
Catostomus commersoni	white sucker				X		X	X							X	
Couesius plumbeus	lake chub										X					
Cyprinella spiloptera	spotfin shiner						X	X					X	X	X	
Cyprinus carpio	common carp	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dorosoma cepedianum	gizzard shad										X		X			
Esox lucius	northern pike					X										
Etheostoma nigrum	johnny darter					X		X					X			
Fundulus diaphanus	banded killifish	X	X	X	X	X	X			X	X	X	X	X	X	X
Hybognathus hankinsoni	brassy minnow						X									
Ictalurus punctatus	channel catfish									X						
Labidesthes sicculus	brook silverside			X												
Lepisosteus oculatus	longnose gar			X							X					
Lepomis cyanellus	green sunfish						X		X			X	X	X	X	X
Lepomis gibbosus	pumpkinseed			X			X							X		

Table 1.3 (cont'd).

Scientific name	Common	A	W	R	P	C	L	K	E	Q	O	T	F	H	B	S
Lepomis macrochirus	bluegill			X	X		X	X				X	X	X	X	X
Luxilus cornutus	common shiner						X				X				X	
Micropterus salmoides	largemouth bass	X		X	X		X	X	X		X			X	X	
Morone chrysops	white bass							X								
Moxostoma erythrurum	golden redhorse										X					
Notemigonus crysoleucas	golden shiner						X									
Notropis atherinoides	emerald shiner						X			X						
Notropis heterolepis	blacknose shiner						X			X						
Notropis hudsonius	spottail shiner	X		X		X	X	X	X	X	X	X	X	X	X	X
Notropis ludibundus	sand shiner													X		X
Notropis rubellus	rosyface shiner										X					
Notropis volucellus	mimic shiner						X									
Perca flavescens	yellow perch						X	X	X	X		X	X	X	X	
Pimephales notatus	bluntnose minnow						X				X					
Pomoxis nigromaculatus	black crappie			X												
Stizostedion vitreum	walleye														X	

General Wetland Characteristics

Seven wetlands were located along the western shore of Saginaw Bay, while eight were located on the eastern shore (Figure 1.2, Table 1.4). The size of the wetlands ranged from 1.6 hectares at Coggins to 26.6 hectares at Hog Island. The distance from the wetland to the nearest river ranged from 0 km at Quanicassee to 8.0 km at Oakhurst. The distance from wetlands to the Saginaw River ranged from 4.8 km (Killarney) to 41.8 km (Au Gres and Sand Point), while the distance to the outer portion of Saginaw Bay ranged from 2.4 km (Au Gres) to 43.9 km (Quanicassee). Six of the fifteen wetlands sampled had one or more structures such as sand bars, gravel bars, or islands that may have provided the wetland area with some degree of shelter from wave action. The cumulative length of these islands, sand bars, or gravel bars ranged from 253 m to 2,173 m.

There was a broad range in the percent cover of open water within a wetland, with values ranging from a low of 10% at Pine River to 96% at Essexville (Table 1.5). Percent cover by emergent vegetation ranged from 1% (Killarney and Oakhurst) to 68% (Pinconning). The amount of cover provided by submersed vegetation also had a broad range from 0% (Pinconning and Fish Point) to 69% (Pine River). The amount of cover by floating leaf vegetation was very low in all fifteen wetlands sampled. Only two of the wetlands (Linwood and Au Gres) had any patches of floating leaf vegetation intersecting a transect. Percent cover of floating leaf vegetation was 5% at Linwood and 22% at Au Gres. All other wetlands sampled had 0% cover of floating leaf vegetation.

Table 1.4: General characteristics of wetlands measured from handheld GPS, 1998 aerial photographs, maps, and visual observations in the field. Numbers in the structure category represent the number of islands, sand bars, and/or gravel bars if present, and their cumulative length (m).

	GPS Coord.	Shore of Bay	Area (ha)	km to Nearest River	km to Sag. River	km to Outer Bay	Structure
Au Gres	43° 59' N 83° 42' W	W	10.9	3.8	41.8	2.4	2, 378 m
WigWam	43° 59' N 83° 48' W	W	5.6	1.1	39.9	10.5	1, 800 m
Pine River	43° 58' N 83° 51' W	W	7.0	0.8	36.5	15.0	-
Pinconning	43° 52' N 83° 55' W	W	6.1	2.4	24.9	23.6	-
Coggins	43° 48' N 83° 55' W	W	1.6	0.2	18.0	29.0	-
Linwood	43° 45' N 83° 57' W	W	8.1	0.1	14.5	34.6	1, 1914
Killarney	43° 40' N 83° 54' W	W	5.1	1.7	4.8	40.2	-
Essexville	43° 38' N 83° 47' W	E	8.8	5.9	6.7	41.3	-
Quanicassee	43° 59' N 83° 41' W	E	6.1	0	16.4	43.9	-
Oakhurst	43° 38' N 83° 37' W	E	5.6	8.0	20.4	35.9	-
Thomas	43° 42' N 83° 33' W	E	6.5	4.9	26.0	28.1	-
Fish Point	43° 42' N 83° 29' W	E	14.6	1.3	34.3	25.7	4, 551
Hog Island	43° 48' N 83° 25' W	E	26.6	1.9	30.0	12.9	6, 2173
Bayport	43° 51' N 83° 22' W	E	2.9	3.8	37.5	7.5	2, 253
Sand Point	43° 53' N 83° 20' W	E	6.6	0.1	41.8	6.4	-

Ta

ve

ea

tra

A

W

P

P

C

L

K

E

Q

C

T

F

H

B

S

Table 1.5: Summary of transect data, indicating percentage cover of different vegetation types (open water, emergent, submersed, and floating leaf) within each wetland, habitat complexity, and maximum water depth measured along transects.

	% Cover Open Water	% Cover Emer. Plants	% Cover Submer. Plants	% Cover Floating Leaf Plants	Habitat Comp.	Max. Water Depth (cm)
Au Gres	33	3	42	22	29	15
WigWam	60	27	13	0	22	15
Pine River	10	21	69	0	12	97
Pinconning	32	68	0	0	20	25
Coggins	70	9	21	0	27	25
Linwood	20	15	60	5	18	61
Killarney	89	1	10	0	21	35
Essexville	96	2	2	0	7	20
Quanicassee	20	62	18	0	38	30
Oakhurst	45	1	54	0	44	61
Thomas	88	2	20	0	23	35
Fish Point	36	64	0	0	24	35
Hog Island	34	34	32	0	41	33
Bayport	15	40	45	0	18	74
Sand Point	69	9	22	0	37	30

H

m

W

R

2

g

w

a

a

1

R

r

b

s

f

F

t

w

R

Habitat complexity values ranged from 7 (Essexville) to 41 (Hog Island). The maximum water depth along a transect ranged from 15 cm at Au Gres and WigWam to 97 cm at Pine River.

Relating Fish Community Characteristics to Wetland Habitat

The abundance of YOY fish was significantly greater (R^2 = 0.677, $F_{1,10}$ = 20.924, p = 0.001) at sites that had one or more structures such as sand bars, gravel bars, or islands that may have provided the wetland with shelter from wave action, compared to sites that lacked such a structure (Figure 1.6). The average catch of fish in wetlands without a structure was 141 ± 36 fish, while the average catch of fish in wetlands with one or more of these structures was 545 ± 106 fish.

Species richness within the twelve wetlands ranged from 6 to 22 species. Results of the ANCOVA (R^2 = 0.854) indicate that there are significant positive relationships between the presence of one or more islands, sand bars, or gravel bars and species richness ($F_{1,8}$ = 21.826, p = 0.002), and percent cover of submersed vegetation ($F_{1,8}$ = 17.335, p = 0.003). A negative relationship was found between species richness and distance from the wetland to the Saginaw River ($F_{1,8}$ = 8.247, p = 0.021).

The Shannon-Weiner species diversity index (H') was used to calculate the diversity of the YOY fish community sampled within each of the twelve wetlands. Species diversity ranged from 0.240 at Pinconning to 1.424 at Pine River. A positive relationship was found between species diversity and maximum

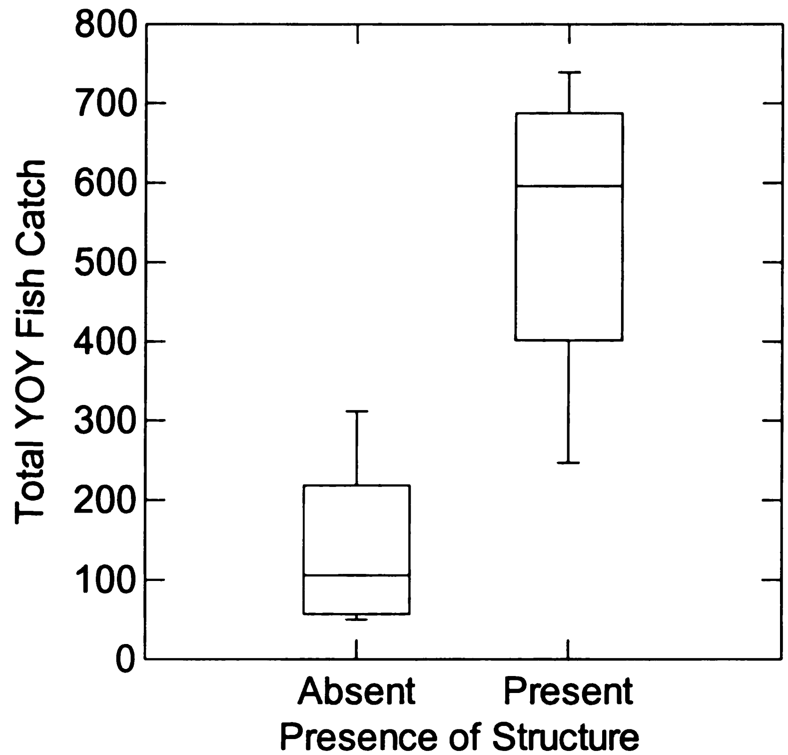


Figure 1.6: Abundance of YOY fish captured in wetlands without a structure such as a sand bar, gravel bar, or island, and wetlands with such a structure.

water depth along a transect ($F_{1,9}$ = 64.385, $p < 0.001$), while a negative relationship was found between species diversity and the amount of coverage of open water ($F_{1,9}$ = 14.617, p = 0.003). Overall model performance resulted in a R^2 = 0.952.

Species evenness for the twelve wetland areas ranged from 0.149 at Pinconning to 0.682 at Thomas. Results of the ANCOVA (R^2 = 0.959) indicate that there are significant positive relationships between species evenness and maximum water depth along a transect ($F_{1,9}$ = 52.118, $p < 0.001$) and percent cover of open water ($F_{1,9}$ = 32.904, $p < 0.001$).

Relating Fish Community Composition to Wetland Habitat

The first two PCoA axes explained 79.7% of the variance in the species presence/absence data, with the first axis explaining 48.3% of the variance, and the second axis explaining 31.4% of the variance. Visual inspection of the PCoA plot (Figure 1.7) indicates that Coggins (C) and Quanicassee (Q) had very similar species composition, with both wetlands having similar scores for axes one and two. Sand Point (S) and Thomas (T) also had similar scores for the first two axes. Other wetlands such as Pine River (R) and Fish Point (F) had similar scores for axis 1, but not for axis 2. Similarly, Linwood (L) and Coggins (C) had similar scores for axis 2, but very different scores along axis 1.

Multiple linear regression analysis was used to relate the wetland scores along axes one and two to wetland habitat characteristics. PCoA scores along

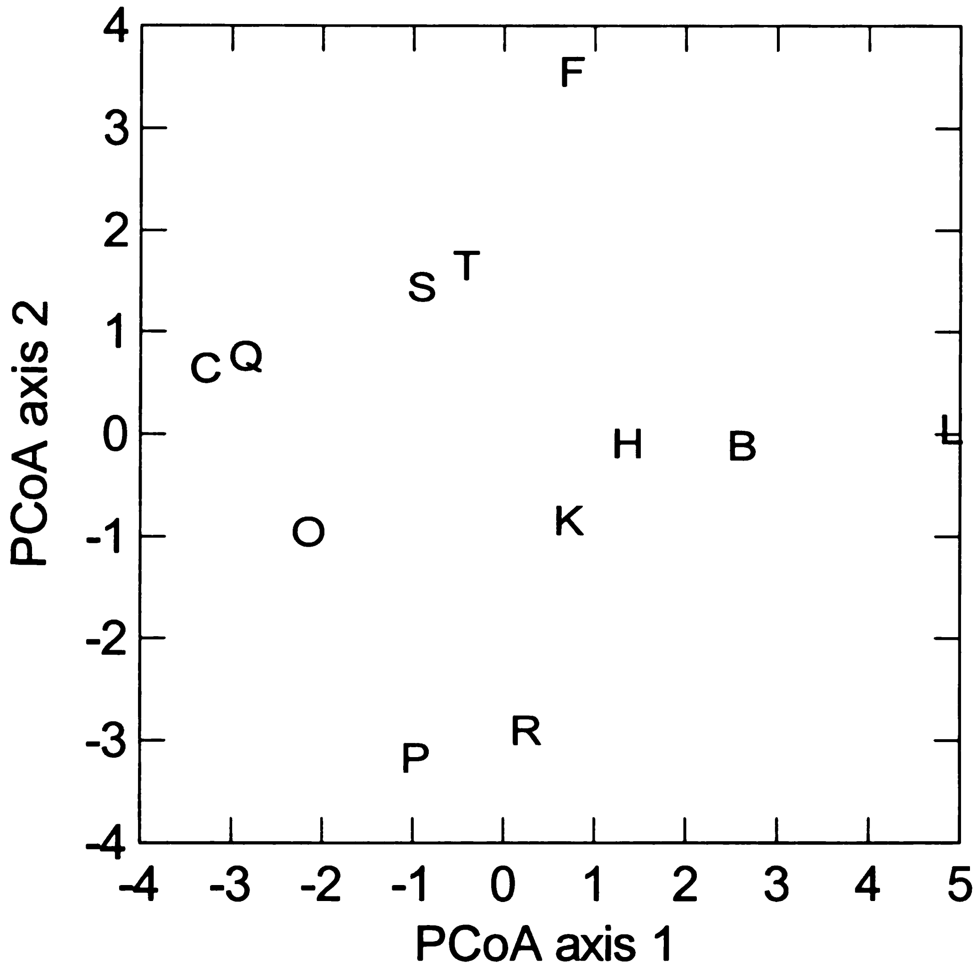


Figure 1.7: Graph of wetland PCoA scores for the first two axes. Symbols represent the first letter in the name of each wetland area sampled, except for the Pine River wetland which is represented by the letter R.

axis 1 we

were sign

one or mo

habitat co

wetlands t

wetlands w

wetlands w

pumpkinse

Hab

much of the

were relate

($F_{1,6}$ = 8.87

located ($F_{1,6}$

12.625, p =

7.927, p = 0

or more isla

shore of Sa

and that we

that were m

largemouth

pumpkinsee

axis 1 were related to characteristics of the wetland habitat ($R^2 = 0.737$). There were significant relationships between PCoA axis 1 scores and the presence of one or more islands, sand bars, or gravel bars ($F_{1,9} = 17.447$, $p = 0.002$), and habitat complexity ($F_{1,9} = 5.188$, $p = 0.048$). PCoA axis 1 scores were higher in wetlands that had one or more islands, sand bars, or gravel bars, and in wetlands with low habitat complexity. Species that were more common in wetlands with high scores along PCoA axis 1 included: bluegill, green sunfish, pumpkinseed, yellow perch, brown bullhead, and spotfin shiner.

Habitat characteristics of the wetlands sampled were also able to explain much of the variation in scores for PCoA axis 2 ($R^2 = 0.871$). Scores for this axis were related to the presence of one or more islands, sand bars, or gravel bars ($F_{1,6} = 8.879$, $p = 0.025$), the shore of Saginaw Bay where the wetland was located ($F_{1,6} = 18.697$, $p = 0.005$), the amount of cover of open water ($F_{1,6} = 12.625$, $p = 0.012$), and the distance from that wetland to the nearest river ($F_{1,6} = 7.927$, $p = 0.031$). In general, wetlands with high scores for PCoA axis 2 had one or more islands, sand bars, or gravel bars, and were located on the eastern shore of Saginaw Bay. Additionally, wetlands with large amounts of open water, and that were located near rivers had higher scores for PCoA axis 2. Species that were more common in wetlands with low scores along PCoA axis 2 included: largemouth bath, common shiner, brown bullhead, white sucker, and pumpkinseed.

Relating

Yellow Pe

YO

the three-

perch in th

cm/week a

growth rat

A si

was found

the amount

perch grew

There was

0.927) betw

wetlands ar

(Figure 1.8)

Spottail Shi

YOY

the three-we

the week pr

Bayport to 0

over all six w

Relating Fish Growth to Wetland Habitat

Yellow Perch

YOY yellow perch were collected in seven different wetland areas during the three-week sampling period in 2001. Mean individual growth rates of yellow perch in the week preceding capture in these wetlands ranged from 0.45 cm/week at Thomas to 0.81 cm/week at Linwood (Table 1.6). Mean weekly growth rate over all seven wetlands was 0.59 ± 0.05 cm/week.

A significant positive relationship (R^2 = 0.792, $F_{1,5}$ = 18.982, p = 0.007) was found between mean growth rates of yellow perch in the seven wetlands and the amount of submersed vegetation cover (Figure 1.8). In general, YOY yellow perch grew better in areas that had higher amounts of submersed vegetation. There was not a statistically significant relationship (R^2 = 0.002, $F_{1,5}$ = 0.009, p = 0.927) between mean weekly growth rate of YOY yellow perch within the seven wetlands and mean standard length of YOY yellow perch from those wetlands (Figure 1.8).

Spottail Shiner

YOY spottail shiners were collected in six different wetland areas during the three-week sampling period in 2001. Mean growth rates of spottail shiners in the week preceding capture in these wetlands ranged from 0.32 cm/week at Bayport to 0.50 cm/week at Fish Point (Table 1.6). Mean weekly growth rate over all six wetlands was 0.43 ± 0.03 cm/week.

Table 1.6

shiner, ba

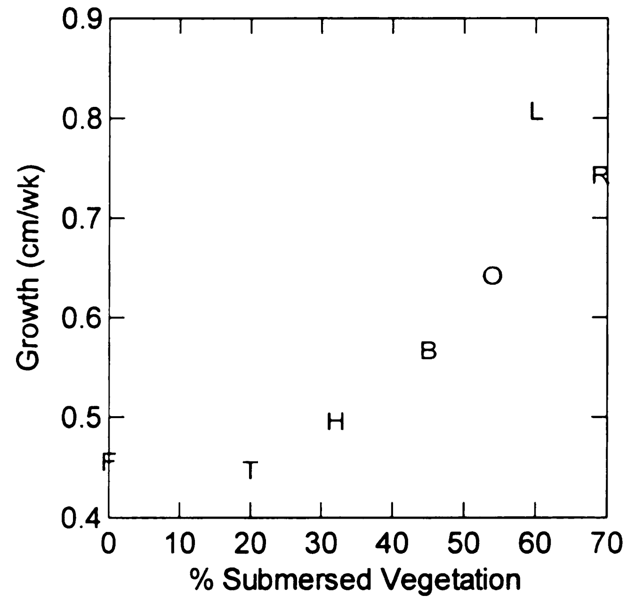
the twelve

Wetland
Pine River
Pinconnin
Coggins
Linwood
Killarney
Quanicass
Oakhurst
Thomas
Fish Point
Hog Island
Bayport
Sand Point

Table 1.6: Mean growth rate (cm/week) of young of year yellow perch, spottail shiner, banded killifish, and bluegill over the week preceding capture, in each of the twelve wetland areas where fish were captured during 2001.

Wetland	Yellow Perch	Spottail Shiner	Banded Killifish	Bluegill
Pine River	0.74 ± 0.11	0.38 ± 0.02	0.55 ± 0.03	0.58 ± 0.03
Pinconning	-	-	0.50 ± 0.02	-
Coggins	-	-	0.49 ± 0.03	-
Linwood	0.81 ± 0.03	0.41 ± 0.02	0.50 ± 0.02	0.59 ± 0.01
Killarney	-	-	-	0.25 ± 0.03
Quanicassee	-	-	-	-
Oakhurst	0.64 ± 0.04	0.47 ± 0.02	0.55 ± 0.05	-
Thomas	0.45 ± 0.04	-	0.47 ± 0.03	0.35 ± 0.01
Fish Point	0.46 ± 0.04	0.50 ± 0.07	0.42 ± 0.07	0.27 ± 0.02
Hog Island	0.50 ± 0.02	-	0.44 ± 0.02	0.24 ± 0.01
Bayport	0.57 ± 0.02	0.32 ± 0.01	0.51 ± 0.02	0.67 ± 0.02
Sand Point	-	0.48 ± 0.05	0.48 ± 0.03	0.30 ± 0.02

A. YOY yellow perch growth vs. % submersed vegetation



B. YOY yellow perch growth vs. standard length of perch

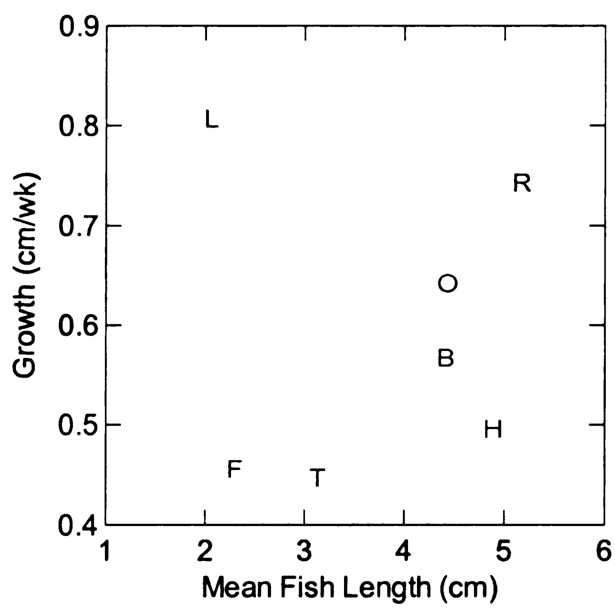


Figure 1.8: Relationship between A) mean growth rates (cm/week) of YOY yellow perch and amount of submersed vegetation cover and B) mean growth rates (cm/week) of perch and mean standard length (cm) of perch. Symbols represent the first letter in the name of each wetland area sampled, except for the Pine River wetland which is represented by the letter R.

ANCOVA was used to relate spottail shiner growth rate to wetland habitat characteristics, and was able to explain a large proportion of the variation in mean growth rates ($R^2 = 0.976$). A positive relationship was found between mean growth rates and habitat complexity ($F_{1,4} = 63.612$, $p = 0.004$), while a significant negative relationship was found between growth rate and maximum water depth sampled along a transect ($F_{1,4} = 20.654$, $p = 0.020$). There was not a statistically significant relationship between mean weekly growth rate of YOY spottail shiners within the six wetlands and mean standard length of YOY spottail shiners from those wetlands ($R^2 = 0.566$, $F_{1,4} = 5.223$, $p = 0.084$).

Banded Killifish

Young of the year banded killifish were collected in ten of the twelve wetland areas during the three-week sampling period in 2001. Mean growth rates of banded killifish in the week preceding capture in these wetlands ranged from 0.42 cm/week at Fish Point to 0.55 cm/week at Oakhurst and Pine River (Table 1.6). Mean growth rate of YOY banded killifish over all ten wetlands was 0.49 ± 0.01 cm/week.

ANCOVA was used to relate banded killifish growth to habitat characteristics ($R^2 = 0.785$). Results of the multiple linear regression indicate that there is a significant negative relationship between killifish growth rate and the presence of one or more islands, sand bars, or gravel bars ($F_{1,7} = 9.726$, $p = 0.017$), and a significant positive relationship with percent cover of submersed

vegetatio
areas tha
abundant
relationsh
of YOY ba
0.137).

<u>Bluegill</u>

The
analyzed fo
wetland ran
(Table 1.6).

A sig
was found b
maximum w
1.9). In ger
areas of dec
0.042, $F_{1,6}$ =
bluegill in th
bluegill from

vegetation ($F_{1,7}$ = 17.591, p = 0.004). In general, banded killifish grew better in areas that lacked islands, sand bars, or gravel bars, but where there was abundant submersed vegetation cover. There was not a statistically significant relationship between mean banded killifish growth rate and mean standard length of YOY banded killifish within the ten wetland areas (R^2 = 0.254, $F_{1,8}$ = 2.726, p = 0.137).

Bluegill

The growth rates of YOY bluegill in the week preceding their capture was analyzed for eight wetland areas. Mean weekly bluegill growth rates within a wetland ranged from 0.24 cm/week at Hog Island to 0.67 cm/week at Bayport (Table 1.6). Overall mean bluegill growth rate was 0.41 ± 0.06 cm/week.

A significant positive relationship (R^2 = 0.756, $F_{1,7}$ = 18.640, p = 0.005) was found between mean growth rates of bluegill in the eight wetlands and the maximum water depth measured along a transect within those wetlands (Figure 1.9). In general, YOY bluegill grew faster in wetland areas that had at least some areas of deeper water. There was not a statistically significant relationship (R^2 = 0.042, $F_{1,6}$ = 0.260, p = 0.628) between the mean weekly growth rate of YOY bluegill in the different wetland areas and the mean standard length of YOY bluegill from those wetlands (Figure 1.9).

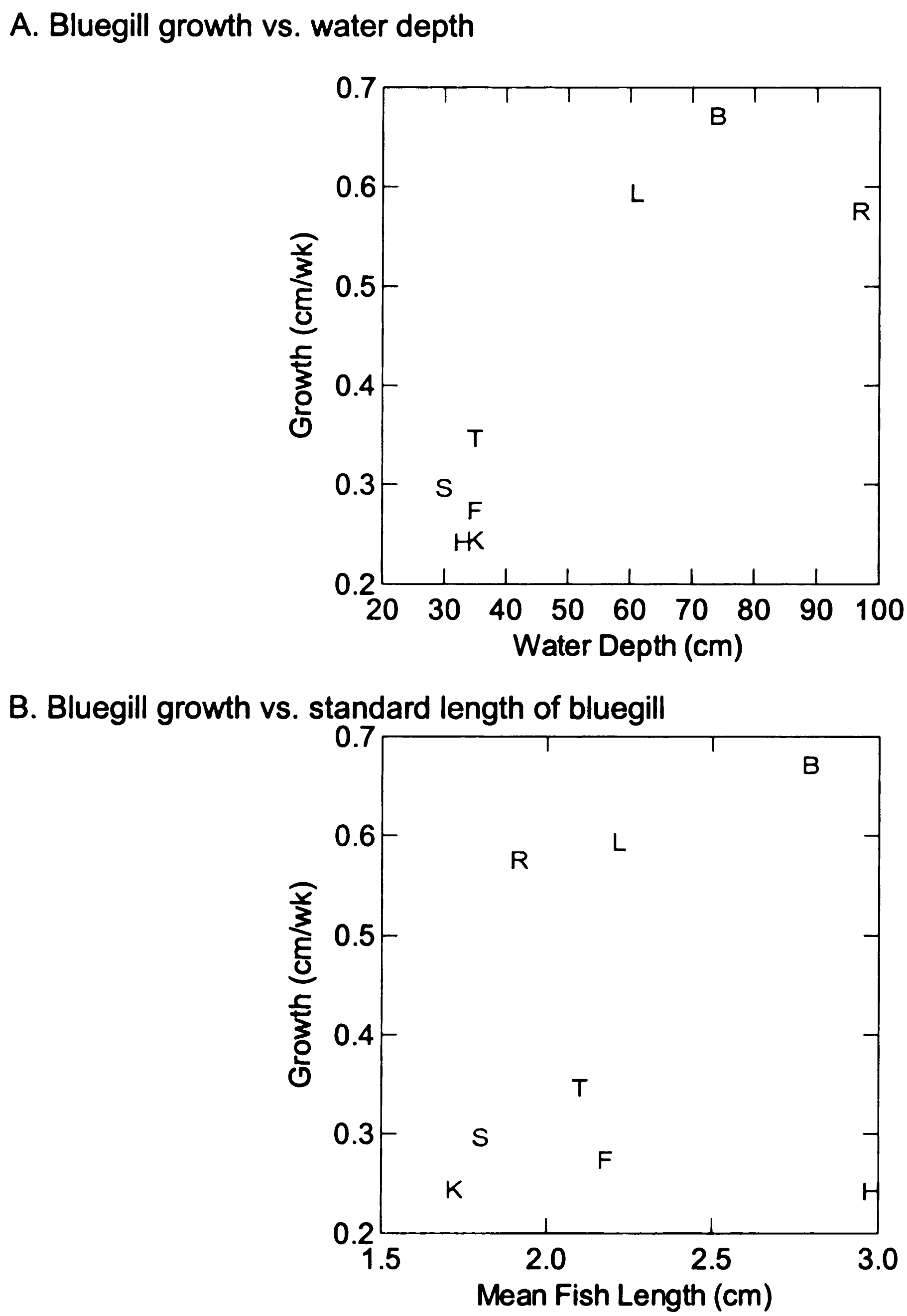


Figure 1.9: Relationship between A) mean growth rate of YOY bluegill (cm/wk) and maximum water depth (cm) measured along a transect and B) mean growth rate of YOY bluegill (cm/wk) and mean standard length of bluegill (cm) in eight wetlands. Symbols represent the first letter in the name of each wetland area sampled, except for the Pine River wetland which is represented by the letter R.

DISCUSSION

Young of the Year Fish Community in Saginaw Bay, Lake Huron

This study sampled the YOY fish community in 2000 and 2001 in fifteen different wetlands areas around Saginaw Bay, Lake Huron. The young of year fish community in these wetlands was numerically dominated by eight fish species: banded killifish, quillback, common carp, spottail shiner, bluegill, green sunfish, goldfish, and yellow perch. The dominant fish species found within Saginaw Bay are similar to those reported for other wetlands in Lake Huron (Leslie and Timmins 1994) and other coastal wetlands throughout the Great Lakes (e.g., Chubb and Liston 1986, Jude and Pappas 1992, Brazner 1997).

Overall, YOY fish from 36 species were captured in the coastal wetlands of Saginaw Bay over 2000 and 2001. This value is within the range of species richness (18-38 species) reported from other studies of coastal wetlands in Lake Huron (e.g., Loftus 1982, Minns et al. 1994, Leslie and Timmins 1997). The number of species captured within a single wetland during this study ranged from 2 to 18 species. This value is low compared to the range (15-41 species) reported in other studies of Great Lakes coastal wetlands, many of which examined both the adult and juvenile fish community (e.g., Chubb and Liston 1986, Poe et al. 1986, Randall et al. 1996, Brazner 1997, Johnson et al. 1997).

Although a total of 36 fish species was captured within the coastal wetlands in Saginaw Bay, twelve of the fish species captured were found in only one wetland area. An abundance of rare species was also documented in a study of coastal wetland areas in Severn Sound, Lake Huron (Leslie and Timmins 1994). Fish species considered to be uncommon in their study outnumbered common species by more than three to one. However the authors noted that it was likely that these rare species were not sampled in proportion to their true abundance, which is probable in this study of YOY fish in Saginaw Bay as well.

Influence of Habitat Characteristics on the YOY Fish Community

A wide range of YOY fish abundances, species richness, diversity, community composition, and fish growth rates were observed among the different wetlands sampled in Saginaw Bay. These results indicate that all wetland environments are not equal in terms of their value for YOY fish. More fish, greater numbers of species, different species, and faster growing fish were collected from certain wetlands compared to others. Table 1.7 provides a summary of the statistically significant relationships between YOY fish community metrics and measured wetland habitat characteristics included in the ANCOVA models.

In general, characteristics of the macrophyte community within the wetlands were important in determining YOY fish use of wetland areas, with percent cover of open water or submersed vegetation having a statistically significant relationship to 60% of the metrics of the YOY fish community

Table 1.7: Summary table indicating relationships between YOY fish community characteristics, fish growth, and habitat characteristics, where + represent statistically significant positive relationships, and – represent statistically significant negative relationships.

	Presence of Structure	Maximum Water Depth	% Submersed Vegetation	% Open Water	Habitat Complexity	Distance to Nearest River	Distance to Saginaw River	Eastern Shore of Sag. Bay
Fish Abundance	+							
Species Richness	+		+				-	
Species Diversity		+		-				
Evenness		+		+				
Community composition								
Axis 1	+				-			
Axis 2	+			+		+		+
GROWTH								
Yellow perch			+					
Spottail shiner		-			+			
Banded killifish	-		+					
Bluegill		+						

measured. In addition to macrophyte cover, habitat characteristics relating to hydrology and geomorphology (presence of one or more islands, sand bars, or gravel bars, and maximum water depth measured along sample transects), had large influences on the YOY fish community.

Aquatic Vegetation

Macrophytes are a key component of the habitat of Great Lakes coastal wetlands, providing young of the year fish with refuge from predation by serving as protective cover that reduces the visibility of YOY fish and the maneuverability of adult piscivores (Savino and Stein 1982, 1989, Werner et al. 1983, Mittelbach 1986, Gotceitas and Colgan 1987, Werner and Hall 1988, Gotceitas 1990a,b, Heck and Crowder 1991). Macrophytes also serve as important habitat for macroinvertebrate and zooplankton food resources (Cardinale et al. 1998). The amount of submersed vegetation and open water had impacts on 60% of the YOY community metrics examined in this study.

There was a significant relationship between the percent cover of submersed vegetation and species richness in wetlands in this study. YOY fish from more species were collected in wetland areas that had high amounts of submersed vegetation cover. Species of YOY fish that were more commonly present in wetlands with high amounts of submersed vegetation cover included: largemouth bass, green sunfish, pumpkinseed, bowfin, longnose gar, and brown bullhead. Several other studies have documented increases in species richness or diversity in wetlands with increased vegetation cover (Keast et al. 1978, Bryan and Scarnecchia 1992, Leslie and Timmins 1994, Minns et al. 1994, Randall et al. 1996, Pierce et al. 2001).

Extremely high plant cover (70-80%), has been shown to result in a decrease in fish species richness (Crowder and Cooper 1982, Wiley et al. 1984, Killgore et al. 1989, Lillie and Budd 1992, Dibble et al. 1996). No decline in species richness with increased vegetation cover was found in this study. Previous studies on the detrimental impacts of high vegetation cover have examined effects of plant cover on the entire fish community, whereas this study focused only on YOY fish use of coastal wetlands. YOY fish are extremely vulnerable to predators, and are more likely to remain associated with vegetation because of the shelter they provide, regardless of potential decreases in foraging efficiency. Larger fish face less of a predation risk, and therefore may move from vegetated areas when macrophytes become too abundant.

Leslie and Timmins (1994) documented a higher diversity of YOY fish in areas of Severn Sound, Lake Huron that had submersed vegetation compared to areas located on exposed shore and dominated by open water habitat. Similarly, this study found a significant negative relationship between species diversity and the amount of open water within a wetland. In general, wetlands with more open water areas, or less vegetation, had lower diversities of YOY fish.

The structure that aquatic macrophytes provide has been shown to have a dramatic influence on the abundance, distribution, and species composition of fish in the littoral zone (Werner et al. 1977, Keast et al. 1978, Poe et al. 1986, Heck and Crowder 1991, Leslie and Timmins 1994, Dibble et al. 1996, Randall et al. 1996, Miranda and Pugh 1997, Weaver et al. 1997, Pierce et al. 2001). These studies have demonstrated a general increase in fish abundance with increasing vegetation cover. This study did not find a relationship between vegetation cover and fish abundance; however, a significant relationship was found between the amount of open water and species composition. Brown bullhead, bowfin, white suckers and emerald shiners were more common in wetlands with low amounts of open water.

Positive relationships were found between the amount of submersed vegetation and the growth of yellow perch and banded killifish. These faster mean weekly growth rates in wetlands with abundant submersed macrophytes are likely a result of the fact that submersed plants serve as habitat for abundant macroinvertebrate and zooplankton food resources (Cardinale et al. 1998).

Presence of Sand Bars, Gravel Bars or Islands

The presence of one or more habitat structures such as sand bars, gravel bars or islands had a large impact on the YOY fish community, with this characteristic appearing in 50% of the models constructed. The presence of one or more of these structures was positively correlated to fish abundance and species richness. More fish were collected, and more species were collected in wetlands that had one or more of these structures than in wetlands that lacked these structures. Additionally, this habitat characteristic impacted fish community composition. Yellow perch, brown bullhead, spotfin shiners, green sunfish, and pumpkinseed were all more common in wetlands with one of these structures than wetlands without. Finally, the growth of YOY banded killifish was slower in wetlands with one or more of these structures.

Although this study did not measure wave or wind energy within the different wetland areas, I hypothesize that sand bars, gravel bars and islands serve to shelter the wetland areas from wave action. The dissipation of wind energy through the presence of vegetation has been shown to result in changes in water quality, turbidity, phytoplankton, epiphytic algae, zooplankton, macroinvertebrates, and fish (Suzuki et al. 1995, Randall et al. 1996, Cardinale et al. 1997, Cardinale et al. 1998). Several studies have documented decreases in the cover of aquatic vegetation with increasing wave action. There was not a statistically significant decrease in the amount of open water in wetlands that had one of these structures ($F_{1,13} = 2.446$, $\alpha = 0.142$), however mean percent open water in areas that lacked one of these structures was 58% while mean percent open water in areas that had one of these structures was 33%.

Additionally, exposure to wave action has been shown to influence the littoral fish community. This study documented large decreases in fish abundance in wetlands that lacked a sand bar, gravel bar or island. In a study comparing fish production in wetland areas in Lakes Ontario and Huron, Randall et al. (1996) found that exposure to wind resulted in lower abundances of fish. Randall et al. (1996) did not compare species richness or composition among the wetland areas.

There was a considerable range in the number of islands, sand bars or gravel bars located adjacent to the wetlands sampled, where only one structure was present at WigWam and Linwood, while 6 structures were present at Hog Island. There was also a large difference in the total length of these structures among wetland areas, ranging from 253 m to 2,173 m. The differences in the number and size of these structures likely affects the impact they have on wind and wave energy, with single larger structures providing the highest degree of shelter from wave and wind energy. Multiple smaller structures may provide some protection from wave energy while allowing for increased mixing and interactions with offshore areas of Saginaw Bay.

Water Depth

The maximum water depth identified along sampling transects also had a large impact on the YOY fish community, being present in 40% of the models developed. Species that were more commonly present in wetlands with greater maximum water depths included: brown bullhead, bowfin, longnose gar, and common shiner. Wetlands that had areas with deeper water levels (>60 cm) had higher species diversity and species evenness. The areas of deeper water likely provided the YOY fish with refuges of cooler water temperatures and higher dissolved oxygen levels during warm summer days, resulting in more diverse fish communities.

Maximum water depth was correlated to the growth of YOY fish of two of the four species examined; bluegill grew faster in wetlands where there were areas of deeper water, whereas spottail shiners grew faster in wetlands where maximum water depths remained quite shallow. According to Leslie and

Timmins (1994), bluegill can be classified as phytophillic species, spending most of their lives in close association with aquatic vegetation, whereas spottail shiners are psammophils preferring sandy habitats. Because of their phytophillic nature, bluegill are more likely to require areas of deeper water in close association to the vegetation. They may have a higher dependence on nearby deeper water refuges in times of low oxygen and extreme water temperatures. Spottail shiners, on the other hand, may be more likely to temporarily leave vegetated areas in search of better habitat conditions.

Water levels within the Great Lakes are cyclical in nature (Geis 1979, Boutin 2000), and water levels within Saginaw Bay during the study period averaged approximately 0.5 meters below the long term average. The importance of having areas of deeper water is likely exaggerated during times of low water levels. It is possible that during times of normal or high water levels, habitat factors other than water depth would increase in importance in their affects on the YOY fish community.

A review of the literature revealed few studies that have examined the role of water depth in influencing the YOY fish community; with the exception of Keast and Harker (1977) who found a steady decrease in fish abundance from an average depth of 0.8 to 8 meters. Although not directly related to maximum water depth, Benson and Magnuson (1992) found a change in species composition with increasing depth gradient.

A few studies have compared fish abundance and diversity in relation to water depth at larger spatial scales. For example, Chubb and Liston (1986) found highest densities of larval fish in shallow (<1 meter) vegetated areas of Pentwater Marsh, Lake Michigan. Similarly, Keast et al. (1978) found that vegetated areas < 2 meters deep had more diverse and abundant fish communities compared to deeper areas of submersed vegetation, and adjacent open water areas In Lake Opinicon. Finally, Bryan and Scarnecchia (1992) documented a higher species richness and abundance of larval and juvenile fish in wetlands areas with a mean water depth less than 1 meter compared to areas with deeper water levels in Spirit Lake, Iowa.

Habitat Complexity

Several studies have documented increases in the species richness and diversity of littoral fish communities with increasing habitat complexity or habitat heterogeneity (e.g., Benson and Magnuson 1992, Tonn and Magnuson 1982, Eadie and Keast 1984, Leslie and Timmins 1994, Jenkins and Sutherland 1997, Weaver et al. 1997). This study did not find a relationship between habitat complexity and species richness or species diversity.

Habitat complexity did have an influence on species composition. Brown bullhead, bowfin, and white suckers were more common in wetlands with low habitat heterogeneity, while gizzard shad and sand shiners were more common in wetlands with high habitat heterogeneity. Weaver et al. (1997) also found vegetation patchiness to be important in determining species assemblages, with some species increasing in abundance with vegetation patchiness, and others decreasing in abundance.

Habitat complexity was positively related to the growth of spottail shiners. The faster growth rates with increased heterogeneity may be a result of the fact that patchiness within vegetation provides prey fishes with a habitat in which shelter is in close proximity to open spaces that harbor rich zooplankton food resources. This reduces the amount of time and energy these fish need to spend moving from areas that provide them with protection from predators to feeding areas.

Importance of Regional Factors

In examining patterns of fish community assemblages in coastal wetland and beach habitat in Green Bay, Lake Michigan, Brazner and Beals (1997) found that fish abundance, species richness, and community composition were greatly influenced by geographical region within the Bay. They found distinct species assemblages in wetlands from the lower, middle and upper portions of the Bay, with regional factors being more important than surrounding development pressure, habitat related factors (e.g turbidity, conductivity, pH, macrophyte cover), predation, or competition in determining the distribution of fish species (Brazner and Beals 1997, Brazner 1997). Regional patterns were also seen in the grouping of fish species utilizing coastal wetlands into assemblages in the Canadian waters of the Great Lakes (Kelso and Minns 1996).

This study examined the impact of several regional factors (e.g., distance from Saginaw River, distance to the outer bay, eastern or western shore of Saginaw Bay) on the YOY fish community. Contrary to the results of Brazner

(1997) and Brazner and Beals (1997), the regional factors examined in this study did not have significant impacts on YOY fish abundance. Additionally, no significant relationships were found between these regional factors and species diversity, species evenness, or fish growth. However, there was a significant relationship between species richness and distance to Saginaw River. Species richness was higher in wetland areas located closer to Saginaw River, and species richness decreased with increasing distance from Saginaw River. Regional factors also appeared to have an impact on species composition, with different fish communities associated with the eastern compared to the western shore of Saginaw Bay. Gizzard shad, green sunfish, sand shiners, and yellow perch were more common in wetlands on the eastern bank, while white suckers, rock bass, and bowfin were more common in wetlands on the western bank of Saginaw Bay.

Future Research Needs

The presence of a structure such as an island, sand or gravel bar within a wetland area had a large impact on YOY fish abundance, species richness, and community composition. These structures may be important because they help to shelter the wetland and the YOY fish community from damaging wave and wind energy. However, more research is needed in determining why these structures had such a positive effect on the YOY fish community, if they have a significant effect on wind and wave energy, and if they may help deter larger predatory fish from entering the wetland environments, and thereby improve the value of the wetland for YOY fish.

There was a high degree of similarity in the types of species that dominated the YOY fish community in the wetlands sampled in Saginaw Bay, as compared to the YOY fish community sampled in other wetlands throughout the Great Lakes. Additionally, species richness in Saginaw Bay was within the range of species richness identified for other Great Lakes' coastal wetlands areas. As a result of this similarity in species composition and richness, it appears that the YOY fish community within Saginaw Bay can be considered representative of a typical YOY fish community of Great Lakes wetlands. Further research is necessary to determine if the patterns identified in this study between habitat characteristics and the YOY fish community can be applied to other wetland areas within the Great Lakes.

Many of the coastal wetland habitats along the Great Lakes are under pressure from development, resulting in degraded water and habitat quality. In order to understand how alterations in coastal wetland systems may influence young of the year recruitment, there is a need to first identify habitat characteristics that may influence YOY community attributes, species composition, and growth rates of YOY fish. This study identified several habitat characteristics that can influence the YOY fish community. However, further research is necessary to determine how these relationships may differ as a result of changes in surrounding land use, development pressure, and human activity in the vicinity of these wetland environments.

Finally, the success of YOY fish within wetland environments is influenced by characteristics of the wetland as a whole, such as those investigated in this study. However, the distribution of YOY fish is not uniform within a wetland, and the success of YOY fish is likely also impacted by within wetland characteristics, such as the types of vegetation habitat available, wetland productivity, and water quality. Future research is needed on how these characteristics may influence YOY fish recruitment.

LITERATURE CITED

Baltz, D.M., C. Rakocinski, and J.W. Fleeger. 1993. Microhabitat use by marsh-edge fishes in a Louisiana estuary. Environmental Biology of Fishes 36:109-126.

Beeton, A., S. Smith and F. Hooper. 1967. Physical limnology of Saginaw Bay, Lake Huron. Technical Report No. 12. Great Lakes Fishery Commission, Ann Arbor, MI.

Benson, B.J. and J.J. Magnuson. 1992. Spatial heterogeneity of littoral fish assemblages in lakes: relation to species diversity and habitat structure. Canadian Journal of Fisheries and Aquatic Sciences 49:1493-1500.

Boutin, C. 2000. Great Lakes Water Levels. NOAA Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan.

Brandt, S.B., J.J. Magnuston, and L.B. Crowder. 1980. Thermal habitat partitioning by fishes in Lake Michigan. Canadian Journal of Fisheries and Aquatic Sciences 37:1557-1564.

Brazner, J.C. 1997. Regional, habitat and human development influences on coastal wetland and beach fish assemblages in Green Bay, Lake Michigan. Journal of Great Lakes Research 23:36-51.

Brazner, J.C. and E.W. Beals. 1997. Patterns in fish assemblages from coastal wetland and beach habitats in Green Bay, Lake Michigan: a multivariate analysis of abiotic and biotic forcing factors. Canadian Journal of Fisheries and Aquatic Sciences 54:1743-1761.

Brazner, J.C., D.K. Tanner, D.A. Jensen and A. Lemke. 1998. Relative abundance and distribution of ruffe (*Gymnocephalus cernuus*) in a Lake Superior Coastal Wetland Fish Assemblage. Journal of Great Lakes Research 24:293-303.

Breder, C.M. Jr. 1960. Design for a fry trap. Zoologica 45:155-160.

Bryan, M.D. and D.L. Scarnecchia. 1992. Species richness, composition, and abundance of fish larvae and juveniles inhabiting natural and developed shorelines of a glacial Iowa lake. Environmental Biology of Fishes 35:329-341.

Cardinale, B.J., T.M. Burton and V.J. Brady. 1997. The community dynamics of epiphytic midge larvae across the pelagic-littoral interface: do animals respond to changes in the abiotic environment. Canadian Journal of Fisheries and Aquatic Science 54:1-9.

Cardinale, B.J., V.J. Brady and T.M. Burton. 1998. Changes in the abundance and diversity of coastal wetland fauna from the open water/macrophyte edge towards shore. Wetlands Ecology and Management 6:59-68.

Chubb, S.L. and C.R. Liston. 1986. Density and distribution of larval fishes in Pentwater Marsh, a coastal wetland on Lake Michigan. Journal of Great Lakes Research 12:332-343.

Comer, A.J., D.A. Albert, H.A. Wells, B.L. Hart, S.B. Raab, D.L. Price, D.M. Kashian, R.A. Corner, and D.W. Shuen. 1995. Michigan's Native Landscape, as Interpreted from General Land Office Surveys, 1816-1856. Michigan Natural Features Inventory Report to Water Division, U.S. EPA and Wildlife Division, Michigan Department of Natural Resources, Lansing, Michigan.

Crowder, L.B. and W.E. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. Ecology 63:1802-1813.

Dewey, M.R. 1992. Effectiveness of a drop net, a pop net, and an electrofishing frame for collecting quantitative samples of juvenile fishes in vegetation. North American Journal of Fisheries Management 12:808-813.

Dibble, E.D., K.J. Killgore, and S.L. Harrel. 1996. Assessment of fish-plant interactions. American Fisheries Society Symposium 16:357-372.

Duffy, K.C. and D.M. Baltz. 1998. Comparison of fish assemblages associated with native and exotic submerged macrophytes in the Lake Pontchartrain estuary, USA. Journal of Experimental Marine Biology and Ecology 223:199-221.

Eadie, J. McA. and A. Keast. 1984. Resource heterogeneity and fish species diversity in lakes. Canadian Journal of Zoology 62:1689-1695.

Francis, R.I.C. 1990. Back-calculation of fish length: a critical review. Journal of Fish Biology 36:883-902.

Freeman, B.J., H.S. Greening, and J.D. Oliver. 1984. Comparison of three methods for sampling fishes and macroinvertebrates in a vegetated freshwater wetland. Journal of Freshwater Ecology 2:603-609.

Geis, J.W. 1979. Shoreline processes affecting the distribution of wetland habitats. Transactions of the North American Wildlife Natural Resources Conference 44:529-542.

Gotceitas, V. and P. Colgan. 1987. Selection between densities of artificial vegetation by young bluegills avoiding predation. Transactions of the American Fisheries Society 116:40-49.

Gotceitas, V. 1990a. Plant stem density as a cue in patch choice by foraging juvenile bluegill sunfish. Environmental Biology of Fishes 29:227-232.

Gotceitas, V. 1990b. Foraging and predator avoidance: a test of a patch choice model with juvenile bluegill sunfish. Oecologia 83:346-351.

Hayes, D.B. C.P. Fererri, W.W. Taylor. 1996. Linking fish habitat to their population dynamics. Canadian Journal of Fisheries and Aquatic Sciences 53:383-390.

Heck, K.L., and L.B. Crowder. 1991. Habitat structure and predator-prey interactions in vegetated aquatic systems. pp282-299 IN S.S. Bell, E.D. McCoy and H.R. Mushinsky (eds.). Habitat structure: the physical arrangement of objects in space. Chapman and Hall, New York.

Herdendorf, C.E., S.M. Hartley, and M.D. Barnes (eds.). 1981. Fish and wildlife resources of the Great Lakes coastal wetlands within the United States. Vol.1: Overview. United States Fish and Wildlife Service, Office of Biological Services, Washington, DC, FWS/OBS-81/02-V3.

Houde, E.D. 1994. Differences between marine and freshwater fish larvae: implications for recruitment. ICES Journal of Marine Science 51:91-97.

Jackson, G. and G.K. Jones. 1999. Spatial and temporal variation in nearshore fish and macroinvertebrate assemblages from a temperate Australian estuary over a decade. Marine Ecology Progress Series 182:253-268.

Jaworski E. and C.N. Raphael. 1978. Fish, wildlife, and recreational values of Michigan's coastal wetlands. Rep. to Lands Resources Programs division, Michigan Department of Natural Resources, Eastern Michigan University, Ypsilanti, Michigan.

Jenkins, G.P. and C.R. Sutherland. 1997. The influence of habitat structure on nearshore fish assemblages in a southern Australian embayment: colonization and turnover rate of fishes associated with artificial macrophytes beds of varying physical structure. Journal of Experimental Marine Biology and Ecology 218:103-125.

Johnson, D.L., W.E. Lynch, and T.W. Morrison. 1997. Fish communities in a diked Lake Erie wetland and an adjacent undiked area. Weltands 17(1):43-54.

Johnson, D.L. and R.A. Stein. 1979. Response of fish to habitat structure in standing water. Special Publication NO. 6, North Central Division, American Fisheries Society, Bethesda, MD.

Jude, D.J. and J. Pappas. 1992. Fish utilization of Great Lakes coastal wetlands. Journal of Great Lakes Research 18:651-672.

Keast, A. and J. Harker. 1977. Fish distribution and benthic invertebrate biomass relative to depth in an Ontario lake. Environmental Biology of Fishes 2(3):235-240.

Keast, A., J. Harker, and D. Turnbull. 1978. Nearshore fish habitat utilization and species associations in Lake Opinicon (Ontario, Canada). Environmental Biology of Fishes 3(2):173-184.

Keast, A. 1984. The introduced aquatic macrophyte, *Myriophyllum spicatum*, as habitat for fish and their invertebrate prey. Canadian Journal of Zoology 62:1289-1303.

Kelso, J.R.M. and C.K. Minns. 1996. Is fish species richness at sites in the Canadian Great Lakes the result of local or regional factors? Canadian Journal of Fisheries and Aquatic Sciences 53(Suppl. 1):175-193.

Killgore, K.J., R.P. Morgan, and N.B. Rybicki. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. North American Journal of Fisheries Management 9:101-111.

Krieger, K.A., D.M. Klarer, R.T. Heath, and C.E. Herdendorf. 1992. A call for research on Great Lakes coastal wetlands. Journal of Great Lakes Research 18:525-528.

Kushlan, J.A. 1981. Sampling characteristics of enclosure fish traps. Transactions of the American Fisheries Society 110:557-562.

Leslie, J.K. and C.A. Timmins. 1994. Ecology of young-of-the-year fishes in Severn Sound, Lake Huron. Canadian Journal of Zoology 72:1887-1897.

Lillie, R.A. and J. Budd. 1992. Habitat architecture of *Myriophyllum spicatum* L. as an index to habitat quality for fish and macroinvertebrates. Journal of Freshwater Ecology 7:113-125.

Liston, C.R. and S.L. Chubb. 1985. Relationships of water level fluctuations and fish. pp 134-136 IN Prince, H.H. and F.M. D'Itri (eds.). Coastal Wetlands. Proceedings of the First Great Lakes Wetlands Colloquium. Lewis Publishers, Inc., Chelsea, MI.

Loftus, D.H. 1982. Larval fish sampling in Lake Huron, 1978. Ontario Fisheries technical Report Series No. 2.

Michaletz, P.H. 1998. Population characteristics of gizzard shad in Missouri reservoirs and their relation to reservoir productivity, mean depth, and sport fish growth. North American Journal of Fisheries Management 18:114-123.

Minns, C.K., V.W. Cairns, R.G. Randall and J.E. Moore. 1994. An index of biotic integrity (IBI) for fish assemblages in the littoral zone of Great Lakes' Areas of Concern. Canadian Journal of Fisheries and Aquatic Science 51:1804-1822.

Miranda, L.E. and L.L. Pugh. 1997. Relationship between vegetation coverage and abundance, size, and diet of juvenile largemouth bass during winter. North American Journal of Fisheries Management 17:601-610.

Mittelbach, G.G. 1986. Predator-mediated habitat use: some consequences for species interactions. Environmental Biology of Fishes 16:159-169.

Petering, R.W. and D.L. Johnson. 1991. Distribution of fish larvae among artificial vegetation in a diked Lake Erie wetland. Wetlands 11:123-138.

Pierce, C.L., M.D. Sexton, M.E. Pelham, and J.G. Larscheid. 2001. Short-term variability and long-term change in the composition of the littoral zone fish community in Spirit Lake, Iowa. American Midland Naturalist 146:290-299.

Pihl, L. and R. Rosenberg. 1992. Production, abundance, and biomass of mobile epibenthic marine fauna in shallow waters, western Sweden. Journal of Experimental Marine Biology and Ecology 57:273-301.

Poe, T.P., C.O Hatcher, C.L. Brown, and D.W. Schloesser. 1986. Comparison of species composition and richness of fish assemblages in altered and unaltered littoral habitats. Journal of Freshwater Ecology 3(4):525-536.

Randall, R.G., C.K. Minns, V.W. Cairns, and J.E. Moore. 1996. The relationship between an index of fish production and submerged macrophytes and other habitat features at three littoral areas in the Great Lakes. Canadian Journal of Fisheries and Aquatic Science 53(Supp1):35-44.

Raposa, K.B. and C.A. Oviatt. 2000. The influence of contiguous shoreline type, distance from shore, and vegetation biomass on nekton community structure in eelgrass beds. Estuaries 23(1):46-55.

Savino, J.F. and R.A. Stein. 1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated, submersed vegetation. Transactions of the American Fisheries Society 111:255-266.

Savino, J.F. and R.A. Stein. 1989. Behavioral interactions between fish predators and their prey: Effects of plant density. Animal Behaviour 37:311-321.

Schelske, C. and J. Roth. 1973. Limnological survey of Lakes Michigan, Superior, Huron, and Erie. Publication No. 17. University of Michigan, Great Lakes Research Division, Ann Arbor, MI.

Skubinna, J.P., T.G. Coon, and T.R. Batterson. 1995. Increased abundance and depth of submersed macrophytes in response to decreased turbidity in Saginaw Bay, Lake Huron. Journal of Great Lakes Research 21(4):476-488.

Stephenson, T.D. 1990. Fish reproductive utilization of coastal marshes of Lake Ontario near Toronto. Journal of Great Lakes Research 16:71-81.

Suzuki, N., S. Endoh, M. Kawashima, Y. Itakura, C.D. McNabb, F.M. D'Itri, and T.R. Batterson. 1995. Discontinuity bar in a wetland of Lake Huron's Saginaw Bay. Journal of Freshwater Ecology 10:111-123.

Tonn, W.M. and J.J. Magnuson. 1982. Patterns in the species composition and richness of fish assemblages in northern Wisconsin lakes. Ecology 63:1149-1166.

Turner, R.E. 1988. Secondary production in riparian wetlands. Transactions of the 53rd North American Wildlife and Natural Resources Conference. 491-501.

Weaver, M.J., J.J. Magnuson, M.K. Clayton. 1997. Distribution of littoral fishes in structurally complex macrophytes. Canadian Journal of Fisheries and Aquatic Science 54:2277-2289.

Werner, E.E., D.J. Hall, D.R. Laughlin, D.J. Wagner, L.A. Wilsmann, and F.C. Funk. 1977. Habitat partitioning in a freshwater fish community. Journal Fisheries Research Board of Canada 34:360-370.

Werner, E.E., G.G. Mittelbach, D.J. Hall, and J.F. Gilliam. 1983. Experimental tests of optimal habitat use in fish: the role of relative habitat profitability. Ecology 64:1525-1539.

Werner, E.E. and D.J. Hall. 1988. Ontogenetic habitat shifts in bluegill: the foraging rate-predation risk trade-off. Ecology 69(5):1352-1366.

Whillans, T.H. 1992. Assessing threats to fishery values of Great Lakes wetlands. *In* Wetlands of the Great Lakes: protection, restoration, policies and status of the science. Proceedings of the International Wetland Symposium, 16-19 May 1990. Edited by J. Kusler and R. Smardon. Association of State Wetland Managers, Inc., Berne, N.Y. pp 156-165.

Wiley, M.J., R.W. Gorden, S.W. Waite and T. Powless. 1984. The relationship between aquatic macrophytes and sport fish production in Illinois ponds: a simple model. North American Journal of Fisheries Management 4:111-119.

CHAPTER 2: EFFECT OF COASTAL WETLAND MICROHABITAT CHARACTERISTICS ON THE DISTRUBUTION OF YOUNG OF THE YEAR FISH IN SAGNINAW BAY, LAKE HURON

ABSTRACT

Although coastal wetlands are important habitat for early life history stages of many fish species, little is known about how wetland habitat characteristics affect the distribution of young of year (YOY) fish. This study examined the relationship between wetland habitat characteristics and the distribution of four fish species: bluegill, banded killifish, yellow perch, and spottail shiner. Changes in habitat preferences as YOY bluegill and yellow perch increased in size and comparisons in habitat preferences between resident and transient wetland species were also examined. A 1-m^2 throw trap was used to sample the distribution of YOY fish within four coastal wetlands in Saginaw Bay, Lake Huron. The number and size of YOY fish, microhabitat characteristics, and adjacent habitat conditions were recorded for each sample. Logistic regression analysis was used to model relationships between the distribution of YOY fish and microhabitat characteristics. Water depth, vegetation type, and water temperature were the most influential characteristics in predicting the distribution of YOY fish. This study did not identify differences in the habitat preferences of YOY bluegill or yellow perch of different size classes. A difference in the types of microhabitat characteristics that were important to resident and transient YOY fish was observed. The presence or absence of resident wetland species (bluegill and banded killifish) was correlated with physical habitat structure such as the type of vegetation present, while the presence or absence of transient

wetland species (yellow perch and spottail shiner) was correlated with variations in water quality.

INTRODUCTION

Coastal wetlands play an important role in Great Lakes ecosystems, and their ecosystem values have been altered and likely compromised by a variety of human influences (Krieger et al. 1992). Among the important but poorly defined values of coastal wetlands is the spawning and early life history habitat that they provide to Great Lakes fishes (Jude and Pappas 1992). Coastal wetlands provide juvenile fish with many benefits including rich food resources and protective cover. This cover reduces the visibility of small fish by providing many places for these fish to hide from predators, and reduces the maneuverability of larger fish (Savino and Stein 1982, 1989, Werner et al. 1983a,b, Mittelbach 1986, Gotceitas and Colgan 1987, Werner and Hall 1988, Gotceitas 1990a,b, Heck and Crowder 1991, Carr 1994). Coastal wetlands also provide young fish with rich zooplankton and macroinvertebrate food sources (Rozas and Odum 1988, Turner 1988, Cardinale et al. 1998).

Alteration of coastal habitats affects the abundance and composition of fish populations that use these habitats (Poe et al. 1986, Leslie and Timmins 1994, Minns et al. 1994, Brazner 1997, Brazner and Beals 1997, Johnson et al. 1997, Duffy and Baltz 1998). The destruction and degradation of coastal wetlands throughout the Great Lakes over the past 200 years have coincided with major changes in the fisheries of the Great Lakes (Krieger et al. 1992).

In order to quantify the impact of habitat alterations on fish populations, there is a need to identify habitat attributes that determine the use of Great Lakes wetlands by fishes. Understanding which habitat characteristics are important to the success of young of the year (YOY) fish can lead to better informed decisions on the management, protection, and restoration of coastal habitat and the Great Lakes fisheries that depend on these habitats.

Several authors have called for more information on the nursery function of Great Lakes coastal wetlands (Herdendorf et al. 1986, Jude and Pappas 1992). This study focuses on the role of coastal wetland areas as early life history habitat for juvenile fish rather than larval fish or spawning habitat for two reasons. First, juveniles have the ability to select habitats, whereas habitats for larval fish are based more on spawning habitat selection by adults and water currents. Additionally, in an examination of potential impacts of habitat alteration on northern pike, *Esox lucius*, recruitment in a Lake Ontario coastal wetland, Casselman and Lewis (1996) concluded that the use of wetlands as early life history habitat plays a more critical role than use of wetlands as spawning habitat in determining year class strength.

Secondly, in freshwater systems, it has been suggested that the growth rate of fish in their first year of life is critical in determining their overwinter survival and ultimately year class strength (Houde 1994). Fish recruitment can be increased by enhancing the survival and growth of juvenile fish within their early life history habitats (Rothschild 1986, Baltz et al. 1993). However, little is known about how environmental factors influence habitat selection by juvenile fish. At the microhabitat level, the habitat preferences of an individual species should be influenced by their ability to forage, grow, and avoid predation (Baltz et al. 1993). Optimal foraging theory predicts that young fish should choose habitat patches that maximize energy intake per unit time, because growth rates, particularly in the first year, must be maximized to increase likelihood of survival to breeding age (Post and Prankevicius 1987, Tonn and Paszkowski 1987). But there is a trade-off between the increased protection from predation and decreased foraging efficiency in areas of increased habitat structure. As a result, a fish should choose the environment that allows them to minimize the predation risk/foraging rate ratio (Werner and Hall 1988, Gotceitas 1990b).

Much of the recent work that has increased our understanding of coastal wetland influences on Great Lakes fish species has used artificial substrates (e.g. Petering and Johnson 1991), was conducted at a coarse spatial scale of resolution (e.g. Jude and Pappas 1992, Brazner 1997), or in a controlled mesocosm setting (e.g. Dionne and Folt 1991). Each of these methods has unique advantages and disadvantages. For example, the use of artificial substrates has the advantage of being able to control vegetation characteristics such as plant density and leaf surface area; however this may not present the same biological situation to juvenile fish as natural vegetation due to changes in food density between artificial and natural stands of vegetation. Using a coarse spatial scale of resolution has been shown to be beneficial in determining the relative importance of wetland habitat compared to other littoral zone environments; however, it lacks information on the specific attributes of wetlands that attract fish. The use of mesocosms has been beneficial in demonstrating changes in the behavior or growth of fish with changes in vegetation density or structure. However, the nature of mesocosms limits the diversity of habitat patches available to an individual fish. This study built upon these previous efforts by quantifying relationships between the presence or absence of juvenile fish in the field and microhabitat characteristics, where the microhabitat of an individual fish is defined as the place where that individual is located at a point in time (Baltz 1990).

The goal of this study was to increase understanding of how wetland microhabitat characteristics influence the distribution of juvenile fish. Specific objectives of this study were to 1) determine which microhabitat characteristics are related to the presence or absence of juvenile fish from four different species, 2) determine if habitat preferences change as YOY fish increase in size, and 3) determine if the same habitat characteristics are important to resident and transient wetland fish species. Distribution patterns of four fish species were investigated: bluegill, *Lepomis macrochirus,* banded killifish, *Fundulus diaphanous,* yellow perch, *Perca flavescens*, and spottail shiner, *Notropis hudsonius.* These species were chosen in part because they are abundant within Saginaw Bay. These species also represent a combination of resident wetland species (bluegill and banded killifish) and transient wetland species (yellow perch and spottail shiner), where resident wetland species are those species that spends the majority of their life cycle in close association with wetland environments. Transient wetland species are those species that may utilize wetlands as juvenile habitat, and intermittently throughout their lifecycle, but may also be commonly found in other aquatic habitats. The four fish species chosen for this study also represent a variety of feeding styles. Juvenile yellow perch are active predators, preying on larger macroinvertebrates and larval fish within wetland environments, banded killifish are surface feeding topminnows, spottail shiners are primarily zooplanktivores, and juvenile bluegill feed on a combination of macroinvertebrate and zooplankton food resources.

METHODS

Study Site Description

Four different wetland areas in Saginaw Bay, Lake Huron were selected as study sites and sampled from May to August, 2001 (Figure 2.1). These wetlands represent a subset of the fifteen locations described in Chapter 1. Compared to the rest of Lake Huron, Saginaw Bay is a eutrophic embayment with high productivity (Jude and Pappas 1992, Skubinna et al. 1995, Cardinale et al. 1998). Emergent vegetation communities within Saginaw Bay wetlands were dominated primarily by *Scirpus pungens* and *Typha angustifolia*. Submersed plant beds were dominated by *Myriophyllum spicatum, Vallisneria americana, Potamogeton* spp. and *Chara globularis.*

Saginaw Bay is relatively shallow with eighty percent of its volume less than 5.5 m in depth (Beeton et al. 1967). Water levels within the Great Lakes are cyclical in nature, with alternating periods of high and low water occurring over a period of 7-10 years (Herdendorf 1992). Water levels in Saginaw Bay during the study averaged approximately 0.5 m below the long term average (Figure 2.2). Periods of low water level can have dramatic impacts on wetland environments, causing vegetation dieback, erosion of wetlands, and lateral displacement of vegetative zones of wetlands (Herdendorf 1992).

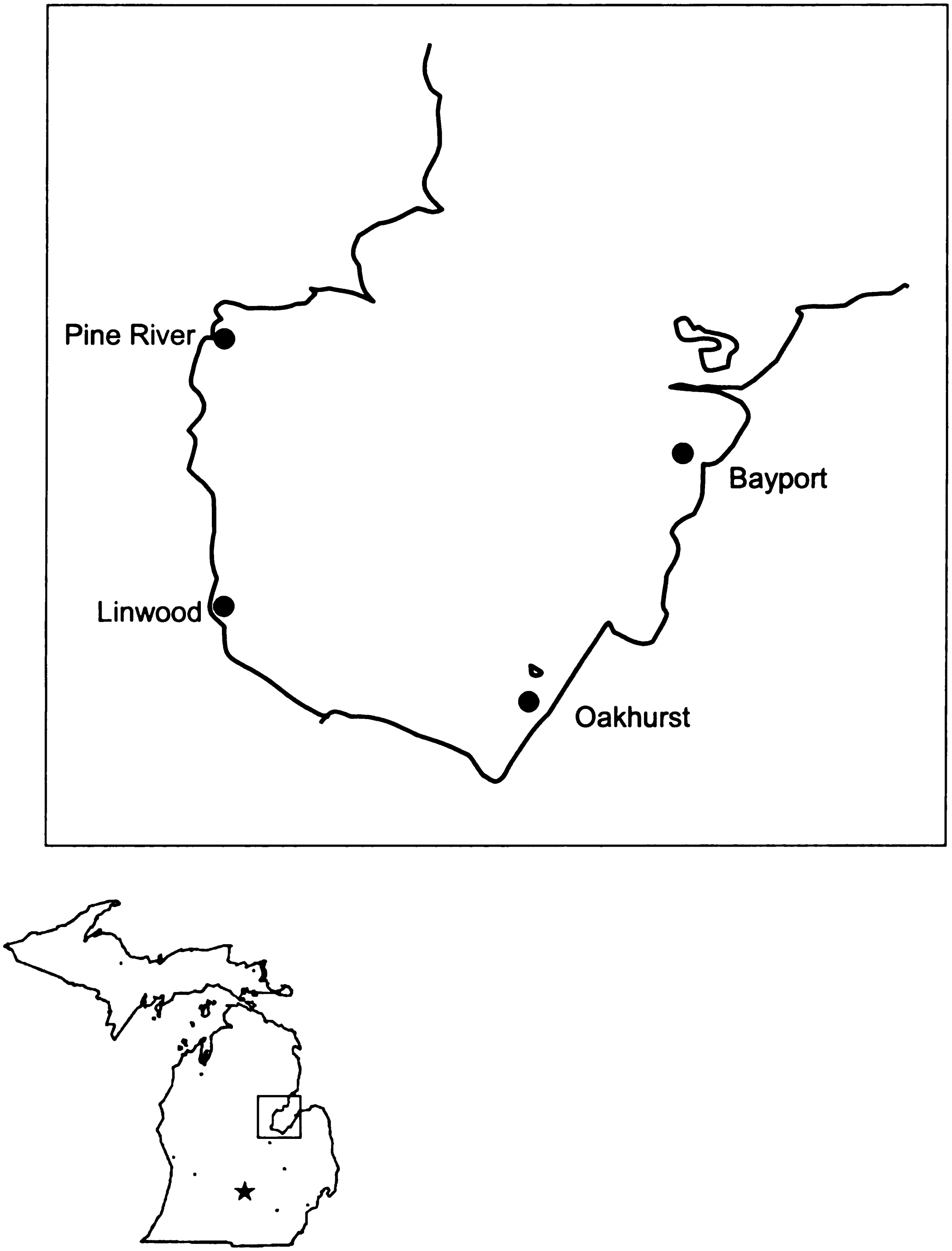


Figure 2.1: Map of approximate locations of study sites in Saginaw Bay, Lake Huron.

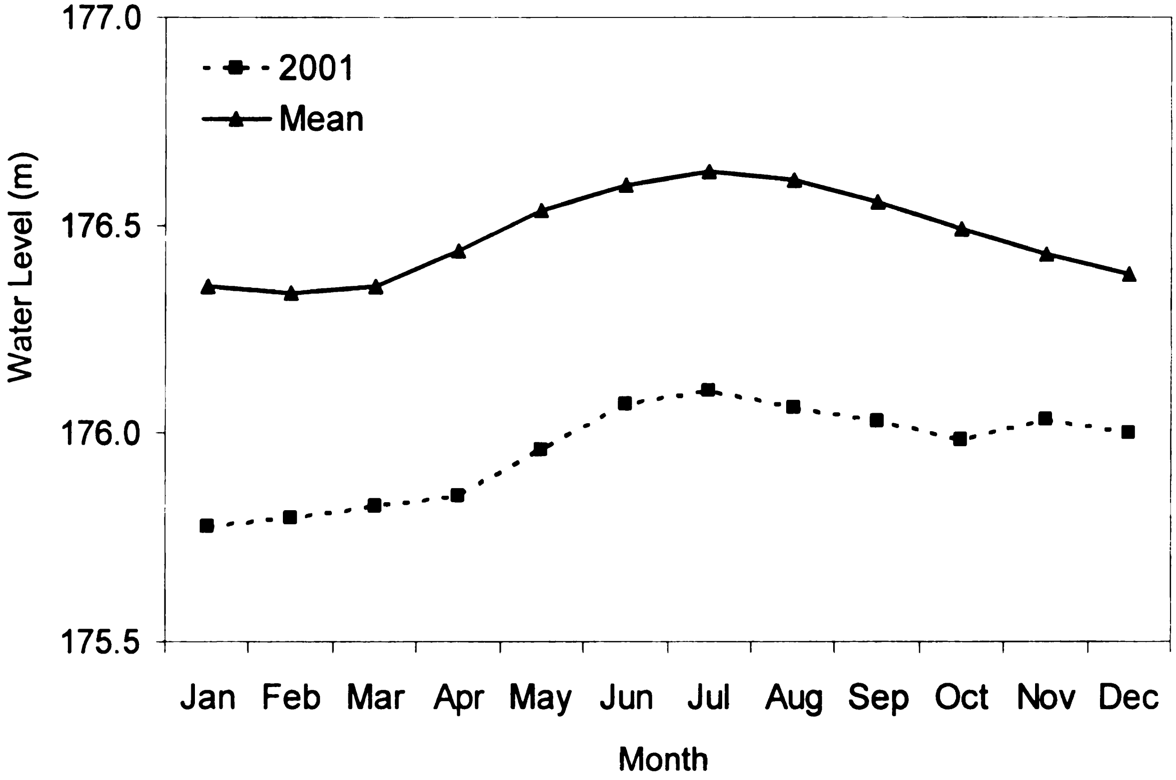


Figure 2.2: Water levels (m IGLD 1985) recorded by NOAA Essexville Station #9075035 in Saginaw Bay, Lake Huron in 2001 compared to long term mean (1918-2000).

Fish Collection

A modified throw trap (Figure 2.3) was used to sample young of the year fish within the wetlands. Throw traps have been shown to be an effective method of sampling YOY fish in vegetated wetlands (Kushlan 1981, Freeman et al. 1984, Dewey 1992, Baltz et al. 1993, Raposa and Oviatt 2000). The throw trap used was designed with an angle iron base, weighted with lead, to cause the trap to sink rapidly. A PVC (4 cm diameter) frame was used for the top of the trap, which would float on the water's surface. Nylon netting (3 mm mesh) was used for the sides of the throw trap. The trap sampled 1 m^2 of wetland habitat up to 1 m in depth. The net was deployed by two people tossing the frame into the water. Pihl and Rosenberg (1982) found that animals generally did not exhibit an avoidance response to throw traps until moving people were within 1.5 m, and our throws typically covered a distance of three to four meters. The trap was deployed a total of 360 times in each wetland between May 15, 2001 and August 15, 2001 for a total of 1,440 samples. Typically 30 samples were taken in each wetland each week. After deployment, the bottom of the frame was pushed into the sediment. A 5 mm mesh seine was used to remove fish from the trap. Seining continued until six consecutive seine hauls resulted in no additional fish being captured.

A stratified random sampling procedure was used to select sample locations. Effort was made to sample the diversity of habitat types available to YOY fish within a given wetland in proportion to the availability of that habitat type. Habitats within the wetlands were classified as open water, emergent,

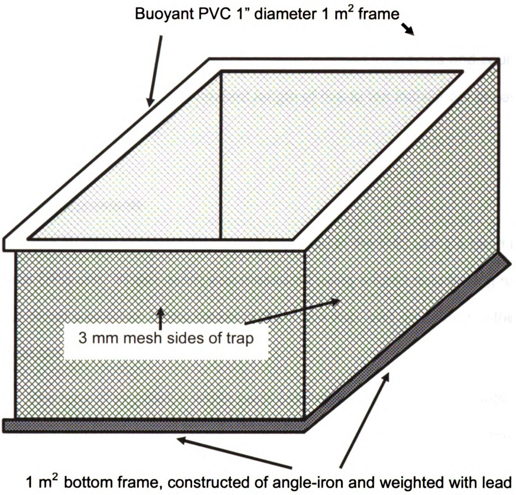


Figure 2.3: Design of 1 m^2 throw trap used to sample YOY fish in wetlands.

submersed, or floating leaf vegetation. Five 200 m transects were established at each wetland site. Habitat type was recorded every 5 meters along the transects, and these data were used to calculate the proportion of a given habitat type within a wetland. All fish collected were identified to species and counted. At each sample location, the standard length of five to ten individuals of each species was recorded.

Habitat Measurements

The location of each sample was recorded in the field using a hand held Garmin GPS unit. Water depth was measured using a hand held folding ruler. Water depth was taken at the center of the throw trap, and measured to the nearest cm.

The type of vegetation within each enclosure was recorded. Plants were identified to species according to Fassett (1985). A count was made of the number of plant stems within each throw trap sample as a measure of vegetation density. For each microhabitat sampling location, the habitat was classified as emergent, submersed, floating leaf vegetation, or open water based upon the dominant vegetation. The percent vegetation cover of emergent, submersed, floating leaf vegetation and open water within each throw trap sample was visually estimated to the nearest 10%.

The nearest habitat type, different from the one where the trap was located, was recorded for each sampling location. For example, if the trap was thrown in submersed vegetation, I recorded which other type of habitat (open water, emergent vegetation, or floating leaf vegetation) was closest to that sample location. After determining what the next nearest habitat type was, the distance to that habitat type was measured to the nearest meter and recorded.

Substrate at each sample location was classified as rock, sand, clay, or organic muck based on the size of soil particles and depth of the organic layer. If the organic layer was more than 4 cm deep, the soil was classified as organic muck.

A YSI model 50b dissolved oxygen meter was used to measure water temperature to the nearest 0.1°C, and dissolved oxygen to the nearest 0.01 mg/L. A YSI model 33 Salinity-Conductivity-Temperature meter was used to measure conductivity to the nearest 1 μS/cm. Temperature, dissolved oxygen, and conductivity measurements were taken at the center of the throw trap, at approximately 2/3 of the water depth.

At each sample location a water sample was taken for later measurement of water clarity. Water samples were collected in a 50 ml dark plastic bottle. The bottles were placed in a dark, cool, container in the field. A Monitek model 21 Nephelometer was used to measure turbidity to the nearest 1 NTU.

Data Analysis

Multiple logistic regression analysis ($\alpha = 0.05$) was used to relate the presence and absence of YOY fish of four fish species to microhabitat characteristics according to procedures outlined in Allison (1999) and Hosmer and Lemeshow (2000). Chi-square test statistics for the significance of microhabitat coefficients were used in selecting variables to include within the logistic regression models. Odds ratios were calculated to describe fish selection for different habitat characteristics. An odds ratio including 1 indicates no preference for the habitat characteristic, odds ratios greater than 1 indicate a preference for the habitat characteristics, and odds ratios less than 1 indicate selection against a habitat characteristic. All quantitative habitat characteristics were standardized to have a mean of 0 and standard deviation of 1. To control for seasonal effects on water temperature, water temperatures were standardized based upon the mean measured water temperature on each sampling date.

The four fish species investigated were: bluegill, banded killifish, yellow perch, and spottail shiner. For the bluegill, only samples taken after July 1, 2001 were included in the analysis because YOY bluegill did not start appearing in samples until after this date. Because YOY bluegill were captured in only one sample from Oakhurst, data from this site were not used to construct the logistic regression models. For the three other species, data from the entire summer and all four wetland sites were used.

To examine if juvenile fish habitat preferences change as the fish increase in size, YOY bluegill and yellow perch were divided into two size categories, small (<25 mm) and large (≥25 mm). A break of 25 mm was chosen because it has been demonstrated that shifts in feeding and habitat use occur around 25 mm for yellow perch (Wahl et al. 1993), bluegill (Bremigan and Stein 1994), as well as several other fish species (Simonovic et al. 1999). Statistically significant interactions between size class and microhabitat characteristics were tested using logistic regression modeling. If there was no statistically significant change in habitat use of fish between the different size classes, a model with pooled data from both size classes was constructed.

Models were constructed examining relationships between YOY fish presence or absence and habitat characteristics in each of the wetlands. When differences in relationships were not found among wetlands, a pooled model was used, combining data from all four wetlands sampled. All data analysis was done using the SAS® System. Variance Inflation Factor (VIF) values were used to test for multicollinearity among variables. Due to strong relationships between the estimated percent cover of vegetation and plant stem density, only vegetation density values were used in the models.

RESULTS

Bluegill

A total of 510 throw trap samples was taken between July 1, 2001 and August 15, 2001, at three of the wetland areas, Pine River, Linwood, and Bayport (Figure 2.1), for a total of 170 samples per wetland. A total of 392 YOY bluegill were collected in 146 (29%) of the samples. Throw trap samples were taken over a wide range of microhabitat conditions. Table 2.1 provides a summary of the habitat conditions sampled for the quantitative variables (water depth, stem density, water temperature, dissolved oxygen, conductivity, turbidity, and distance to next habitat type), and Table 2.2 provides a summary for the categorical variables (habitat type, substrate, and next habitat type).

YOY bluegill sampled were classified as small (< 25 mm in length) or large (> 24 mm in length). Small YOY bluegill were captured in 87 (60%) of the samples where bluegill were present. Large YOY bluegill were captured in 86 (59%) of the samples where bluegill were present. YOY bluegill from both size classes were captured in 27 (18%) of the samples where YOY bluegill were present. Size class was not a significant predictor of the presence or absence of YOY bluegill (X^2_1 = 0.0712, p = 0.7896). Interactions between size class and other habitat variables also were not significant (e.g., size class and water depth, X^2_1 = 1.6282, p = 0.2019). Because interactions between microhabitat variables and size class were not statistically significant in the logistic regression model,

Table 2.1: Mean, standard deviation, and range of microhabitat conditions sampled at Linwood, Bayport, and Pine River wetlands from July 1, 2001 to August 15, 2001.

Variable	Mean	St. Dev.	Minimum	Maximum
Water depth (cm)	42.5	18.6	5	97
Stem density	26.8	19	0	103
Water temp (°C)	24.4	2.8	20.2	35.8
Dissolved Oxygen (mg/l)	8.3	2.6	3.12	12.54
Conductivity (μS/cm)	1005	658	280	1880
Turbidity (NTU)	17.9	20	2	200
Distance to next habitat (m)	17.6	37.5	1	410

Table 2.2: Number and percent of categorical microhabitat variable conditions sampled at Linwood, Bayport, and Pine River wetlands from July 1, 2001 to August 15, 2001.

Variable	# of Samples	% of Samples
Habitat		
Emergent	118	23
Submersed	322	63
Open water	66	13
Floating leaf	4	1
Sediment		
Rock	1	<1
Sand	1	<1
Clay	346	68
Organic	162	32
Next Habitat Type		
Emergent	268	53
Submersed	135	26
Open water	94	18
Floating leaf	13	3

data for both size classes were pooled for further analysis of relationships between YOY bluegill presence or absence and microhabitat characteristics.

Of the 146 samples where YOY bluegill were collected, 49 (34%) of these samples were taken at Pine River, 45 (31%) of these samples were taken at Linwood, and 52 (36%) of these samples were taken at Bayport. There were no statistically significant differences in the predicted probability of presence of YOY bluegill among the wetland areas (X^2_2 = 1.4181, p = 0.4921). Additionally, interactions between wetland and microhabitat characteristics were not significant (e.g. water depth, X^2_2 = 5.0349, p = 0.0807). Data from the three wetlands were thus pooled for use in constructing logistic regression models relating the presence or absence of YOY bluegill to microhabitat characteristics.

Logistic regression identified four microhabitat characteristics, water depth, habitat type, stem density, and distance to next habitat type, that were significantly associated with the presence or absence of YOY bluegill (Table 2.3, Figure 2.4). Water quality variables such as water temperature (X^2_1 = 0.3143, p = 0.5751), dissolved oxygen (X^2_1 = 0.0166, p = 0.8975), conductivity (X^2_1 = 0.2328, p = 0.6295), and turbidity (X^2_6 = 0.7895, p = 0.3743) were not significant predictors of the presence or absence of YOY bluegill.

The resulting logistic regression model correctly predicted the presence or absence of YOY bluegill 74.6% of the time. The overall model was statistically significant (Wald's X^2_6 = 81.4339, p < 0.0001). Regression coefficients were negative for emergent vegetation and distance to next habitat type, and positive for water depth, floating leaf and submersed vegetation, and stem density.

Table 2.3: Estimated coefficients, standard errors, and X^2 tests for the logistic regression model for bluegill habitat selection.

Variable	**D.F.**	**Coeff.**	**Std. Err.**	X^2	**P>X^2**
Intercept	1	-2.1876	0.3076	50.5840	<0.0001
Water depth	1	0.5209	0.0925	31.7322	<0.0001
Habitat					
Emergent	1	-0.2278	0.3603	0.3999	0.5271
Floating leaf	1	0.4470	0.8186	0.2981	0.5851
Submersed	1	0.5067	0.3291	9.8234	0.0017
Stem density	1	0.2482	0.1091	5.1771	0.0229
Distance to next habitat	1	-0.6846	0.2304	8.8284	0.0030

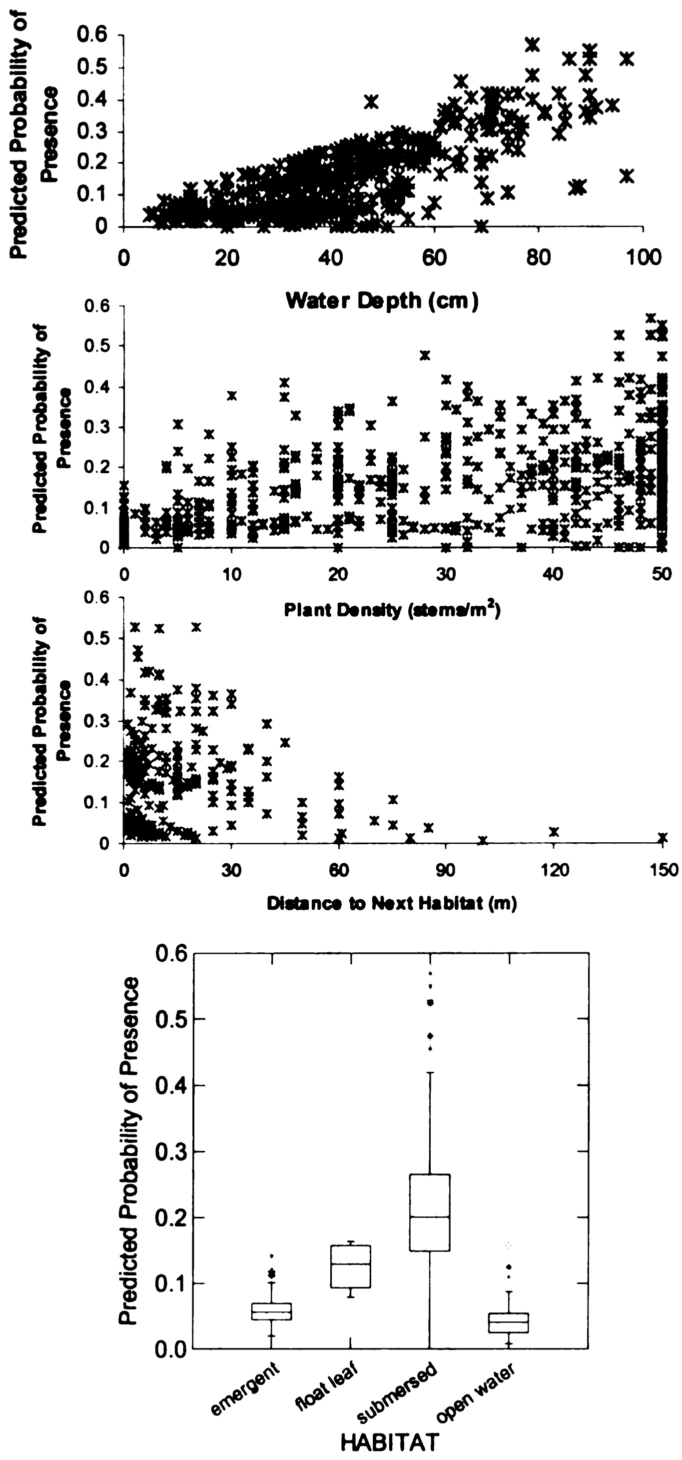


Figure 2.4: Relationships between the predicted probability of presence of YOY bluegill and water depth, plant density, distance to next habitat, and type of vegetation present.

Regression coefficients for emergent and floating leaf vegetation habitat types were not statistically significant.

The odds ratio estimate for water depth is 1.684, indicating that YOY bluegill are more likely to be located in deeper water (Table 2.4). Odds ratio estimates for emergent and floating leaf vegetation did not indicate any preference for these habitats over open water. However, the odds ratio estimate for submersed vegetation is 3.430, indicating that YOY bluegill prefer submersed vegetation habitat over open water. The odds ratio estimate for stem density was 1.282, indicating that the likelihood of sampling YOY bluegill showed a slight increase in more densely vegetated habitats. The odds ratio estimate for distance to next habitat was 0.504, indicating that YOY bluegill are more likely to be located near the edge of habitat patches.

The residual chi square test (X^2_{21} = 26.5138 p = 0.1875) and Hosmer Lemeshow goodness of fit test (X^2_8 = 6.5096, p = 0.5903) indicate that the model provided a reasonable fit to the data, and that residuals from the model were not associated with other (not included) explanatory variables.

Banded Killifish

A total of 1,440 throw trap samples was taken between May 15, 2001 and August 15, 2001, at four wetland areas, Pine River, Linwood, Oakhurst, and Bayport, for a total of 360 samples per wetland. A total of 1,808 YOY banded killifish were collected in 414 (29%) of the samples. Throw trap samples were taken over a wide range of microhabitat conditions. Table 2.5 provides a

Table 2.4: Estimated odds ratio point estimates and 95% Wald Confidence Limits for variables in the bluegill habitat selection logistic regression model.

Variable	Point Estimate	Minimum	Maximum
Water depth	1.684	1.404	2.018
Habitat			
Emerge. vs. open water	1.645	0.589	4.597
Floating vs. open water	3.231	0.331	31.564
Sub. vs. open water	3.430	1.340	8.777
Stem density	1.282	1.035	1.587
Distance to next habitat	0.504	0.321	0.792

Table 2.5: Mean, standard deviation, and range of microhabitat conditions sampled at Pine River, Linwood, Oakhurst, and Bayport wetlands from May 15, 2001 to August 15, 2001.

Variable	Mean	St. Dev.	Minimum	Maximum
Water depth (cm)	33.8	17.4	3	97
Stem density	19.6	32.0	0	103
Water temp (°C)	22.3	4.8	12.5	35.8
Dissolved oxygen (mg/l)	7.6	2.8	0.41	12.54
Conductivity (μS/cm)	516	360	210	1880
Turbidity (NTU)	36.7	51.6	1	560
Distance to next habitat (m)	31.0	69.8	1	700

summary of the habitat conditions sampled for the quantitative variables (water depth, stem density, water temperature, dissolved oxygen, conductivity, turbidity, and distance to next habitat type), and Table 2.6 provides a summary for the categorical variables (habitat type, substrate, and next habitat type).

Of the 414 samples where YOY banded killifish were collected, 115 (28%) of these samples were taken at the Pine River, 174 (42%) of these samples were conducted at Linwood, 57 (14%) of these samples were taken at Oakhurst, and 68 (16%) of these samples were taken at Bayport. There was a statistically significant relationship between which wetland the sample was collected and the predicted presence of YOY banded killifish (X^2_3 = 190.7959, $p < 0.0001$). 0.0004). Interactions between microhabitat characteristics and wetland were tested, and were not statistically significant (p values ranged from 0.3479 to 0.8667). Due to the large difference in the percent of samples containing YOY banded killifish among the different wetland areas, I retained wetland where the sample was taken as an explanatory factor for constructing logistic regression models relating the presence or absence of YOY banded killifish to microhabitat characteristics.

Logistic regression identified four characteristics, wetland, type of habitat, next habitat type, and turbidity, which had statistically significant relationships with the presence or absence of YOY banded killifish (Table 2.7, Figure 2.5). The resulting logistic regression model correctly predicted the presence or absence of YOY banded killifish 81.8% of the time. The overall model was statistically significant (Wald's X^2_{11} = 298.6320, $p < 0.0001$).

Table 2.6: Number and percent of categorical microhabitat variable conditions sampled at Pine River, Linwood, Oakhurst, and Bayport wetlands from May 15, 2001 to August 15, 2001.

Variable	# of Samples	% of Samples
Habitat		
Emergent	248	17.2
Submersed	658	45.7
Open water	525	36.5
Floating leaf	9	0.6
Sediment		
Rock	2	0.1
Sand	328	22.8
Clay	784	54.4
Organic	326	22.6
Next Habitat Type		
Emergent	645	44.8
Submersed	329	22.8
Open water	448	31.1
Floating leaf	18	1.3

Table 2.7: Estimated coefficients, standard errors, and X^2 tests for the logistic regression model for YOY banded killifish habitat selection.

Variable	D.F.	Coeff.	Std. Err.	X^2	$P>X^2$
Intercept	1	-0.4110	0.3278	1.5724	0.2099
Wetland					
Linwood	1	0.6148	0.1211	25.7672	<0.0001
Oakhurst	1	-0.1915	0.1665	1.3239	0.2499
Bayport	1	-0.7602	0.1365	31.0151	<0.0001
Habitat					
Emergent	1	0.0847	0.2398	0.1246	0.7241
Floating leaf	1	1.0175	0.5681	3.2082	0.0733
Submersed	1	0.5546	0.2065	7.2114	0.0072
Next Habitat Type					
Emergent	1	-0.1834	0.2752	0.4440	0.5052
Floating leaf	1	1.9845	0.7760	6.5398	0.0105
Submersed	1	-0.3934	0.2852	1.9032	0.1677
Turbidity	1	-0.6874	0.1361	25.5250	<0.0001

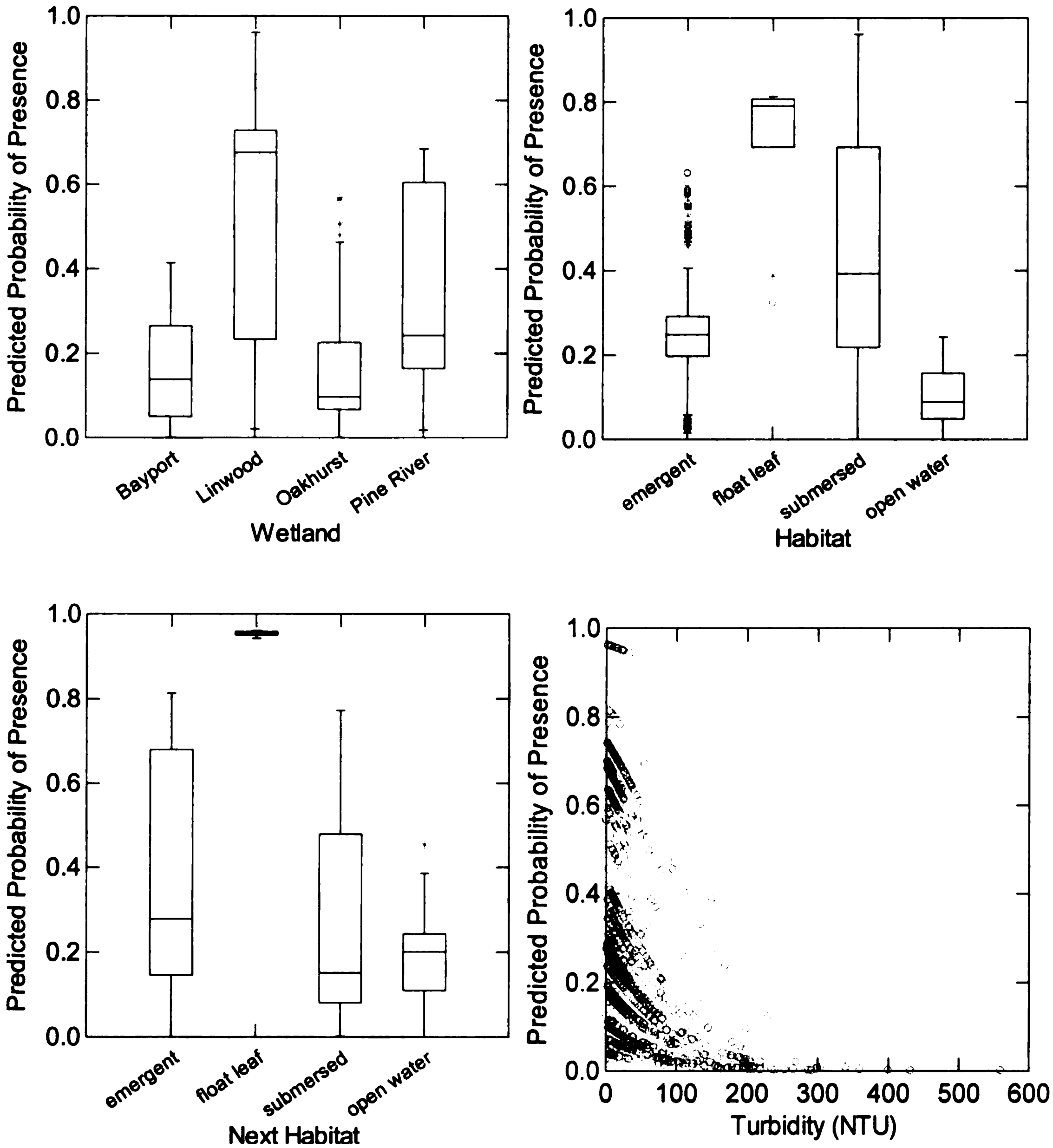


Figure 2.5: Relationships between microhabitat characteristics (wetland, habitat type, next habitat type, and turbidity) and the predicted probability of presence of YOY banded killifish.

The odds ratio estimates for wetland were calculated based upon comparisons to Pine River wetland (Table 2.8). The odds ratio estimate for Linwood is 1.320, however the confidence interval for this estimate contains 1, indicating no difference in the likelihood of sampling YOY banded killifish at Linwood compared to Pine River. The odds ratio estimates and confidence intervals for Oakhurst and Bayport are both less than 1, indicating that YOY banded killifish are less likely to be present in samples from these wetlands than at Pine River. Odds ratio estimates for habitat type were calculated based upon comparisons to open water. The confidence intervals for emergent, floating leaf, and submersed vegetation are all greater than 1, indicating that banded killifish are more likely to be sampled in vegetated habitats than open water. The odds ratio estimates for next habitat type were also calculated based upon comparisons to open water. All of the next habitat type odds ratio estimates and confidence intervals are greater than one, indicating that YOY banded killifish are less likely to be captured near open water habitat than emergent, submersed, or floating leaf vegetation. The odds ratio estimate for turbidity is 0.503 indicating that YOY banded killifish are more likely to be present in areas with low turbidity.

The residual chi square test (X^2_5 = 0.9518, p = 0.9170) and Hosmer Lemeshow goodness of fit test (X^2_8 = 15.1020, p = 0.0572) indicate that the model provides a reasonable fit to the data, and that residuals from the model were not associated with other (not included) explanatory variables.

Table 2.8: Estimated odds ratio point estimates and 95% Wald Confidence Limits for variables in the banded killifish habitat selection logistic regression model.

Variable	Point Estimate	Minimum	Maximum
Wetland			
Oakhurst vs. Pine	0.590	0.370	0.939
Bayport vs. Pine	0.334	0.223	0.500
Linwood vs. Pine	1.320	0.928	1.878
Habitat			
Emerge vs. open	5.706	3.454	9.426
Floating vs. open	14.502	3.214	65.432
Submersed vs. open	9.129	6.330	13.165
Next Habitat Type			
Emerge. vs. open	3.402	2.225	5.202
Floating vs. open	29.734	3.808	232.192
Submersed vs. open	2.758	1.807	4.208
Turbidity	0.503	0.385	0.667

Yellow Perch

A total of 849 yellow perch was collected in 2001 from the 1440 samples, over a wide range of microhabitat conditions (Tables 2.5 and 2.6). Yellow perch were collected in 348 or 24% of the samples. YOY yellow perch were divided into two size categories. Large YOY yellow perch (> 24 mm in length) were present in 178 or 51% of the samples where yellow perch were collected. Small YOY yellow perch (< 25 mm in length) were present in 194 or 56% of the samples where yellow perch were collected. Fish from both size classes were found in 24 (7%) of the samples where yellow perch were collected. There was not a statistically significant relationship between size class and the predicted presence or absence of YOY yellow perch ($X^2_1 = 0.0498$, $p = 0.8234$). Interactions between size class and other microhabitat variables also were not significant (p values ranged from 0.1258 to 0.8624). Therefore, YOY yellow perch from both size classes were pooled for further analysis of relationships between yellow perch presence or absence and microhabitat characteristics.

Of the 348 samples where YOY yellow perch were collected, 58 (17%) of these samples were taken at Pine River, 54 (16%) of these samples were conducted at Linwood, 76 (22%) of these samples were taken at Oakhurst, and 160 (46%) of these samples were taken at Bayport. There was not a statistically significant relationship between which wetland the sample was taken in and the predicted presence of YOY yellow perch ($X^2_3 = 5.2905$, $p = 0.1517$). There was a statistically significant interaction between wetland and water depth ($X^2_3 = 23.9679$, $p < 0.0001$). However, there was a significant difference in the mean water depth and range of water depths available for fish among the three habitats ($F_{3,1436}$ = 116.550, $p < 0.0001$, Table 2.9). Interactions between wetland and the remaining microhabitat characteristics were not significant (p values ranged from 0.0552, to 0.9526). Due to the lack of statistically significant relationships, data from all four wetlands were pooled for use in constructing logistic regression models relating the presence or absence of YOY yellow perch to microhabitat characteristics.

Logistic regression identified three microhabitat characteristics, water depth, water temperature, and conductivity, which had statistically significant relationships with the presence or absence of YOY yellow perch (Table 2.10, Figure 2.6). The resulting logistic regression model correctly predicted the presence or absence of YOY yellow perch 75.5% of the time. The overall model was statistically significant (Wald's X^2_3 = 25.8195, $p < 0.0001$). Regression coefficients were negative for water temperature, and positive for water depth and conductivity. Microhabitat variables selected to describe physical habitat conditions such as habitat type (X^2_3 = 0.4170, p = 0.9367), plant stem density (X^2_1 = 0.3851, p = 0.5349), next habitat type (X^2_3 = 0.3147, p = 0.9572), and distance to next habitat patch (X^2_1 = 3.1993, p = 0.0737) were not significant predictors of the presence or absence of YOY yellow perch.

The odds ratio estimate for water depth is 1.670, indicating that YOY yellow perch are more likely to be located in deeper water (Table 2.11). The odds ratio estimate for water temperature is 0.440, indicating that the probability of presence of YOY yellow perch increases with cooler water temperatures. The

Table 2.9: Mean, standard deviation, minimum, maximum, median, and quartiles of water depths (cm) sampled in each of the four wetland areas.

Wetland	Mean	St. Dev.	Min.	Max.	Median	1st Quar.	3rd Quar.
Pine River	47.8	20.7	4	97	46	32	64
Linwood	30.2	11.1	4	55	32	20	38
Oakhurst	28.3	12.2	3	61	27	19	37
Bayport	30.3	17.4	3	74	29	15	43

Table 2.10: Estimated coefficients, standard errors, and X^2 tests for the logistic regression model for yellow perch habitat selection.

Variable	D.F.	Coeff.	Std. Err.	X^2	$P>X^2$
Intercept	1	-3.7307	0.3786	97.0818	<0.0001
Water depth	1	0.5130	0.2017	6.4671	0.0110
Water temperature	1	-0.8217	0.3540	5.3888	0.0203
Conductivity	1	0.7739	0.2151	12.9464	0.0003

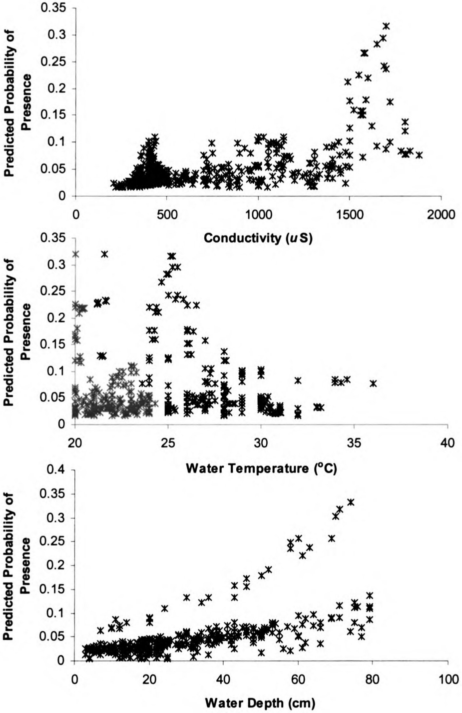


Figure 2.6: Relationships between the predicted probability of presence of YOY yellow perch and conductivity, water temperature, and water depth.

Table 2.11: Estimated odds ratio point estimates and 95% Wald Confidence Limits for variables in the yellow perch habitat selection logistic regression model.

Variable	Point Estimate	Minimum	Maximum
Water depth	1.670	1.125	2.480
Water temperature	0.440	0.220	0.880
Conductivity	2.168	1.422	3.305

odds ratio estimate for conductivity is 2.168 indicating that YOY yellow perch were more likely to be present in areas with high water conductivity.

The residual chi square test (X^2_{11} = 8.8394, p = 0.6367) and Hosmer Lemeshow goodness of fit test (X^2_8 = 4.7285, p = 0.7862) indicate that the model provided a reasonable fit to the data, and that residuals from the model were not associated with other (not included) explanatory variables.

Spottail Shiner

A total of 819 YOY spottail shiners was collected in 2001 from 1440 samples, over a wide range of microhabitat conditions (Tables 2.5 and 2.6). Spottail shiners were collected in 277 or 19% of the samples. Of the 277 samples where YOY spottail shiners were collected, 100 (36%) of these samples were taken at Bayport, 40 (15%) of these samples were conducted at Linwood, 93 (34%) of these samples were taken at Oakhurst, and 44 (16%) of these samples were taken at Pine River. There was a statistically significant relationship between which wetland the sample was taken in and the predicted presence of YOY spottail shiner (X^2_3 = 13.0233, p = 0.0046). Interactions between wetland and microhabitat characteristics were not significant (p-values ranged from 0.3816 to 0.6681), with the exception of wetland*water depth (X^2_3 = 13.0233, p = 0.0046). However, there was a significant difference in the ranges of water depths sampled among the four wetland areas ($F_{3,1436}$ = 116.550, p < 0.0001, Table 2.9).

Logistic regression identified five microhabitat characteristics, water temperature, water depth, turbidity, wetland, and dissolved oxygen, which had statistically significant relationships with the presence or absence of YOY spottail shiners (Table 2.12, Figure 2.7). The resulting logistic regression model correctly predicted the presence or absence of small YOY spottail shiners 78.4% of the time. The overall model was statistically significant (Wald's X^2_7 = 94.0427, $p < 0.0001$). Regression coefficients were negative for turbidity, and positive for water temperature, water depth, and dissolved oxygen. The only coefficient within the wetland variable that was statistically significant was for Bayport. Microhabitat variables selected to describe physical habitat conditions such as habitat type (X^2_3 = 0.3488, p = 0.9506), plant stem density (X^2_1 = 2.7237, p = 0.0989), next habitat type (X^2_3 = 2.2077, p = 0.5304), and distance to next habitat patch (X^2_1 = 0.0075, p = 0.9308) were not significant predictors of the presence or absence of YOY spottail shiner.

The odds ratio estimate for water temperature is 2.283, indicating that YOY spottail shiner are more likely to be found in areas with warmer water temperatures (Table 2.13). The odds ratio estimate for water depth is 1.527, indicating that YOY spottail shiner are more likely to be present in areas of deeper water. The odds ratio estimate for turbidity is -0.5054, indicating that the likelihood of presence of YOY spottail shiner decreases with increased turbidity. The odds ratios for wetland were calculated based upon comparisons to the Pine River wetland. The confidence interval for the odds ratio estimate for Linwood includes 1, indicating no difference in the likelihood of sampling YOY spottail

Table 2.12: Estimated coefficients, standard errors, and X^2 tests for the logistic regression model for spottail shiner distribution.

Variable	**D.F.**	**Coeff.**	**Std. Err.**	X^2	$P>X^2$
Intercept	1	-1.7633	0.1147	236.2869	<0.0001
Water temperature	1	0.8253	0.1233	44.7905	<0.0001
Water depth	1	0.4230	0.1096	14.9115	0.0001
Turbidity	1	-0.5054	0.1562	10.4669	0.0012
Wetland					
Linwood	1	-0.3278	0.1973	2.7617	0.0965
Oakhurst	1	0.2045	0.1745	1.3746	0.2410
Bayport	1	0.7240	0.1827	15.7057	<0.0001
Dissolved oxygen	1	0.3200	0.0990	10.4413	0.0012

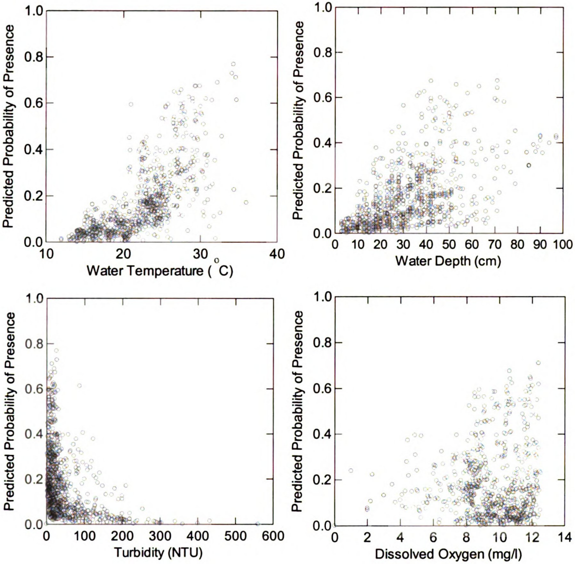


Figure 2.7: Relationships between the likelihood of presence of YOY spottail shiner and water temperature, water depth, turbidity and dissolved oxygen.

Table 2.13: Estimated odds ratio point estimates and 95% Wald Confidence Limits for variables in the spottail shiner habitat distribution logistic regression model.

Variable	Point Estimate	Minimum	Maximum
Water temperature	2.283	1.793	2.907
Water depth	1.527	1.232	1.892
Turbidity	0.603	0.444	0.891
Wetland			
Linwood vs. Pine River	1.314	0.691	2.499
Oakhurst vs. Pine River	2.237	1.203	4.160
Bayport vs. Pine River	3.761	1.987	7.116
Dissolved oxygen	1.377	1.134	1.672

shiners at Linwood compared to Pine River wetland. However, the odds ratio estimate for Bayport (3.761) and Oakhurst (2.237),and their confidence intervals are both greater than 1, indicating that there is a higher probability of sampling YOY spottail shiners if the sample is taken at Bayport or Oakhurst compared to Pine River wetland. The odds ratio estimate for dissolved oxygen is 1.377, indicating that the probability of presence of YOY spottail shiners increases with increased oxygen concentrations.

The residual chi square test (X^2_{11} = 9.9719, p = 0.5329) and Hosmer Lemeshow goodness of fit test (X^2_8 = 6.5496, p = 0.5859) indicate that the model provided a reasonable fit to the data, and that residuals from the model were not associated with other (not included) explanatory variables.

DISCUSSION

Influence of microhabitat characteristics on YOY fish distribution

This study examined the spatial distribution of young of the year bluegill, banded killifish, yellow perch, and spottail shiners. These species were not uniformly distributed within the wetland areas investigated, and there were predictable patterns in their distribution. Logistic regression was used to model the presence or absence of YOY fish based upon microhabitat characteristics, with the models correctly predicting the presence or absence of fish 74.6% to 81.8% of the time. With the exception of substrate type, all of the microhabitat variables measured were associated with the presence or absence of YOY fish for at least one of the species investigated (Table 2.14).

Water depth was the most influential microhabitat characteristic, showing a statistically significant relationship with the presence or absence of YOY fish from three of the four species investigated (Table 2.14). In all three cases, YOY fish had a higher likelihood of presence in areas with deeper water levels. Habitat type, water temperature, and turbidity were also important, and were significant variables in 50% of the models. The other microhabitat characteristics measured, plant density, distance to next habitat type, next habitat type, dissolved oxygen, and conductivity, showed significant relationships with the presence or absence of YOY fish from one of the species investigated.

Table 2.14: Overall % concordance of logistic regression models and microhabitat characteristics that showed statistically significant relationships with the predicted presence or absence of YOY fish. Numbers indicate regression coefficients. For habitat and next habitat type, letters indicate fish habitat preference, where S = submersed vegetation, E = emergent vegetation, and O = open water habitat.

	% Concor.	Habitat Type	Plant Density	Next Habitat Type	Distance to Next Habitat	Water Depth	Water Temp.	Diss. Oxygen	Cond.	Turbidity
Bluegill	74.6	S>E,O	0.25		-0.68	0.52				
B. killifish	81.8	S, E>O		E,S>O						-0.69
Y. perch	75.5					0.51	-0.82		0.77	
Sp. shiner	78.4					0.42	0.83	0.32		-0.51

Water Depth

Water depth showed a statistically significant relationship with the presence or absence of YOY fish from three of the four species investigated (Table 2.14). In all three cases, YOY fish were more likely to be sampled from deeper water habitats (70 – 100 cm). Water depth also had a large impact on the young of year fish community at the macrohabitat scale (see chapter one) showing positive relationships with species diversity, species evenness, and growth of YOY bluegill.

Deeper water may be important to young of the year fish for several reasons. First of all, deeper water may provide young fish with a refuge from warm water temperatures during hot summer months. Measured water temperatures ranged as high as 35.8 °C during the study period. These very warm water temperatures may be detrimental to fish growth, and as a result during warm days, YOY fish may seek out pockets of deeper water to escape high temperatures. Secondly, areas of deep water may provide young fish with a refuge from avian predation. Avian predators, including herons, egrets, and terns, were frequently seen throughout Saginaw Bay. These birds commonly feed upon fish. As a result of the presence of these birds, young fish may select deeper water habitat to avoid predation.

The data collected as part of this study showed an increase in likelihood of presence of YOY fish with increased water depth; however, the use of a throw trap limited sampling to areas with water levels less than 100 cm. Several other studies have indicated that there is an increase in the density and diversity of

YOY fish in wetland areas less than 1 to 2 m in depth (Keast et al. 1978, Chubb and Liston 1986, Bryan and Scarnecchia 1992). Data here complement these studies by indicating that while YOY fish may be more abundant in shallow wetland areas (< 1-2 m), they may be selecting for deeper habitats within this range.

Water levels in the Great Lakes are cyclical in nature (Herdendorf 1992), and during the study period water levels were approximately 0.5 m below the long term mean. It is possible that during times of low water levels in Saginaw Bay, the importance of water depth to YOY fish may be exaggerated. Saginaw Bay has a shallow littoral slope. As a result of water levels being 0.5 m below the long term mean, there were few areas within the wetlands I sampled where there was habitat with water depths greater than 0.5 m, adjacent to vegetation. However, if low water levels within Saginaw Bay continue, over time the submersed vegetation community will spread into areas further off-shore where there is deeper water.

Habitat Type

The presence of vegetation structure was important in determining the presence or absence of YOY fish from two of the four species investigated (Table 2.14). Young of the year bluegill and banded killifish selected vegetated habitats over areas of open water. The importance of vegetation in providing habitat for young fish has been documented in several studies (e.g. Chubb and Liston 1986, Conrow et al. 1990, Petering and Johnson 1991, Leslie and Timmins 1994, Minns et al. 1997, Brazner and Beals 1997, Duffy and Baltz 1998). Vegetated habitats provide benefits over open water such as increased protection from predation (e.g. Werner et al. 1983b, Gotceitas and Colgan 1987, Gotceitas 1990b, Heck and Crowder 1991). Vegetation cover was also important to young of year fish at the t the macrohabitat scale. The percent cover of submersed vegetation showed positive relationships with species richness, while the amount of open water showed negative relationships with species diversity, and influenced species composition (see chapter 1).

While this study adds support to the general finding that the presence of vegetation structure is important to young fish, this study also suggests that the type of vegetation present may also influence the presence or absence of some species of young fish. Bluegill were more likely to be collected from submersed vegetation habitats over areas of emergent vegetation and open water, while banded killifish preferred both types of vegetated habitats over open water. In addition to influencing the presence or absence of YOY fish, the abundance of vegetation may also affect their growth rates. The growth of banded killifish was positively related to the amount of submersed vegetation cover at the macrohabitat scale (see chapter 1).

The type of vegetation present may be important to young fish because the foraging efficiency of individual fish may decline with changes in the vegetation community structure and increased habitat complexity (Winfield 1986, Diehl 1988, Gotceitas 1990b, Dionne and Folt 1991). However, the protection that vegetation provides to young fish from predation will increase with vegetation complexity (Werner et al. 1983a,b, Lillie and Budd 1992, Jacobsen and Berg 1998). Crowder and Cooper (1982) suggested that the value of aquatic plants as habitat for fish varies among plant species based on the density and architecture of the species. While few studies have been conducted documenting the distribution of young fish in the wild in response to different plant communities, Petering and Johnson (1991) used artificial substrates to demonstrate a preference of larval fish to floating leaf and emergent vegetation over submersed vegetation. This study suggests that YOY fish from different species may prefer different types of vegetation structure, based upon the habitat needs of each species.

The presence of vegetation may not be important to all species of YOY fish. This study found no relationship between the presence or absence of YOY yellow perch and spottail shiner and aquatic vegetation. In a study by Fisher et al. (1999), they also found no relationship between the abundance of juvenile yellow perch and the presence of emergent or submersed aquatic vegetation. However, at the macrohabitat scale, I did find a positive relationship between growth rates of yellow perch and the amount of submersed vegetation (see Chapter 1).

<u>Water Temperature</u>

Water temperature was important in describing the distribution of yellow perch and spottail shiners. In their first year of life, fish need to grow rapidly to increase their likelihood of overwinter survival (Post and Prankevicius 1987, Tonn and Paszkowski 1987). Spottail shiners may select warmer temperatures because they can grow faster as water temperatures increase.

Young of the year yellow perch selected habitats with cooler water temperatures. Compared to spottail shiners, yellow perch can be considered cool water species. Tidwell et al. (1999) raised juvenile yellow perch in tanks with water temperatures of 20°C, 24°C, and 28°C. They found that yellow perch grew significantly better in water temperatures of 24°C compared to 28°C, and survival rates were higher for perch 24°C tanks compared to 28°C. Measured water temperatures across the duration of this study ranged from 12.5°C to 35.8°C, and were 28°C or warmer 14.6% of the time. Growth rates of YOY yellow perch in Saginaw Bay may be hindered as water temperatures approached 35.8 °C, and as a result they selected habitats with cooler water temperatures.

Fisher et al. (1999) showed that the abundance of juvenile yellow perch in South Dakota lakes was negatively correlated to water temperatures. Results of this study also indicate that water temperatures are important to the distribution of YOY yellow perch, with perch preferring cooler water temperatures.

While there are few studies that have examined the effects of temperature on the distribution of YOY fish, there are several studies that compare yearly fluctuations in temperature to spawning success and larval fish densities (e.g. Chubb and Liston 1986). Results of this study, and those by Fisher et al. (1999) and Darf and Powell (1997), indicate that within a year, water temperatures within the early life history habitat are associated with YOY fish distribution, and therefore may influence their likelihood of survival. Further investigation of the impacts of water temperature on fish distribution and abundance is necessary to determine its potential importance to YOY fish growth, and probability of survival.

Turbidity

The presence or absence of two of the four fish species investigated was related to turbidity. Both banded killifish and spottail shiner were more likely to be sampled in areas with higher water clarity. Several other studies have also documented the importance of turbidity with regards to fish distribution in the Great Lakes (Jude and Pappas 1992, Petering and Johnson 1991, Brazner and Beals 1997). Increased turbidity may inhibit the ability of YOY fish to locate and capture prey. As a result, YOY banded killifish and spottail shiners may select areas with improved water clarity.

Other Microhabitat Characteristics

Although water depth, habitat type, water temperature, and turbidity were the most common habitat characteristics to influence the distribution of YOY fish, other microhabitat characteristics such as plant density, conductivity, distance to next habitat, and dissolved oxygen also influenced YOY fish presence or absence (Table 2.14). For example, YOY bluegill selected habitats with increased plant density, which may be a result of increased protection from predators in more densely vegetated habitat (Savino and Stein 1989, Gotceitas 1990a, Lillie and Budd 1992). Therefore, it may be important to evaluate additional microhabitat characteristics to determine their potential impacts on the distribution, growth, and survival of YOY fish. Which microhabitat characteristics are important to fish distribution will vary among species.

Ontogenetic Shifts in Habitat Use

Many fish species undergo ontogenetic shifts in habitat use as they develop (e.g. Werner and Hall 1988, Post and McQueen 1988, Wahl et al. 1993, Eggleston 1995, Simonovic et al. 1999, Svanbaeck and Ekloev 2002). These shifts in habitat use can influence fish growth rates (Ruzycki and Wurtsbaugh 1999, Dahlgren and Eggleston 2000), and typically occur in response to changes in diet (VanderKooy et al. 2000, Svanbaeck and Ekloey 2002) or predation risk (Werner and Hall 1988, Sillett and Foster 2000, Dahlgren and Eggleston 2000). Although other authors have demonstrated ontogenetic shifts in habitat use by bluegill and yellow perch (Post and McQueen 1988, Werner and Hall 1988, Wahl et al. 1993), results of our logistic regression modeling did not indicate differences in the distribution of smaller (<25 mm) and larger (>24 mm) fish from these species in response to the microhabitat characteristics measured. However, the previously mentioned studies on bluegill and yellow perch were conducted at larger temporal and spatial scales; documenting broad habitat shifts (e.g. offshore vs. inshore), over longer time spans (larval to juvenile to adult stages) and greater size differences.

Resident vs. Transient Wetland Species

This study examined the influence of microhabitat characteristics on the distribution of YOY fish from two resident wetland species (bluegill and banded killifish) and two transient wetland species (yellow perch and spottail shiner). A summary of the results of the logistic regression modeling is presented in Table 2.14. These results indicate a difference in the types of microhabitat characteristics that were important to YOY fish from both groups. In general, the resident wetland species were responding to microhabitat characteristics that describe the physical structure of the habitat (e.g. habitat type, plant density). Contrary to this, the presence or absence of transient wetland species was not correlated to microhabitat characteristics used to describe physical habitat conditions. No statistically significant relationships were found between the presence or absence of these fish and microhabitat characteristics such as habitat type, next habitat type, and vegetation density. Instead, these fish were associated with variation in water quality parameters such as water temperature, dissolved oxygen, conductivity, and turbidity. These results suggest a significant difference in the way that YOY fish from resident and transient wetland species respond to conditions within wetlands. Resident wetland species appear to be more restricted in their distribution to the type of habitat structure within wetlands, while the presence or absence of transient wetland species was not related to the microhabitat characteristics measured here to describe physical habitat conditions. Further research is needed to determine if this pattern applies to a broader suite of transient and resident wetland species, and to determine what implications this may have for wetland and fisheries management.

LITERATURE CITED

Allison, P.D. 1999. Logistic Regression Using the SAS System: Theory and Application. SAS Institute, Inc., Cary, NC.

Baltz, D.M. 1990. Autecology. pp. 585-607 *IN* C.B. Schreck and P.B. Moyle (eds.). Methods for Fish Biology. American Fisheries Society, Bethesda, MD.

Baltz, D.M., C. Rakocinski, and J.W. Fleeger. 1993. Microhabitat use by marsh-edge fishes in a Louisiana estuary. Environmental Biology of Fishes 36:109-126.

Beeton, A., S. Smith and F. Hooper. 1967. Physical limnology of Saginaw Bay, Lake Huron. Technical Report No. 12. Great Lakes Fishery Commission, Ann Arbor, MI.

Brazner, J.C. 1997. Regional, habitat and human development influences on coastal wetland and beach fish assemblages in Green Bay, Lake Michigan. Journal of Great Lakes Research 23:36-51.

Brazner, J.C. and E.W. Beals. 1997. Patterns in fish assemblages from coastal wetland and beach habitats in Green Bay, Lake Michigan: a multivariate analysis of abiotic and biotic forcing factors. Canadian Journal of Fisheries and Aquatic Sciences 54:1743-1761.

Bremigan, M.T. and R.A. Stein. 1994. Gape-dependent larval foraging and zooplankton size: Implications for fish recruitment across systems. Canadian Journal of Fisheries and Aquatic Sciences 51:913-922.

Bryan, M.D. and D.L. Scarnecchia. 1992. Species richness, composition, and abundance of fish larvae and juveniles inhabiting natural and developed shorelines of a glacial Iowa lake. Environmental Biology of Fishes 35:329-341.

Cardinale, B.J., V.J. Brady and T.M. Burton. 1998. Changes in the abundance and diversity of coastal wetland fauna from the open water/macrophyte edge towards shore. Wetlands Ecology and Management 6:59-68.

Carr, M.H. 1994. Predicting recruitment of temperate reef fishes in response to changes in macrophyte density caused by disturbance. pp 255-269 *IN* D.J. Stouder, K.L. Fresh, R.J. Feller (eds.). Theory and Application in Fish Feeding Ecology. University of South Carolina Press, Columbia, SC.

Casselman, J. M., and C.A. Lewis. 1996. Habitat requirements of northern pike (*Esox lucius*). Canadian Journal of Fisheries and Aquatic Science 53:161-174.

Chubb, S.L. and C.R. Liston. 1986. Density and distribution of larval fishes in Pentwater Marsh, a coastal wetland on Lake Michigan. Journal of Great Lakes Research 12:332-343.

Conrow, R., A.V. Zale, and R.W. Gregory. 1990. Distributions and abundances of early life stages of fishes in a Florida lake dominated by aquatic macrophytes. Transactions of the American Fisheries Society 119:521-528.

Crowder, L.B. and W.E. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. Ecology 63:1802-1813.

Dahlgren, C.P. and D.B. Eggleston. 2000. Ecological processes underlying ontogenetic habitat shifts in a coral reef fish. Ecology 81:2227-2240.

Darf, B.A. and J.C. Powell. 1997. Distribution, abundance, and habitat characteristics of juvenile tautog (*Tautoga onitis,* Family Labridae) in Narragansett Bay, Rhode Island, 1988-1992. Estuaries 20:589-600.

Dewey, M.R. 1992. Effectiveness of a drop net, a pop net, and an electrofishing frame for collecting quantitative samples of juvenile fishes in vegetation. North American Journal of Fisheries Management 12:808-813.

Diehl, S. 1988. Foraging efficiency of three freshwater fishes: effects of structural complexity and light. Oikos 53:207-213.

Dionne, M. and C.L. Folt. 1991. An experimental analysis of macrophytes growth forms as fish foraging habitat. Canadian Journal of Fisheries and Aquatic Sciences 48:123-131.

Duffy, K.C. and D.M. Baltz. 1998. Comparison of fish assemblages associated with native and exotic submerged macrophytes in the Lake Pontchartrain estuary, USA. Journal of Experimental Marine Biology and Ecology 223:199-221.

Eggleston, D.B. 1995. Recruitment in Nassau grouper *Epinephelus striatus*: post-settlement abundance, microhabitat features, and ontogenetic habitat shifts. Marine Ecology Progress Sweries 124:9-22.

Fassett, N.C., 1985. A Manual of Aquatic Plants. The University of Wisconsin Press, Madison, WI.

Fisher, S.J., C.R. Pyle, and D.W. Willis. 1999. Habitat use by age-0 yellow perch in two South Dakota glacial lakes. Ecology of Freshwater Fish 8:85-93.

Freeman, B.J., H.S. Greening, and J.D. Oliver. 1984. Comparison of three methods for sampling fishes and macroinvertebrates in a vegetated freshwater wetland. Journal of Freshwater Ecology 2:603-609.

Gotceitas, V. and P. Colgan. 1987. Selection between densities of artificial vegetation by young bluegills avoiding predation. Transactions of the American Fisheries Society 116:40-49.

Gotceitas, V. 1990a. Plant stem density as a cue in patch choice by foraging juvenile bluegill sunfish. Environmental Biology of Fishes 29:227-232.

Gotceitas, V. 1990b. Foraging and predator avoidance: a test of a patch choice model with juvenile bluegill sunfish. Oecologia 83:346-351.

Heck, K.L., and L.B. Crowder. 1991. Habitat structure and predator-prey interactions in vegetated aquatic systems. pp282-299 IN S.S. Bell, E.D. McCoy and H.R. Mushinsky (eds.). Habitat structure: the physical arrangement of objects in space. Chapman and Hall, New York.

Herdendorf , C.E. 1992. Lake Erie Coastal Wetlands: an overview. Journal of Great Lakes Research 18:533-551.

Herdendorf, C.E., C.N. Raphael, and E. Jaworski. 1986. The ecology of the coastal marshes of western Lake Erie: a community profile. U.S. Fish and Wildlife Service Biological Report 85.

Hosmer, D.W. and S. Lemeshow. 2000. Applied Logistic Regression, 2^{nd} edition. John Wiley & Sons, Inc., New York, NY.

Houde, E.D. 1994. Differences between marine and freshwater fish larvae: implications for recruitment. ICES Journal of Marine Science 51:91-97.

Jacobsen, L. and S. Berg. 1998. Diel variation in habitat use by planktivores in field enclosure experiments: the effect of submerged macrophytes and predation. Journal of Fish Biology 53:1207-1219.

Johnson, D.L., W.E. Lynch, and T.W. Morrison. 1997. Fish communities in a diked Lake Erie wetland and an adjacent undiked area. Weltands 17(1):43-54.

Jude, D.J. and J. Pappas. 1992. Fish utilization of Great Lakes coastal wetlands. Journal of Great Lakes Research 18:651-672.

Keast, A., J. Harker, and D. Turnbull. 1978. Nearshore fish habitat utilization and species associations in Lake Opinicon (Ontario, Canada). Environmental Biology of Fishes 3(2):173-184.

Krieger, K.A., D.M. Klarer, R.T. Heath, and C.E. Herdendorf. 1992. A call for research on Great Lakes coastal wetlands. Journal of Great Lakes Research 18:525-528.

Kushlan, J.A. 1981. Sampling characteristics of enclosure fish traps. Transactions of the American Fisheries Society 110:557-562.

Leslie, J.K. and C.A. Timmins. 1994. Ecology of young-of-the-year fishes in Severn Sound, Lake Huron. Canadian Journal of Zoology 72:1887-1897.

Lillie, R.A. and J. Budd. 1992. Habitat architecture of *Myriophyllum spicatum* L. as an index to habitat quality for fish and macroinvertebrates. Journal of Freshwater Ecology 7:113-125.

Liston, C.R., and S.L. Chubb. 1986. Relationships of water level fluctuations and fish. pp 121-140 *IN* Prince, H.H. and F.M. D'Itri (eds.). *Coastal Wetlands.* Lewis Publishers, Inc., Chelsea, MI.

Minns, C.K., V.W. Cairns, R.G. Randall and J.E. Moore. 1994. An index of biotic integrity (IBI) for fish assemblages in the littoral zone of Great Lakes' Areas of Concern. Canadian Journal of Fisheries and Aquatic Science 51:1804-1822.

Mittelbach, G.G. 1986. Predator-mediated habitat use: some consequences for species interactions. Environmental Biology of Fishes 16:159-169.

Petering, R.W. and D.L. Johnson. 1991. Distribution of fish larvae among artificial vegetation in a diked Lake Erie wetland. Wetlands 11:123-138.

Pihl, L. and R. Rosenberg. 1992. Production, abundance, and biomass of mobile epibenthic marine fauna in shallow waters, western Sweden. Journal of Experimental Marine Biology and Ecology 57:273-301.

Poe, T.P., C.O Hatcher, C.L. Brown, and D.W. Schloesser. 1986. Comparison of species composition and richness of fish assemblages in altered and unaltered littoral habitats. Journal of Freshwater Ecology 3(4):525-536.

Post, J.R., and D.J. McQueen. 1988. Ontogenetic changes in the distribution of larval and juvenile yellow perch (Perca flavescens): A response to prey or predators? Canadian Journal of Fisheries and Aquatic Sciences 45: 1820-1826.

Post, J.R., and A.B. Prankevicius. 1987. Size-selective mortality of young-of-the-year yellow perch (*Perca flavescens*): evidence from otolith microstructure. Canadian Journal of Fisheries and Aquatic Sciences 44:1840-1847.

Raposa, K.B. and C.A. Oviatt. 2000. The influence of contiguous shoreline type, distance from shore, and vegetation biomass on nekton community structure in eelgrass beds. Estuaries 23(1):46-55.

Rothschild, B.J. 1986. Dynamics of marine fish populations. Harvard University Press, Cambridge, MA 277pp.

Rozas, L.P. and W.E. Odum. 1988. Occupation of submerged aquatic vegetation by fishes: testing the roles of food and refuge. Oecologia 77:101-108.

Ruzycki, J.R. and W.A. Wurtsbaugh. 1999. Ontogenetic habitat shifts of juvenile Bear Lake sculpin. Transactions of the American Fisheries Society 128:1201-1212.

Savino, J.F. and R.A. Stein. 1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated, submersed vegetation. Transactions of the American Fisheries Society 111:255-266.

Savino, J.F. and R.A. Stein. 1989. Behavioral interactions between fish predators and their prey: Effects of plant density. Animal Behaviour 37:311-321.

Sillett, K.B. and S.A. Foster. 2000. Ontogenetic niche shifts in two populations of juvenile threespine stickleback, *Gasterosteus aculeatus,* that differ in pelvic spine morphology. Oikos 91:468-476.

Simonovic, P.D., P. Garner, E.A. Eastwood, V. Kovac, and G.H. Copp. 1999. Correspondence between ontogenetic shifts in morphology and habitat use in minnow *Phoxinus phoxinus*. Environmental Biology of Fishes 56:117-128.

Skubinna, J.P., T.G. Coon, and T.R. Batterson. 1995. Increased abundance and depth of submersed macrophytes in response to decreased turbidity in Saginaw Bay, Lake Huron. Journal of Great Lakes Research 21(4):476-488.

Svanbaeck, R. and P. Ekloev. 2002. Effects of habitat and food resources on morphology and ontogenetic growth trajectories in perch. Oecologia 131:61-70.

Tidwell, J.H., S.D. Coyle, J. Evans, C. Weibel, J. McKinney, K. Dodson, and H. Jones. 1999. Effect of culture temperature on growth, survival, and biochemical composition of yellow perch *Perca flavescens*. Journal of the World Aquaculture Society 30(3):324-330.

Tonn, W.M. and C.A. Paszkowski. 1987. Habitat use of the central mudminnow (*Umbra limi*) and yellow perch (*Parca flavercens*) in *Umbra-Perca* assemblages: the role of competition, predation, and abiotic environment. Canadian Journal of Zoology 65:862-870.

Turner, R.E. 1988. Secondary production in riparian wetlands. Transactions of the 53rd North American Wildlife and Natural Resources Conference. 491-501.

VanderKooy, D.E., C.F. Rakocinski, and R.W. Heard. 2000. Trophic relationships of three sunfishes (*Lepomis* spp.) in an estuarine bayou. Estuaries 23:621-632.

Wahl, C.M., E.L. Mills, W.N. McFarland, and J.S. DeGisi. 1993. Ontogenetic changes in prey selection and visual acuity of the yellow perch, Perca flavescens. Canadian Journal of Fisheries and Aquatic Sciences 50:743-749.

Werner, E.E. and D.J. Hall. 1988. Ontogenetic habitat shifts in bluegill: the foraging rate-predation risk trade-off. Ecology 69(5):1352-1366.

Werner, E.E., G.G. Mittelbach, D.J. Hall, and J.F. Gilliam. 1983a. Experimental tests of optimal habitat use in fish: the role of relative habitat profitability. Ecology 64:1525-1539.

Werner, E.E., J.F. Gilliam, D.J. Hall, and G.G. Mittelbach. 1983b. An experimental test of the effects of predation risk on habitat use in fish. Ecology 64:1540-1548.

Winfield, I.J. 1986. The influence of simulated aquatic macrophytes on the zooplankton consumption rate of juvenile roach, *Rutilus rutilus*, and perch, *Perca fluviatilis*. Journal of Fish Biology 29:37-48.

CHAPTER 3: EFFECTS OF VEGETATION AND FISH DENSITY ON THE GROWTH OF YOUNG OF THE YEAR BLUEGILL

ABSTRACT

Although wetland environments are important habitats for juvenile bluegill, young of the year (YOY) bluegill are not uniformly distributed within wetlands, and often inhabit vegetated areas in preference to open water. The goal of this study is to determine if YOY bluegill habitat preferences influence fish success as measured by their growth rates. Additionally, effects of fish density and macroinvertebrate and zooplankton resource levels on bluegill growth are discussed. Two enclosure experiments were conducted to examine bluegill growth rates under different habitat conditions. The first experiment compared bluegill growth rates in emergent vegetation, submersed vegetation, and open water habitats. The second experiment evaluated bluegill growth rates at high and low fish densities in submersed vegetation and open water. Water quality within the enclosures was monitored daily, zooplankton populations were monitored weekly, and macroinvertebrates were sampled at the beginning and end of the experiment. Fish growth and diet were assessed at the end of the experiment. Few differences in zooplankton abundance were found among habitat types. Macroinvertebrates were more abundant in vegetated areas than open water. Bluegill fed on both macroinvertebrates and zooplankton in all habitats; however, they consumed more zooplankton biomass and less macroinvertebrate biomass in open water than in vegetated habitats in experiment one. Fish grew slower in emergent habitat than submersed vegetation or open water in experiment one. In experiment two, habitat type had

no impact on growth rates at low fish density, however at high densities YOY bluegill grew better in submersed vegetation than in open water. In both submersed vegetation and open water habitats, bluegill grew faster at lower densities. Bluegill also had faster growth rates in experiment one where food resources were more abundant.

INTRODUCTION

Wetland environments serve as important early life history habitats for many fish species, including bluegill (*Lepomis macrochirus*). Potential benefits of wetland areas for juvenile bluegill include the high primary productivity of these environments, reduced risk of predation, and the rich zooplankton and benthos food source that wetlands provide (e.g. Mittelbach 1984, Rozas and Odum 1988, Turner 1988, Werner and Hall 1988, Schramm and Jirka 1989, Jude and Pappas 1992, Cardinale et al. 1998). However, the abundance and distribution of young of the year (YOY) bluegill are not uniform within wetlands (see Chapter 2) or among wetland areas (see Chapter 1). The structure that aquatic macrophytes provide influences the distribution of YOY bluegill. In general, they are more likely to be found in submersed vegetation habitats compared to areas of emergent vegetation or open water (see Chapter 2). The goal of this study is to determine if YOY bluegill habitat preferences influence individual growth rate.

The habitat preferences of a species should be influenced by the fish's ability to forage, grow, and avoid predation. Optimal foraging theory predicts that young fish should choose habitat patches that maximize energy intake per unit time, because growth rates, particularly in the first year, must be maximized to survive to breeding age (Post and Prankevicius 1987, Tonn and Paszkowski 1987, Houde 1994). Studies have shown that the foraging efficiency of individual fish may decline with changes in the vegetation community structure and increased habitat complexity (Winfield 1986, Diehl 1988, Gotceitas 1990a, Dionne and Folt 1991), but the protection that vegetation provides to young fish from predation increases with vegetation complexity (Crowder and Cooper 1982, Werner et al. 1983b, Lillie and Budd 1992, Jacobsen and Berg 1998). As a result, a fish should choose the environment that allows it to minimize the predation risk/foraging rate ratio (Gotceitas 1990b).

Previous studies on bluegill have shown that bluegill switch habitats and diet in response to food availability, predation risk, competition, and experience in a habitat type (Werner and Hall 1976, 1977, 1979, Mittelbach 1981, 1984, Werner et al. 1981, 1983a). There are tradeoffs in the energetic return of feeding between open water and vegetated habitats. Bluegill feeding on zooplankton in open water environments spend little time searching and handling prey, but the small prey size makes each item's overall profitability low. In vegetated environments, bluegill feeding on macroinvertebrates spend longer periods in search for prey, due to the increased habitat structure, and in handling prey, due to their increased size, both of which act to lower prey profitability (Mittelbach 1981). Adult bluegill have been shown to select prey to optimize their energy intake (Werner and Hall 1974), and switch habitats from vegetated areas to open water as the relative profitability of the different habitats change (Mittelbach 1981). In general, adults will grow faster in areas of vegetated habitat, but move to open water in response to competition (Werner and Hall 1977, 1979). Smaller bluegill, however, may remain in vegetated habitats where they feed less optimally and are subject to more intense competition. Foraging in open water may be more profitable, but the increased protection from predation in vegetated habitats outweighs the benefit of open water feeding (Mittelbach 1981, 1984, 1988, Werner et al. 1983a, Werner and Hall 1988, Gotceitas 1990b). However, in areas with high populations of zooplanktivorous fish and low abundances of zooplankton, juvenile bluegill may grow faster in vegetated areas compared to areas of open water (Belk 1993).

While there have been several studies examining bluegill use of different habitats, most of these studies have focused on shifts in diet and energy consumption between habitats. Few studies have examined growth rates of bluegill confined to different habitats, and of these, all focused on larger fish (age one and older) and evaluated the impacts of competition on growth rates rather than potential effects of habitat type. Fish growth in their first year of life is critical in determining the length of time they spend vulnerable to predators, the over winter survival rate, and year class strength (Mittelbach 1984, Houde 1994). The goal of this study is to examine the impacts of selecting different habitat types on the growth rates of YOY bluegill. Specific objectives of this study are to: 1) compare the growth of YOY bluegill in different habitat types, 2) compare the abundance and types of food resources in different habitats, 3) compare the diet of YOY bluegill in different habitats, and 4) determine if fish density influences growth rates of YOY bluegill in different habitats.

METHODS

Study Site Description

One wetland and one pond located at the Experimental Lakes Area at Michigan State University, Ingham County, Michigan were selected as study sites. The first experiment took place in a 0.40 hectare wetland. This wetland had a maximum water depth of 1.3 m. The plant community within the wetland was dominated by cattails (*Typha* spp.), Eurasian water milfoil (*Myriophyllum spicatum*), and common waterweed (*Elodea canadensis*). The only fish captured within the wetland were fathead minnows (*Pimephales promelas*). Due to low oxygen concentrations and declining water levels in the wetland, the second experiment was conducted in a larger pond at the Experimental Lakes Area. Pond 4 is approximately 5 hectares in size, with a maximum water depth of 2.4 m, and average depth of 1.8 m. Vegetation within the pond is dominated by common reed (*Phragmites australis*), Eurasian water milfoil (*Myriophyllum spicatum*), and common waterweed (*Elodea canadensis*). The fish community within the pond is dominated by sunfish (*Lepomis* spp.), brook sticklebacks (*Culaea inconstans*), and fathead minnows.

Experiment 1

A total of 24 enclosures were used in experiment 1. Each square enclosure measured 1 m on a side, and was constructed with a polyvinyl chloride pipe frame (2.5 cm in diameter) covered with 500 μm mesh made of plastic sidewalk underliner. The enclosures were fixed into the substrate with stakes at least 10 cm deep. The bottom of the sides of the enclosures were weighted with chain, and buried in the sediment to prevent fish from escaping. The tops of the enclosures were covered with orange plastic construction fencing to prevent avian predation. The enclosures were placed within the wetlands so that eight enclosures were located in emergent vegetation, eight were located in submersed vegetation, and the remaining eight enclosures were located in open water habitat. Water depths where enclosures were placed ranged from 28 to 64 cm, with a mean of 45 cm. Two enclosures in each habitat type were randomly selected to serve as controls and were not stocked with fish. The remaining enclosures were stocked with YOY bluegill (size ranged from 17 to 23 mm, standard length) captured from a local lake on July 23 – July 25, 2002. Before stocking of fish, each enclosure was extensively seined to remove any fish that may have been inadvertently captured while the enclosures were installed.

A YSI model 55 dissolved oxygen meter was used to sample water temperature and dissolved oxygen concentrations in the enclosures daily, before 10 am. Readings were taken at approximately two-thirds of the water depth.

A modified Gerking sampler (Gerking 1957) was used to sample macroinvertebrates in the enclosures at the beginning and end of the experiment. Each sample covered 491 cm^2, and water depth at the time of each sample was measured for later calculation of water volume and macroinvertebrate density. The Gerking sampler was placed over a random patch of open water, emergent, or submersed vegetation within the enclosure, and quickly pushed down to the sediment surface. Vegetation, if present, was cut at the substrate surface, and the bottom of the sampler was closed. The sampler was then inverted and the sample was filtered through a 253 μm mesh nylon netting. Macroinvertebrates were picked from the samples and preserved in a 90% ethanol solution. The plant material was placed into sealed plastic bags and frozen for later analysis. In the lab, plant samples were allowed to thaw, washed, and examined under a microscope for associated macroinvertebrates, which were hand picked from the plant material. All macroinvertebrates from the ethanol sample in the field and associated plant material were then identified to order, and measured for body length and head capsule width using a dissecting scope and digitizing tablet. Plants were identified to species according to Fassett (1985), and dried in an oven at 80°C for 24 hours and weighed to the nearest 0.001 g to estimate macrophyte biomass. A subsample of 20 macroinvertebrates from each order were measured for body length and head capsule width, and then dried in an oven at 105°C for four hours (Smock 1980). After drying, the macroinvertebrates were weighed to the nearest 0.0001 gram. Data from these macroinvertebrates were used to construct regression relationships between head capsule width and dry weight. Head capsule width was measured for all macroinvertebrates captured, and used to calculate macroinvertebrate biomass within the enclosures from the regression relationships. Macroinvertebrates from the order gastropoda were not included in calculations of overall macroinvertebrate biomass because they did not represent a food resource for the YOY bluegill.

A 76 mm diameter tube sampler was used to sample zooplankton within the entire water column. Zooplankton were sampled at the beginning and end of the experiment, as well as weekly throughout the study. Two samples with the tube sampler were taken during each sampling event. Water depth was recorded for each sample for later calculation of water volume and zooplankton density. The samples were combined and filtered through an 80 μm filter, and preserved in 20 ml of a 90% ethanol solution. A 1 ml sedgewick rafter counting cell was used for counting zooplankton and estimating zooplankton density. Zooplankton within the counting cell were examined under a dissecting scope at 40x power, and classified as *Daphnia* spp., *Bosmina* spp., *Chydorus* spp., *Ceriodaphnia* spp., or calanoid, cyclopoid, or nauplii copepods according to Balcer et al. (1984). Rotifers and other species of small zooplankton were not counted. One ml aliquots were subsampled until a minimum of 100 zooplankton were counted. Body length of the first 20 zooplankton within a classification group was measured using a digitizing tablet according to procedures outlined in Culver et al. (1985). Once 100 zooplankton were counted the remainder of the counting cell was examined, and subsampling for that sample was discontinued. Body length-weight regression relationships from Culver et al. (1985) were used to calculate zooplankton biomass.

At the end of the experiment, August 19, 2002, seining was conducted to remove the stocked bluegill from the enclosures. The standard length of all fish was recorded, and fish were weighed to the nearest 0.0001 gram. Fish were preserved in a 90% ethanol solution. In the lab, the sagittal otolith was dissected and used to measure growth rates. An Optimas imaging system was used to measure the total radius of the otolith, and the radius of the otolith before the last seven, fourteen, and twenty-one rings were deposited. Growth rates of fish were calculated according to procedures for the body proportional hypothesis outlined in Francis (1990).

Stomachs were removed from the YOY bluegill for examination of diet. Dissected stomachs were weighed to the nearest 0.00001 gram, and contents of the stomachs were identified under a dissecting scope. Macroinvertebrates were identified to order, and head capsule width was measured with a digitizing tablet. Zooplankton were classified as cladocerans or copepods, and body length of zooplankton was measured using the digitizing tablet.

Experiment 2

A total of 18 enclosures were installed along the littoral edge of Pond 4, in areas of submersed vegetation and open water (9 enclosures each). Design of the enclosures was the same as for those used in experiment 1. The mean water depth where enclosures were installed was 49.8 cm, and ranged from 39 to 61 cm. Before stocking of fish, each enclosure was extensively seined to remove any fish that may have been inadvertently captured while the enclosures were installed. Enclosures were stocked with YOY bluegill (size ranged from 21 to 28 mm, standard length) from a local lake on August 21, 2002. Three randomly assigned enclosures in open water and submersed vegetation were stocked with 0, 5, or 15 YOY bluegill.

Following the sampling procedures detailed for experiment one, dissolved oxygen and temperature readings were taken each morning. Macroinvertebrates were sampled using a modified Gerking sampler at the beginning and end of the experiment. Zooplankton samples were taken with a tube sampler weekly. All macroinvertebrate and zooplankton samples were processed as described for experiment one.

Fish were harvested from the enclosures after 23 days on September 12, 2002. All fish were preserved in 90% ethanol solution. Standard length of all fish was measured to the nearest mm, and all fish were weighed to the nearest 0.0001 g. The diet and growth rates of all fish were sampled according to procedures outlined in experiment 1.

Data Analysis

Repeated Measures Analysis of Variance ($\alpha = 0.05$) was used to analyze differences in water temperature, dissolved oxygen, zooplankton and macroinvertebrate density, and biomass among the habitat types and fish densities over time (Littell et al. 1991). Analysis of Variance ($\alpha = 0.05$) was used to analyze differences in mean fish growth rates, stomach weights, and diet composition. All data analysis was done using the SAS system.

RESULTS

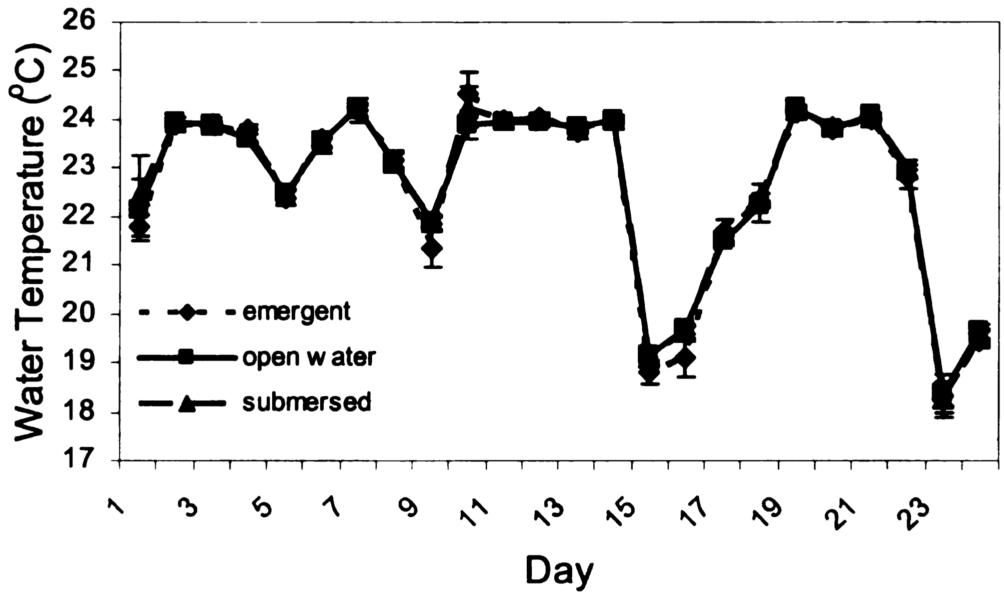
Experiment 1

Muskrat activity and low oxygen levels within the wetland resulted in the destruction of enclosures or loss of fish in three of the eight enclosures located in emergent vegetation, and two of the eight enclosures located in open water and submersed vegetation. As a result, all comparisons between enclosures with fish and those without fish were made by comparing only enclosures where bluegill were captured at the end of the experiment to enclosures that were not stocked with YOY bluegill.

WATER QUALITY

Water temperatures varied throughout the duration of experiment one, ranging from 17.3°C to 25.9°C, with an average water temperature of 22.7°C (Figure 3.1). Water temperatures were similar among habitat types on any given day ($F_{2,21} = 2.09$, $p = 0.1492$). Dissolved oxygen levels also varied daily throughout the experiment (Figure 3.1), ranging from 0.14 mg/l to 12.25 mg/l, with an average of 3.05 mg/l. Differences in dissolved oxygen concentrations among the habitat types were observed ($F_{2,21} = 29.13$, $p < 0.0001$), with highest concentrations in open water habitats, ranging from 0.47 to 9.91 mg/l, with an average of 3.76 mg/l. Submersed vegetation had the next highest oxygen concentrations, ranging from 0.49 to 10.31 mg/l, with an average of

A. Water Temperature



B. Dissolved Oxygen

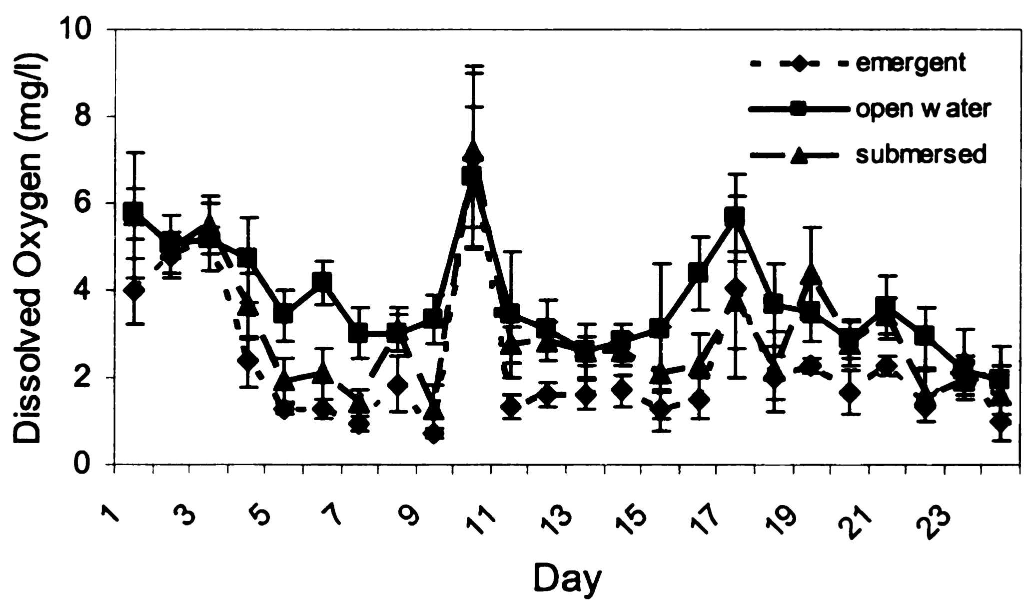


Figure 3.1: Water temperature (A) and dissolved oxygen concentration (B) (mean ± 2×standard error) in experiment one enclosures located in emergent vegetation, open water and submersed vegetation.

3.08 mg/l. Enclosures located in emergent vegetation had the lowest oxygen concentrations, ranging from 0.14 to 12.25 mg/l with an average of 2.31 mg/l.

ZOOPLANKTON

In general, the zooplankton communities were dominated by copepods (Figure 3.2). Nauplii made up the highest percentage by density of the zooplankton community, averaging 38.8%, while cyclopoid copepods averaged 21.2%, and calanoid copepods averaged 7.6%. The cladocerans were dominated by *Chydorus* spp. (12.6%), followed by *Ceriodaphnia* spp. (9.6%), *Daphnia* spp. (7.7%) and *Bosmina* spp. (2.5%). There was little difference in the percent contribution of each zooplankton taxa to overall zooplankton density over the course of the experiment (Figure 3.2).

Cladoceran density varied over time ($F_{5,16} = 5.82$, $p = 0.0030$) ranging from 0.02 to 1.53 cladocerans per cm^3 of water, with an average of 0.32 cladocerans per cm^3 of water (Figure 3.3). The pattern of variation in cladoceran density over time was not the same among all three habitat types ($F_{2,20} = 4.04$, $p = 0.0336$), and there were differences in overall cladoceran density among habitat types ($F_{10,32} = 2.19$, $p = 0.0456$). Submersed vegetation had higher densities than emergent ($t = 2.58$, $p = 0.0174$) or open water habitat ($t = 2.48$, $p = 0.0219$). There was no difference in cladoceran density among emergent vegetation and open water ($t = 0.11$, $p = 0.9164$). The pattern of variation

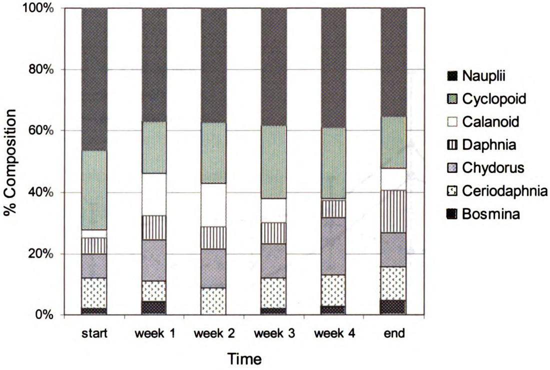
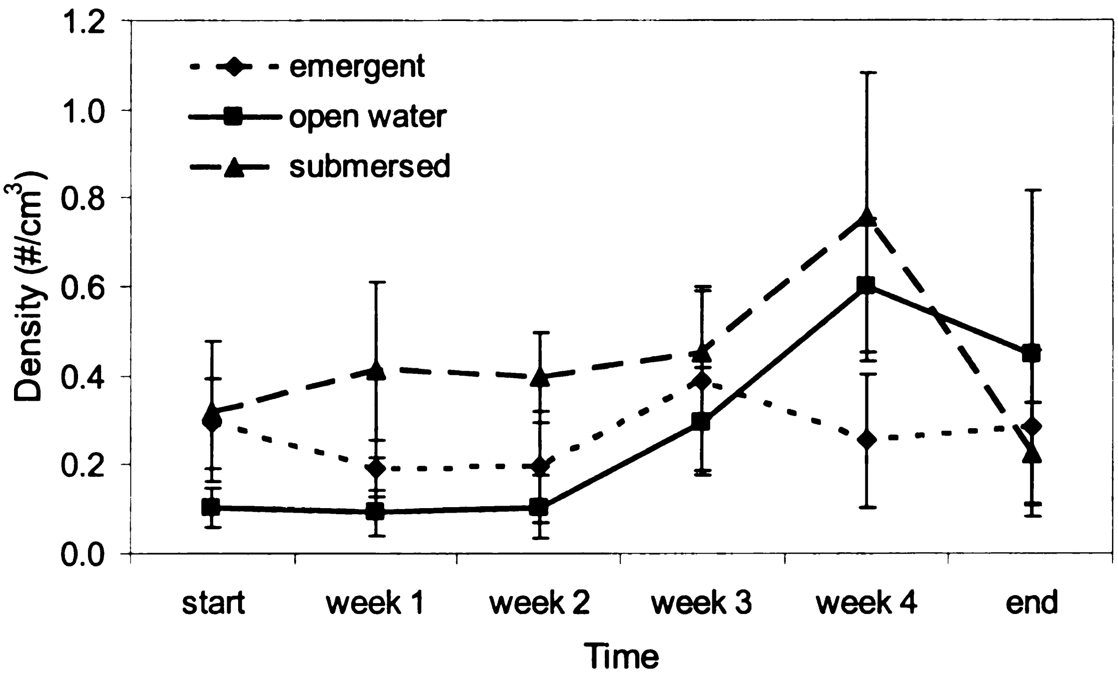


Figure 3.2: Taxonomic composition (by density) of zooplankton during experiment one.

A. Cladocerans



B. Copepods

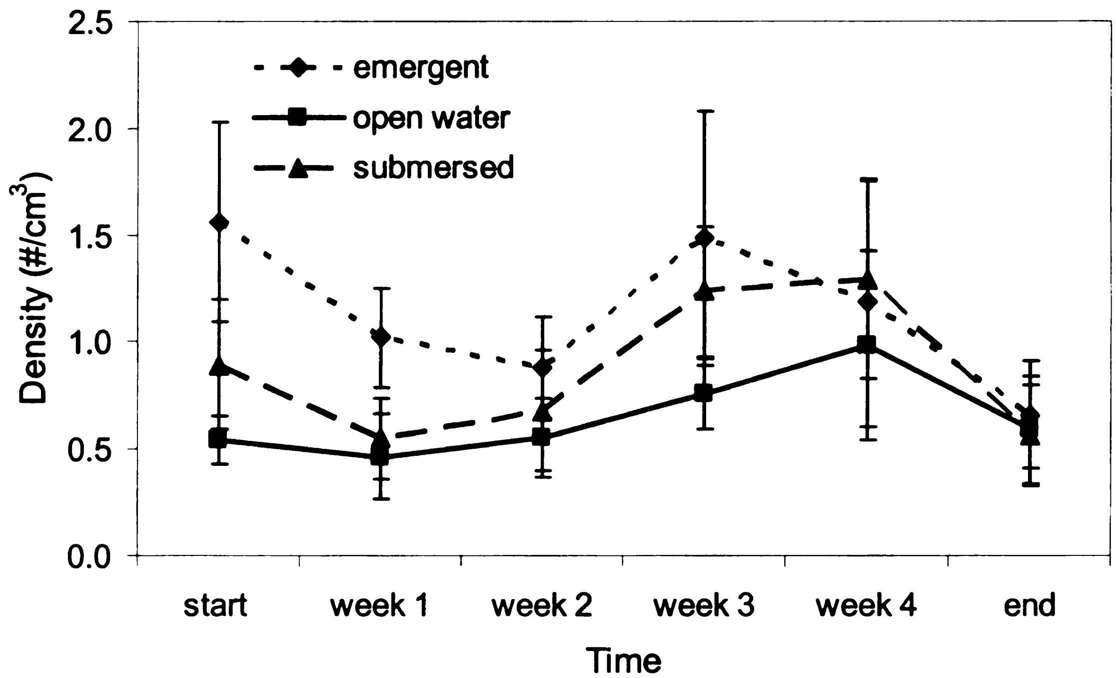


Figure 3.3: Density (mean ± 2× standard errors) of A) cladocerans and B) copepods sampled in enclosures in different habitat types in experiment one.

in cladoceran density over time was similar between enclosures where fish were present and absent ($F_{5,16}$ = 0.90, p = 0.5038), and overall cladoceran density did not differ between enclosures with and without fish ($F_{1,20}$ = 0.00, p = 0.9638).

The biomass of cladocerans (Figure 3.4), remained fairly constant over the duration of the experiment ($F_{5,16}$ = 1.86, p = 0.1583). The variation in cladoceran biomass over time was similar among habitats ($F_{10,32}$ = 1.14, p = 0.3639), and a similar amount of cladoceran biomass was found in all habitat types ($F_{2,20}$ = 2.47, p = 0.11031). No differences were found in how cladoceran biomass varied over time in enclosures with fish compared to those without ($F_{5,16}$ = 1.92, p = 0.1468), or in the overall amount of cladoceran biomass in enclosures with or without fish ($F_{1,20}$ = 0.02, p = 0.8779).

Copepod density varied over time ($F_{5,16}$ = 7.09, p = 0.0011), ranging from 0.107 to 2.83 copepods per ml of water, with an average of 0.882 copepods per ml of water (Figure 3.3). Although the pattern of variation in copepod density was similar among habitat types ($F_{10,32}$ = 1.49, p = 0.1876), there were differences in overall copepod density among habitats ($F_{2,20}$ = 4.42, p = 0.0258). With a mean of 1.134 copepods per ml of water, emergent vegetation had higher densities of copepods than open water (mean of 0.649) or submersed vegetation (mean of 0.870). Similar densities ($F_{1,20}$ = 1.03, p = 0.3234), and patterns of variation in copepod density over time ($F_{5,16}$ = 0.93, p = 0.4893) were found in enclosures with and without YOY bluegill.

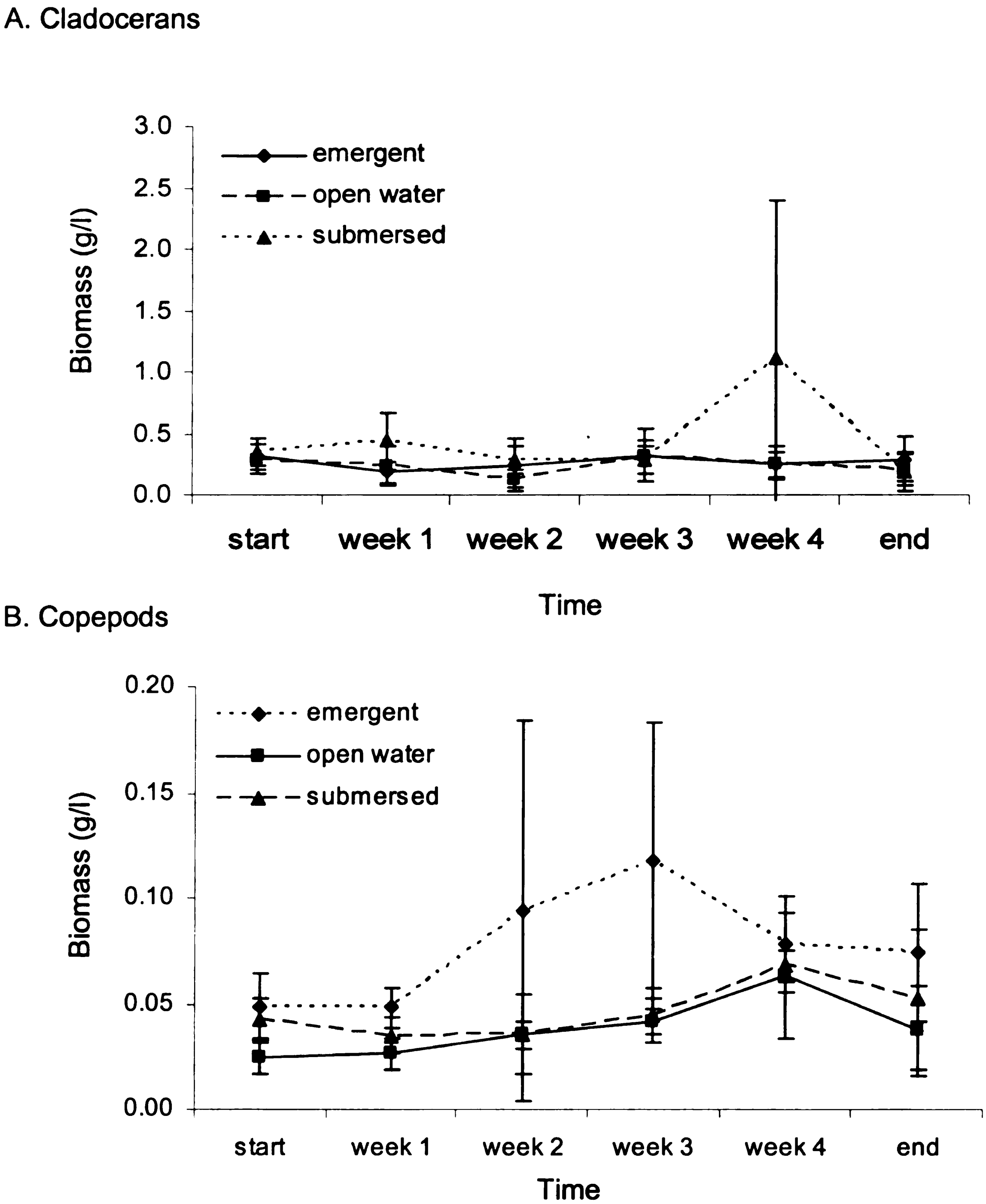


Figure 3.4: Biomass (mean µg/l ± 2× standard error) of A) cladocerans and B) copepods sampled in enclosures in different habitat types during experiment one.

Copepod biomass (Figure 3.4) varied over the duration of experiment one ($F_{5,16}$ = 9.00, p = 0.0003), in a similar pattern among the different habitat types ($F_{10,32}$ = 0.70, p = 0.7189). However, with a mean of 0.078 ± 0.070 g/l, there was a greater biomass of copepods ($F_{2,20}$ = 7.06, p = 0.0048) sampled in emergent vegetation than in open water (0.038 ± 0.027 g/l) or submersed vegetation (0.046 ± 0.024 g/l). Similar patterns in variation of copepod biomass over time ($F_{5,16}$ = 0.62, p = 0.6862) were found in enclosures with and without fish. Additionally, no differences were found in copepod biomass between enclosures with and without fish ($F_{1,20}$ = 0.01, p = 0.9354).

MACROINVERTEBRATES

Macroinvertebrates from twelve different taxa were sampled from experiment one enclosures (Table 3.1). Overall, macroinvertebrates were dominated by gastropods and hemipterans; however, ephemeroptera and odonates were also abundant. Several taxa were only found in the emergent vegetation habitat type, including amphipoda and aranea. There was only one taxon, coleoptera, which was present in open water or submersed vegetation habitat and not in emergent vegetation.

Macroinvertebrate densities were similar at the beginning and end of the experiment ($F_{1,20}$ = 0.26, p = 0.6140), averaging 440 macroinvertebrates/m^3 at the start of experiment one, and 403 macroinvertebrates/m^3 at the end of experiment one (Figure 3.5). There were no differences in the pattern of change in macroinvertebrate density from the start to the end of the experiment in

Table 3.1: Mean density (#/m^3 ± standard deviation) of macroinvertebrates from different taxonomic groupings sampled in experiment one enclosures located in different habitat types. Where amp = amphipoda, ara = aranea, col = coleoptera, com = collembola, dec = decapoda, dip = diptera, eph = ephemeroptera, gas = gastropoda, hem = hemiptera, hir = hirudinea, odo = odonata, and tri = trichoptera.

	Amp	Ara	Col	Com	Dec	Dip	Eph	Gas	Hem	Hir	Odo	Tri
Emergent	12±46	27±60	0	5±21	3±14	10±28	43±78	255±285	111±102	102±112	19±37	23±54
Open water	0	0	5±21	0	5±14	0	54±107	31±68	129±129	3±12	23±39	3±11
Submersed	0	0	6±16	0	0	36±77	25±34	136±164	68±93	16±27	90±102	25±44

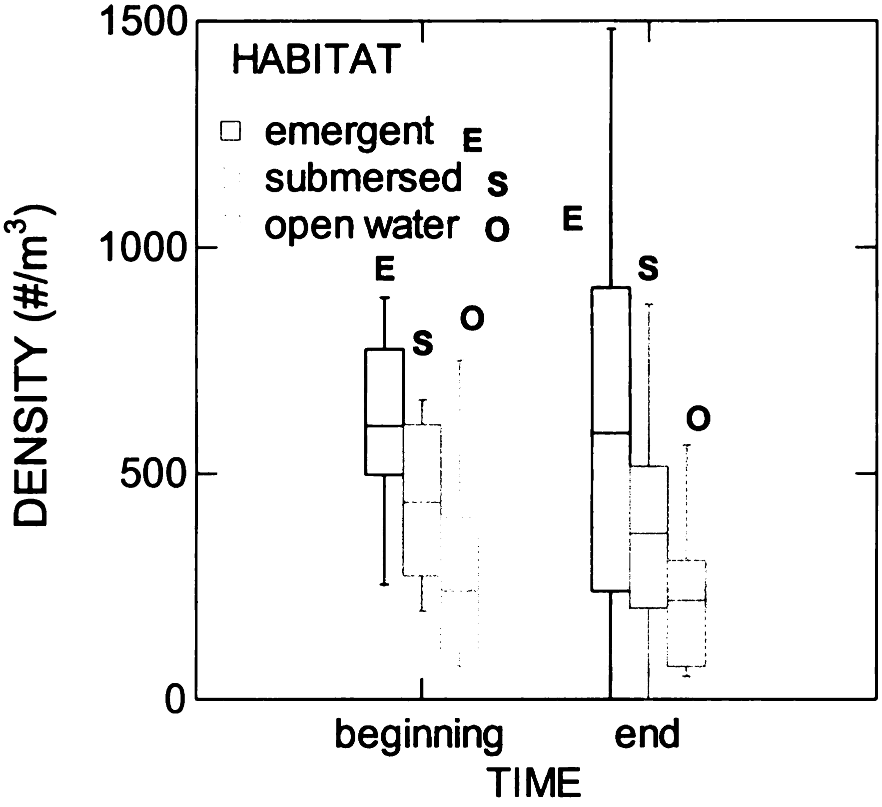


Figure 3.5: Density of macroinvertebrates sampled in enclosures from different habitats at the beginning and end of experiment one.

enclosures located in different habitats ($F_{2,20}$ = 0.16, p = 0.8550), or in enclosures with or without YOY bluegill ($F_{1,20}$ = 0.15, p = 0.7034). However, with a mean of 610 macroinvertebrates/m^3, there was a higher density of macroinvertebrates ($F_{2,20}$ = 5.06, p = 0.0166) in emergent vegetation habitat then in open water (252 macroinvertebrates/m^3) or submersed vegetation (408 macroinvertebrates/m^3). There was not a difference in the density of macroinvertebrates in enclosures with YOY bluegill compared to those without YOY bluegill ($F_{1,20}$ = 1.57, p = 0.2243).

Macroinvertebrate biomass ranged from a mean of 0.814 ± 0.311 mg /l at the start of the experiment, to 0.283 mg/l at the end of the experiment (Figure 3.6); however, this difference was not statistically significant ($F_{1,20}$ = 4.33, p = 0.0506). Additionally, the pattern of macroinvertebrate biomass measured at the beginning to the end of the experiment was similar in each of the habitats ($F_{2,20}$ = 1.70, p = 0.2072) and in enclosures with and without YOY bluegill ($F_{1,20}$ = 1.37, p = 0.2549). Similar amounts of macroinvertebrate biomass were measured in enclosures from all habitat types ($F_{2,20}$ = 1.69, p = 0.2105), and enclosures with or without fish ($F_{1,20}$ = 0.78, p = 0.3872).

FISH GROWTH

The mean growth rate of fish within an enclosure ranged from 0.347 mm/day to 0.700 mm/day with an overall mean of 0.523 ± 0.103 mm/day (Figure 3.7). With a mean growth rate of 0.271 mm/day, bluegill from enclosures with emergent vegetation had slower growth rates ($F_{2,8}$ = 11.046, p = 0.005) than

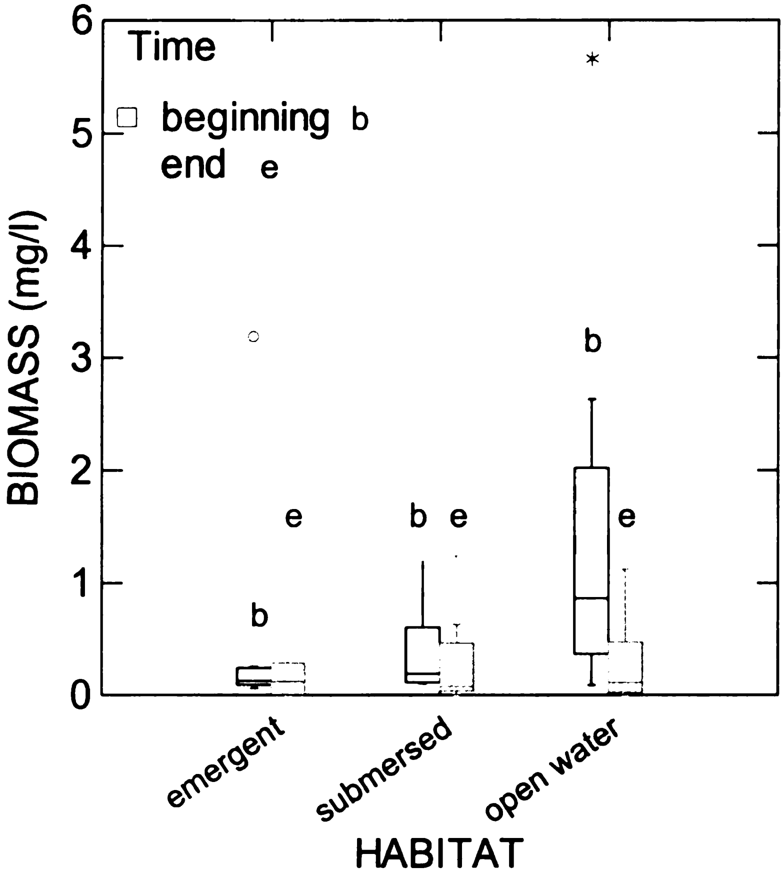


Figure 3.6: Biomass (mg/l) of macroinvertebrates at the beginning and end of experiment one, sampled in enclosures located in emergent vegetation, open water, and submersed vegetation habitat.

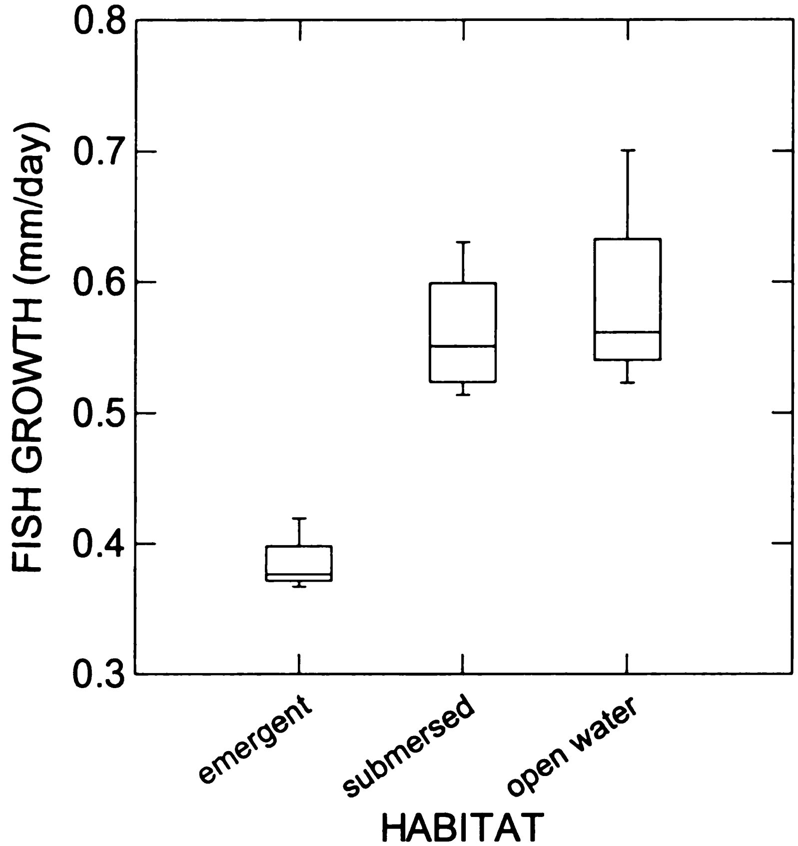


Figure 3.7: Growth (mm/day) of YOY bluegill in experiment one enclosures located in different habitat types.

bluegill from enclosures located in open water (mean = 0.410 mm/day) or submersed vegetation habitats (mean = 0.393 mm/day).

FISH DIET

Weights of YOY bluegill stomachs ranged from a low of 0.02304 g to 0.11811 g (Figure 3.8). Stomach weight was similar among fish harvested from enclosures located in different habitats ($F_{2,8}$ = 0.117, p = 0.891).

The diet of bluegill in all habitat types was numerically dominated by zooplankton, both cladocerans and copepods (Figure 3.9). However, the main contributors to biomass within the stomachs of bluegill were macroinvertebrates, with high amounts of diptera and ephemeroptera biomass consumed (Figure 3.9). To compare bluegill diet among habitat types, prey items were grouped as macroinvertebrates and zooplankton (Figure 3.10). There was a significant difference in the biomass of zooplankton within the stomachs of fish from open water enclosures compared to other habitat types ($F_{2,8}$ = 4.750, p = 0.044). With a mean zooplankton biomass of 81 μg per stomach, there was a greater amount of zooplankton biomass dissected from the stomach's of bluegill from open water habitat than from emergent or submersed vegetation (means = 25 and 22 μg per stomach respectively). With a mean of 171 μg per stomach, there was less macroinvertebrate biomass ($F_{2,8}$ = 5.236, p = 0.035) in the stomachs of bluegill from open water enclosures than from submersed or emergent enclosures (means were 537 and 769 μg per stomach respectively).

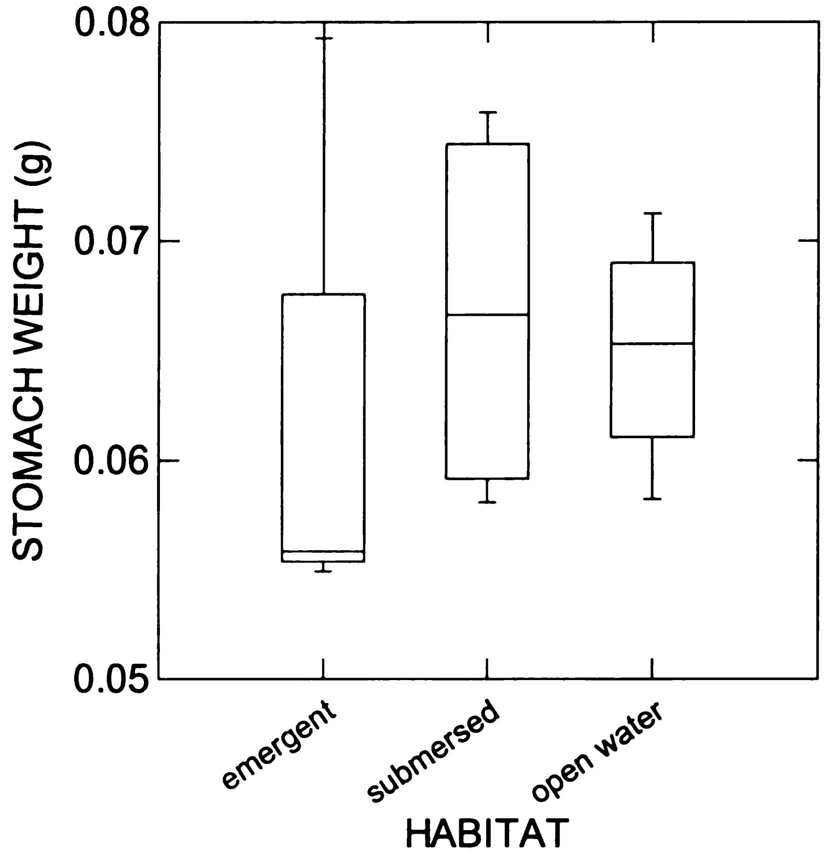
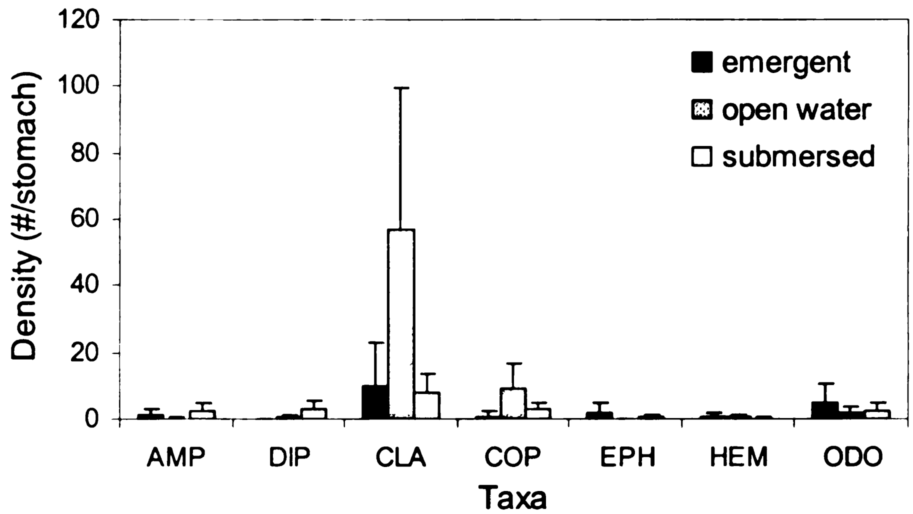


Figure 3.8: Comparison of YOY bluegill stomach weight (g) among different habitat types in experiment one.

A. Density



B. Biomass

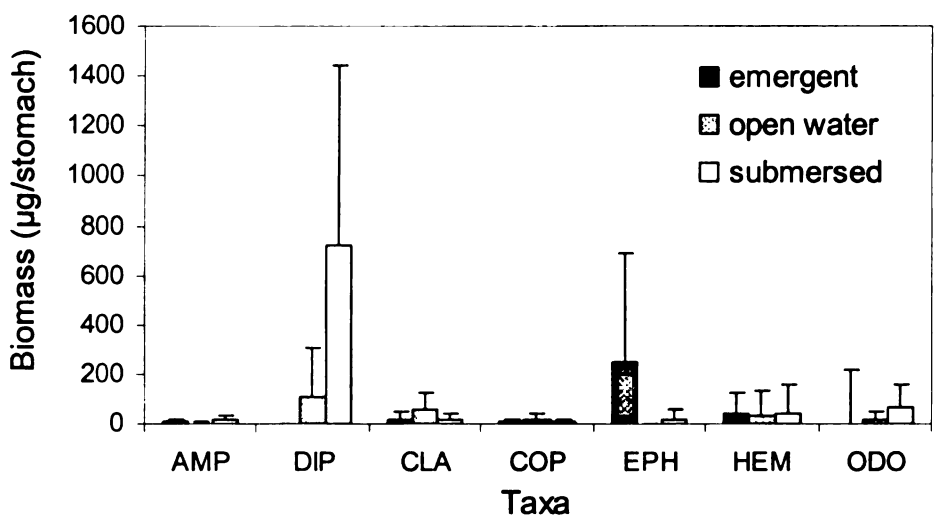
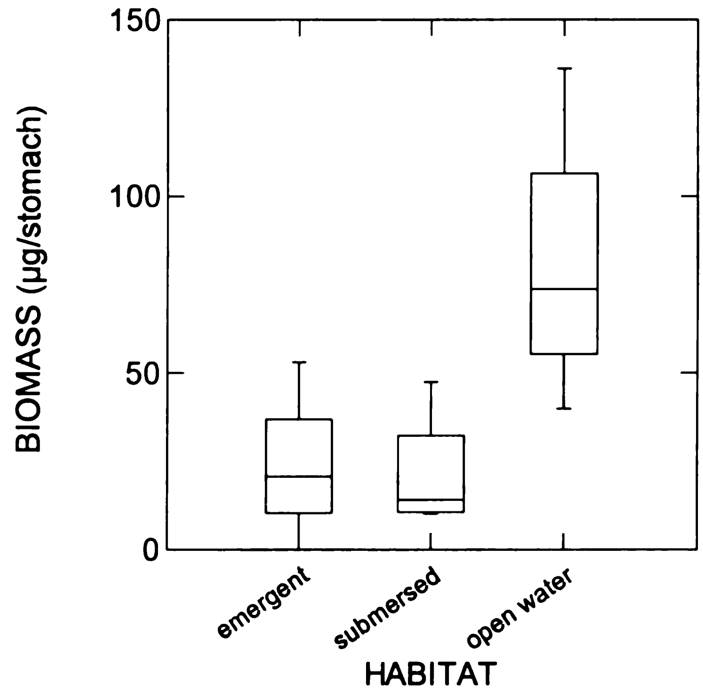


Figure 3.9: Density (mean # / stomach ± 2×standard error) (A) and biomass (mean µg / stomach ± 2 standard error) (B) of organisms dissected from stomachs of bluegill in experiment one enclosures from different habitats. Where AMP = amphipoda, DIP = diptera, CLA = cladocera, COP = copepod, EPH = ephemeroptera, HEM = hemiptera, and ODO = odonata.

A. Zooplankton



B. Macroinvertebrates

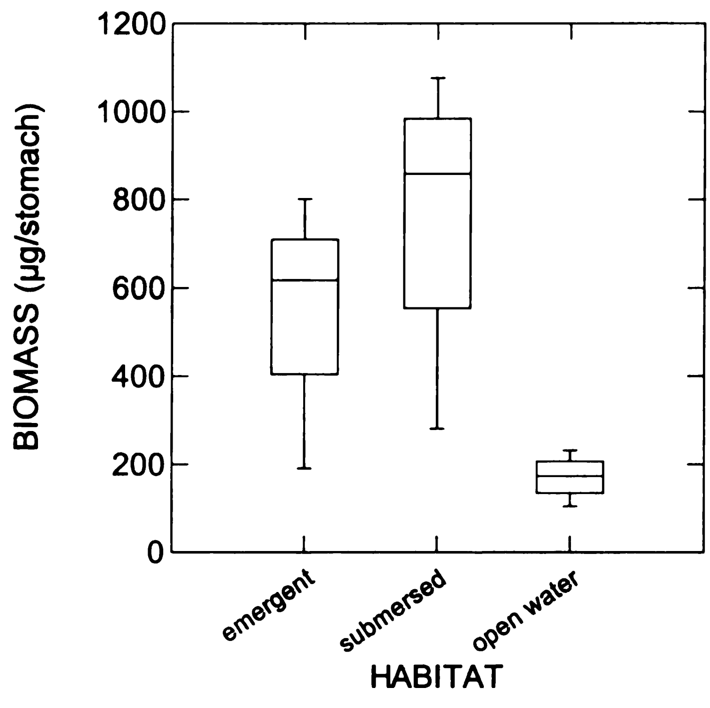


Figure 3.10: Biomass of A) zooplankton and B) macroinvertebrates dissected from bluegill stomachs in experiment one enclosures located in different habitats.

Experiment 2

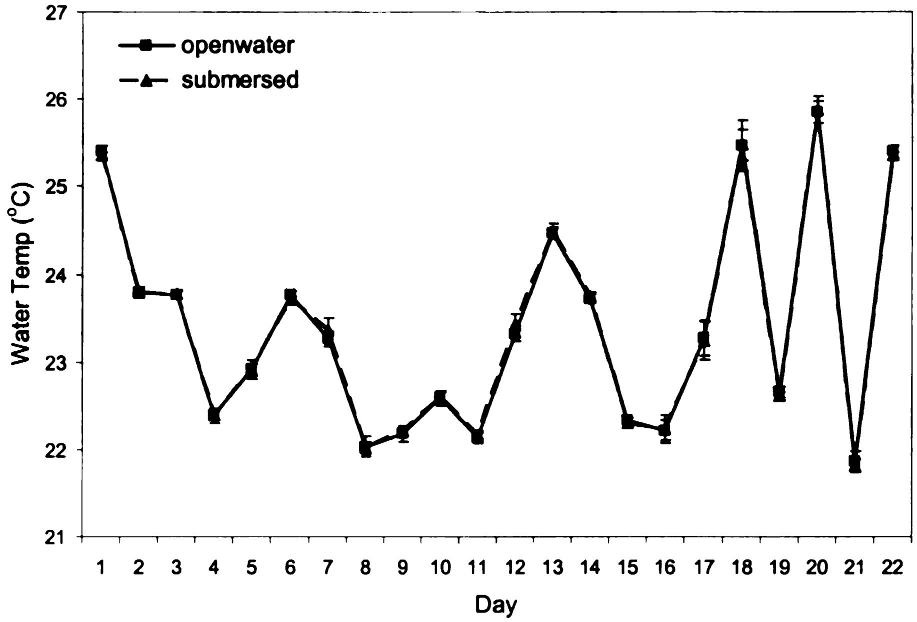
WATER QUALITY

Water temperatures varied throughout the duration of experiment two, ranging from a low of 21.8°C to a high of 25.9°C, with an average water temperature of 23.4°C (Figure 3.11). However, on any given day during the experiment, the water temperature in submersed vegetation and open water enclosures was similar ($F_{1,16} = 0.02$, $p = 0.8945$). Dissolved oxygen concentrations also varied daily throughout the experiment (Figure 3.11), ranging from a low of 2.43 mg/l to a high of 10.11 mg/l, with an average of 6.15 mg/l. Mean oxygen concentrations were similar ($F_{1,16} = 4.29$, $p = 0.0549$) in open water (6.41 mg/l) and submersed vegetation habitats (5.89 mg/l) throughout the study.

ZOOPLANKTON

In general, the zooplankton communities within the enclosures were dominated by copepods (Figure 3.12). Nauplii had the highest density in all habitats and levels of fish density, followed by cyclopoid and calanoid copepods. The cladoceran community was dominated by *Daphnia* spp., *Chydorus* spp., and *Bosmina* spp., with very few *Ceriodaphnia* spp (Figure 3.12). There was little difference in the composition or relative contribution of different zooplankton taxa to the total density of zooplankton over the course of the experiment.

A. Water Temperature



B. Dissolved Oxygen

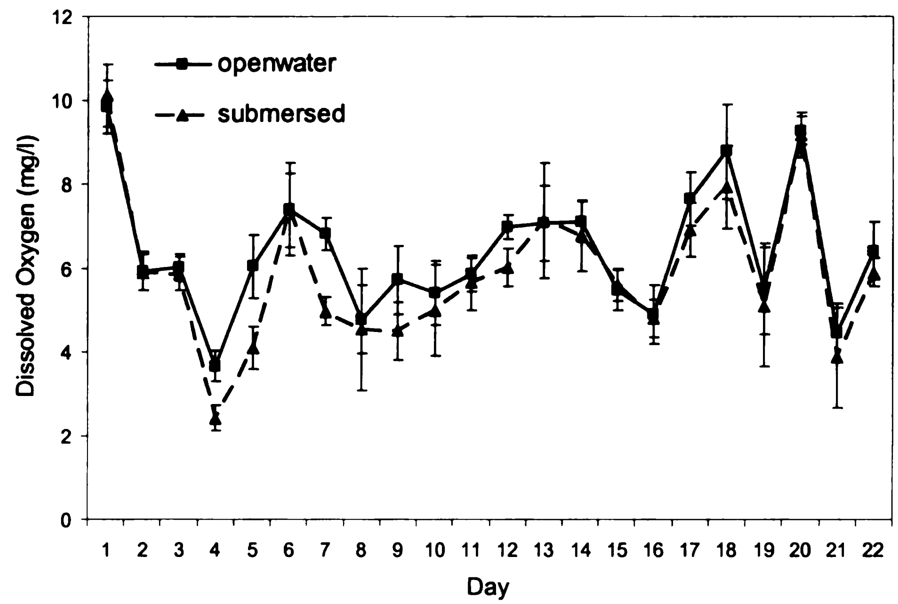


Figure 3.11: Water temperature (A) and dissolved oxygen concentration (B) (mean ± 2×standard error) in experiment two enclosures located in open water and submersed vegetation.

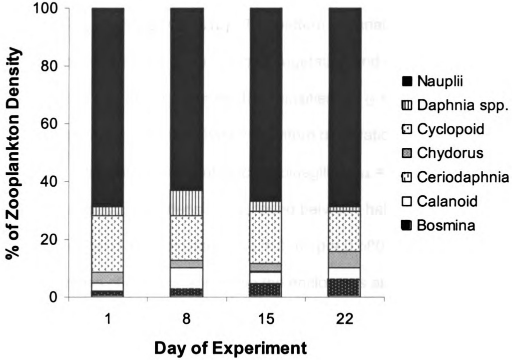


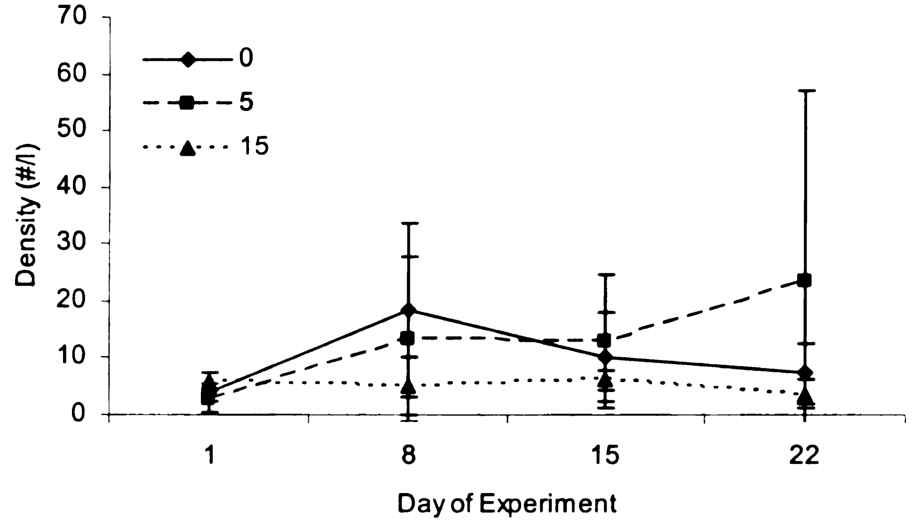
Figure 3.12: Taxonomic composition (by density) of zooplankton during experiment two.

Cladoceran density varied little over the duration of experiment two (Figure 3.13, $F_{3,12} = 1.85$, $p = 0.1918$). The pattern in variation of cladoceran density over time was similar in submersed vegetation and open water ($F_{3,12} = 0.61$, $p = 0.6228$), and among different fish densities ($F_{3,12} = 0.36$, $p = 0.7844$). Additionally, habitat type did not affect the pattern of variation in cladoceran density among different densities of stocked bluegill ($F_{1,14} = 4.19$, $p = 0.0599$). Little variation in cladoceran density was found between habitat types ($F_{1,14} = 1.38$, $p = 0.2593$), and fish densities ($F_{1,14} = 0.32$, $p = 0.5808$).

The biomass of cladocerans within the enclosures also varied over time (Figure 3.14, $F_{3,13} = 3.81$, $p = 0.0370$). The pattern in change of cladoceran biomass over time was similar between open water and submersed vegetation ($F_{3,13} = 0.70$, $p = 0.5677$), and overall biomass was similar between the two habitats ($F_{1,15} = 0.08$, $p = 0.7767$). Changes in cladoceran biomass over time varied among fish densities ($F_{3,13} = 4.04$, $p = 0.0311$), although overall biomass was similar among enclosures stocked with 0, 5, or 15 YOY bluegill ($F_{1,15} = 0.55$, $p = 0.4716$).

Copepod density was fairly constant during experiment two (Figure 3.15, ($F_{3,12} = 0.86$, $p = 0.4881$), with both habitats ($F_{3,12} = 1.28$, $p = 0.3243$) and all levels of fish density ($F_{3,12} = 0.70$, $p = 0.5725$) showing similar patterns in variation in copepod density over time. Additionally, habitat type did not affect the pattern of variation in copepod density among different densities of stocked bluegill ($F_{1,14} = 0.66$, $p = 0.4287$). There were similar densities of copepods in

A. Open Water



B. Submersed Vegetation

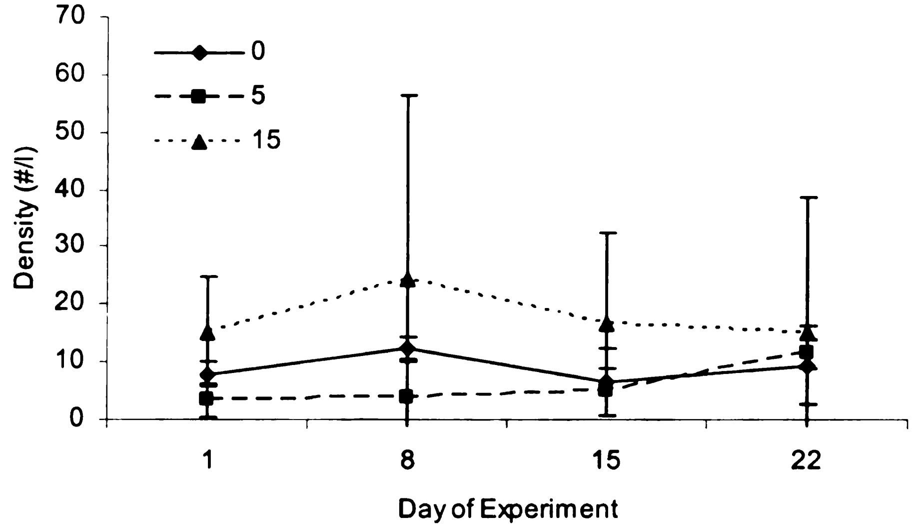
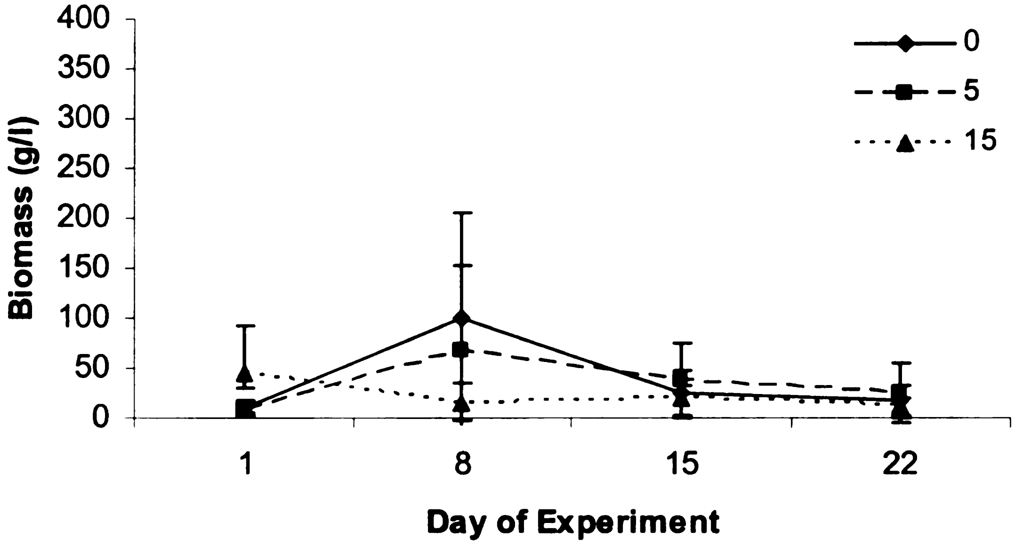


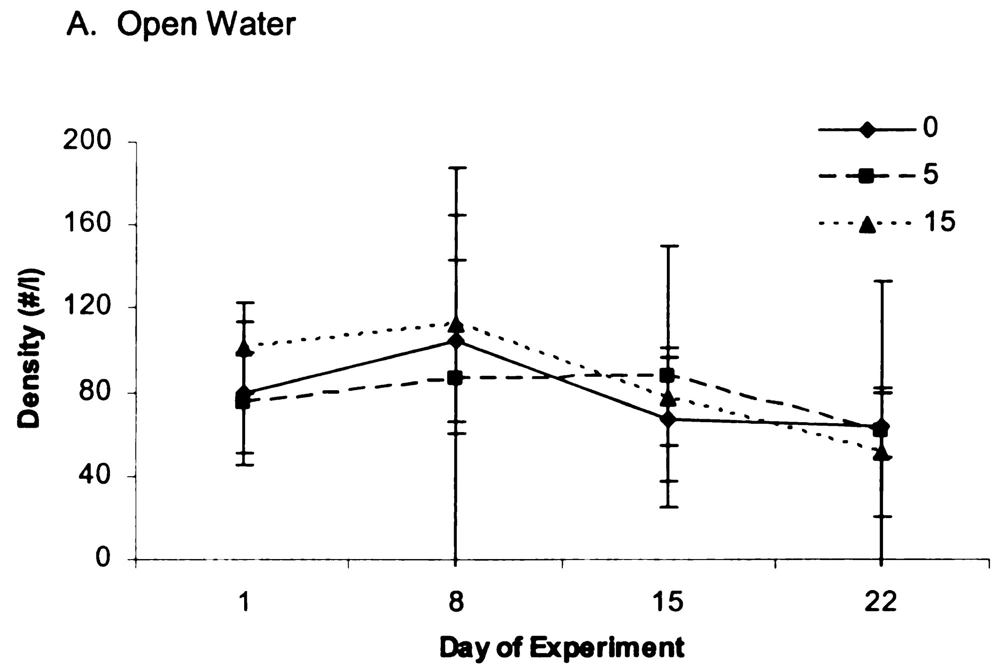
Figure 3.13: Mean density (#/l ± 2×standard error) of cladocerans in enclosures located in A) open water and B) submersed vegetation during experiment two.

A. Open water



B. Submersed Vegetation

Figure 3.14: Biomass (mean ± 2×standard error g/l) of cladocerans sampled in enclosures stocked with different densities of bluegill in A) open water and B) submersed vegetation during experiment two.



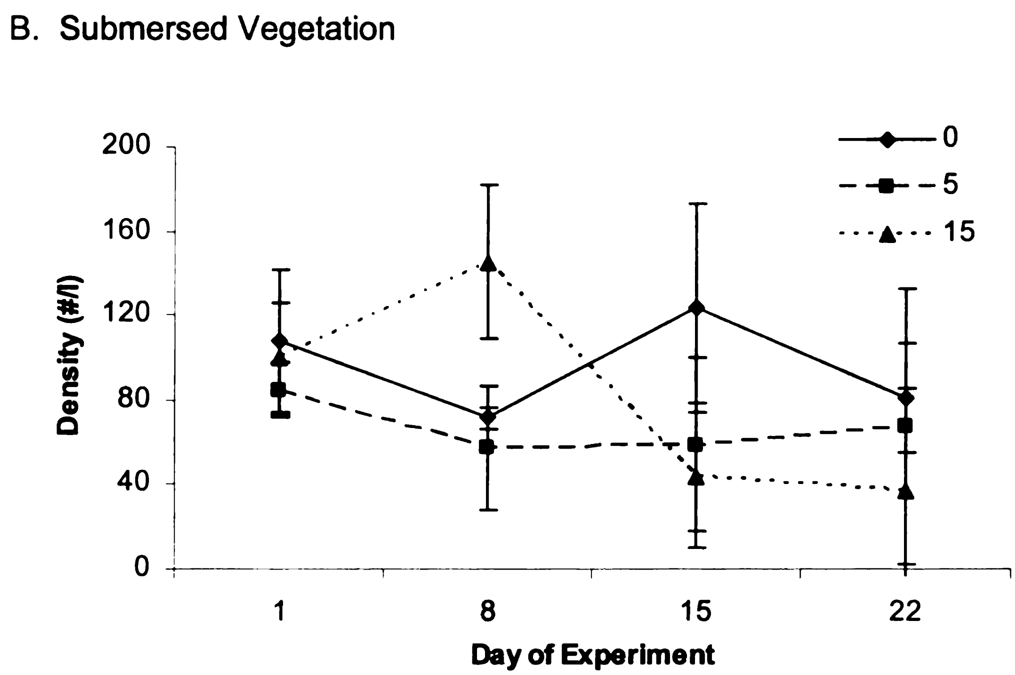


Figure 3.15: Mean density (#/l ± 2×standard error) of copepods in enclosures located in A) open water and B) submersed vegetation during experiment two.

enclosures located in different habitats ($F_{1,14}$ = 0.05, p = 0.8234) and with different densities of bluegill ($F_{1,14}$ = 0.06, p = 0.8126).

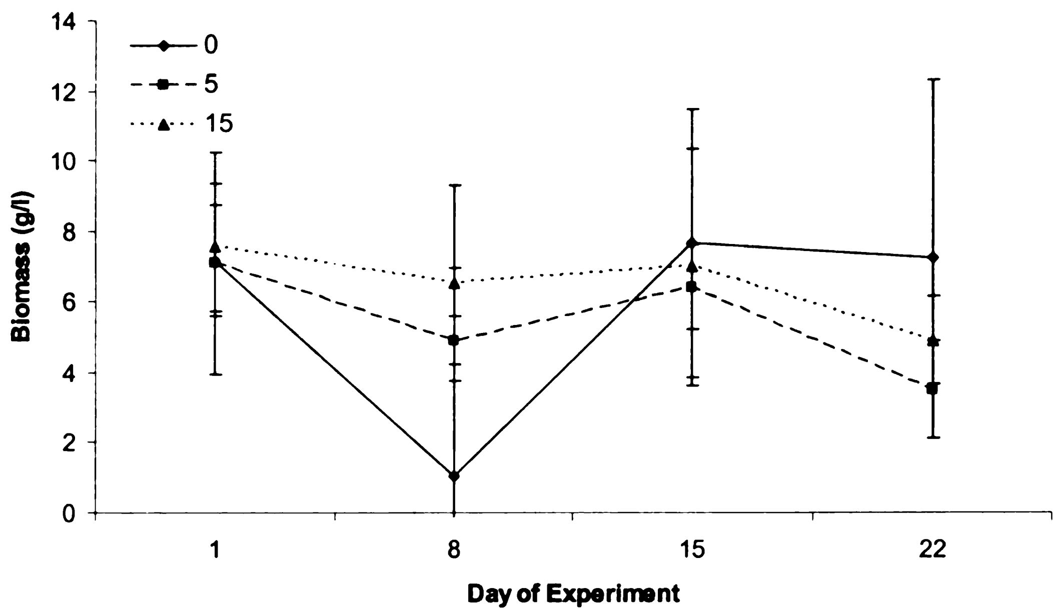
The biomass of copepods varied little over the duration of experiment two (Figure 3.16, $F_{3,13}$ = 0.59, p = 0.6349). Patterns in variation of copepod biomass were similar among the different habitat types ($F_{3,13}$ = 1.34, p = 0.3055) and stocked densities of fish ($F_{3,13}$ = 0.42, p = 0.7412). Copepod biomass was similar in submersed vegetation and open water ($F_{1,15}$ = 0.13, p = 0.7228), and in enclosures stocked with different densities of YOY bluegill ($F_{1,15}$ = 0.64, p = 0.4347).

MACROINVERTEBRATES

Macroinvertebrates from eight different taxa were sampled from experiment two enclosures (Table 3.2). Macroinvertebrates were dominated by trichoptera; however, odonata and ephemeroptera were also abundant. Two taxa, gastropoda and hemiptera, were sampled only in enclosures that were not stocked with fish.

Macroinvertebrate density (Figure 3.17) was similar at the beginning and end of experiment two (means = 70 ± 131 and 56 ± 102 macroinvertebrates / m^3 respectively, $F_{1,14}$ = 0.15, p = 0.7014). The pattern of change in macroinvertebrate density over time was the same for both habitat types ($F_{1,14}$ = 0.03, p = 0.8544), all levels of fish density ($F_{2,14}$ = 0.69, p = 0.5173), and among habitats and fish densities ($F_{2,12}$ = 0.62, p = 0.5529). With a mean of

A. Open Water



B. Submersed Vegetation

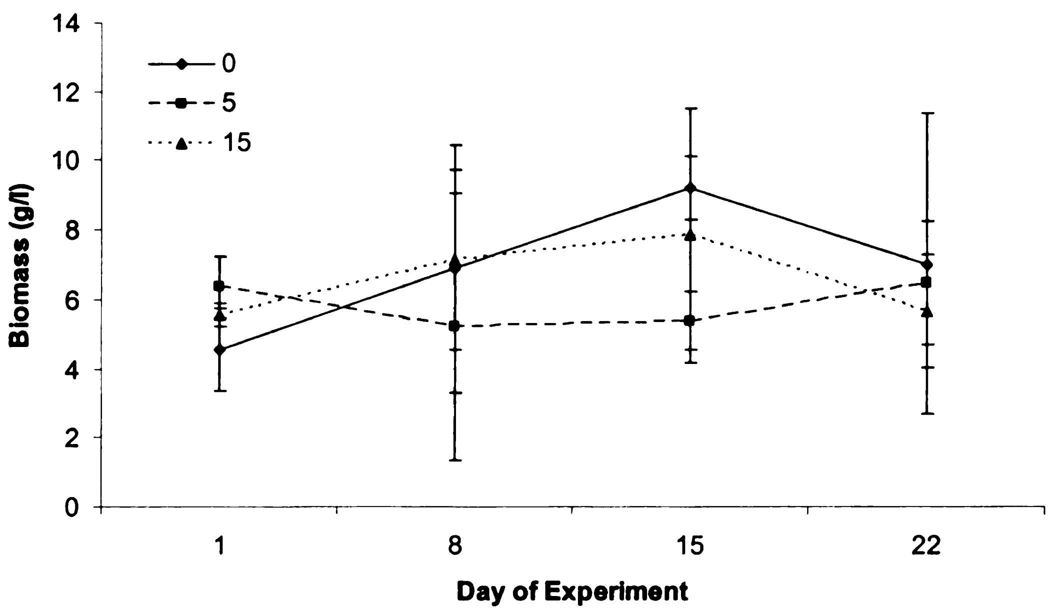


Figure 3.16: Mean biomass (g/l ± 2×standard error) of copepods in enclosures located in A) open water and B) submersed vegetation during experiment two.

Table 3.2: Mean density (#/m^3 ± standard deviation) of macroinvertebrates from different taxonomic groupings sampled in experiment two enclosures located in different habitat types, with different fish densities. Where col = collembola, dec = decapoda, dip = diptera, eph = ephemeroptera, gas = gastropoda, hem = hemiptera, odo = odonata, and tri = trichoptera.

	Col	Dec	Dip	Eph	Gas	Hem	Odo	Tri
Open, 0	0	0	0	0	0	0	0	14 + 25
Open, 5	0	0	0	0	0	0	0	12 ± 20
Open, 15	0	0	0	26 ± 23	0	0	13 ± 22	0
Sub, 0	0	0	0	9 ± 22	16± 30	6 ± 17	20 ± 36	12 ± 35
Sub, 5	7 ± 18	0	11 ± 30	9 ± 27	0	0	15 ± 28	120 ± 225
Sub, 15	11 ± 30	34 ± 96	0	17 ± 48	0	0	6 ± 17	55 ± 61

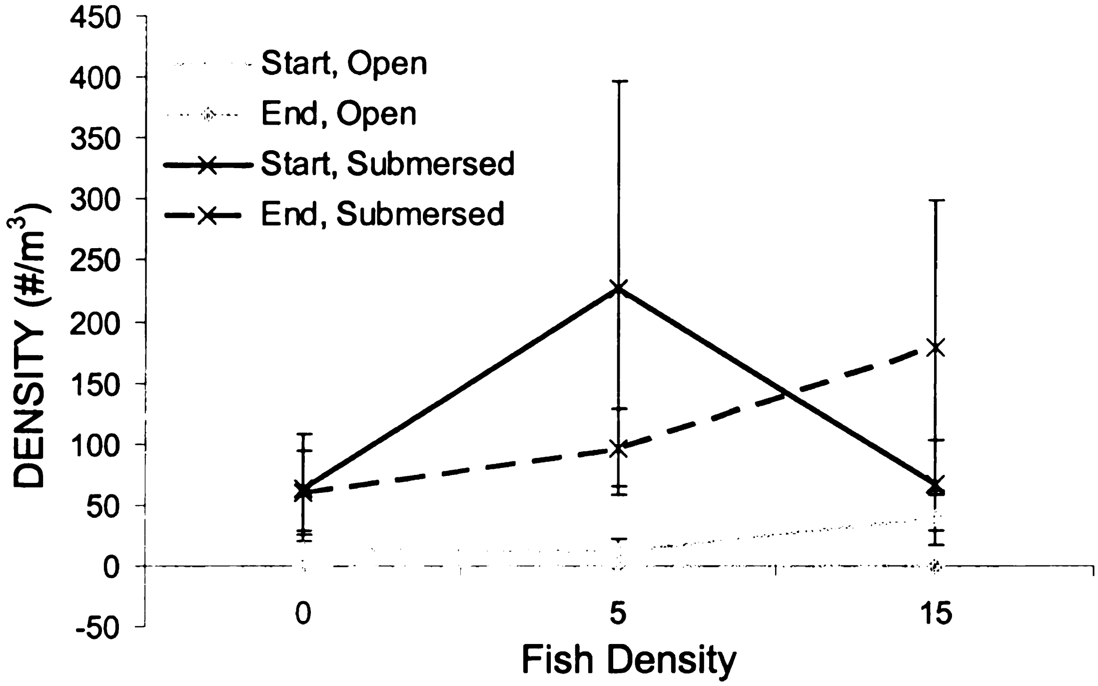


Figure 3.17: Density of macroinvertebrates (#/m^3) at the beginning and end of experiment two sampled in open water and submersed vegetation enclosures stocked with different densities of YOY bluegill.

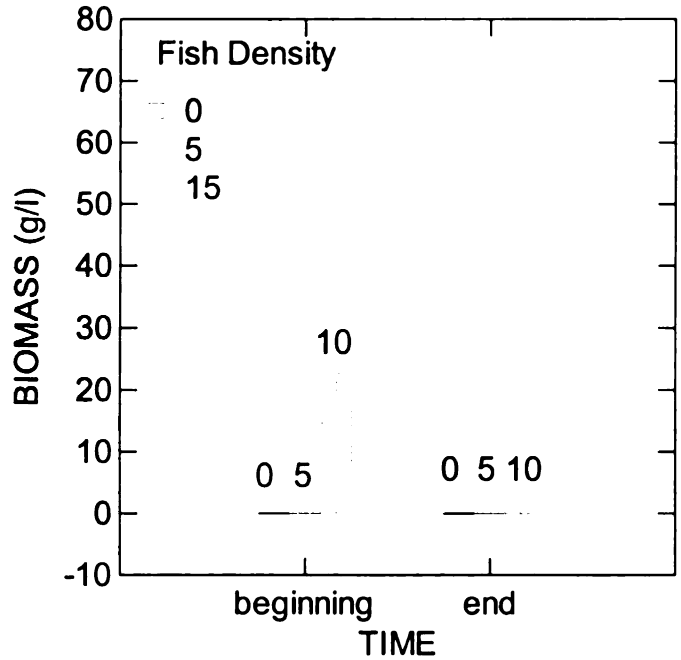
7 macroinvertebrates / m^3, a lower density of macroinvertebrates was sampled in enclosures located in open water than in submersed vegetation (mean = 115 macroinvertebrates / m^3, $F_{1,14} = 8.39$, $p = 0.0117$). Macroinvertebrate densities were similar in enclosures stocked with 0, 5, or 15 YOY bluegill ($F_{2,14} = 0.67$, $p = 0.5265$).

Macroinvertebrate biomass (Figure 3.18) was similar at the beginning (mean = 12.3 ± 21.7 g/l) and end (mean = 2.5 ± 4.2 g/l) of experiment two ($F_{1,15} = 3.74$, $p = 0.0722$). Similar patterns in variation of macroinvertebrate biomass over time were found in both habitat types ($F_{1,15} = 1.70$, $p = 0.2114$) and all levels of fish density ($F_{1,15} = 0.27$, $p = 0.6100$). No differences were found in macroinvertebrate biomass among different habitat types ($F_{1,15} = 3.62$, $p = 0.0765$), or enclosures with different densities of fish ($F_{1,15} = 0.76$, $p = 0.3984$).

FISH GROWTH

All stocked fish were recovered from the enclosures, with the exception of one of the open water enclosures where only 13 of the 15 stocked fish were recovered. Mean fish growth rates of enclosures ranged from 0.269 to 0.410 mm/day, with a mean of 0.327 mm/day (Figure 3.19). Slower growth rates were observed in enclosures stocked with higher densities of YOY bluegill ($F_{1,9} = 8.91$, $p = 0.0153$). No differences were observed in overall mean growth rates of YOY bluegill among the two habitat types ($F_{1,9} = 0.26$, $p = 0.6210$); however, at a density of 15 fish per square meter, YOY bluegill grew better in submersed vegetation habitat compared to open water habitat ($F_{1,4} = 8.15$, $p = 0.0462$).

A. Open Water



B. Submersed Vegetation

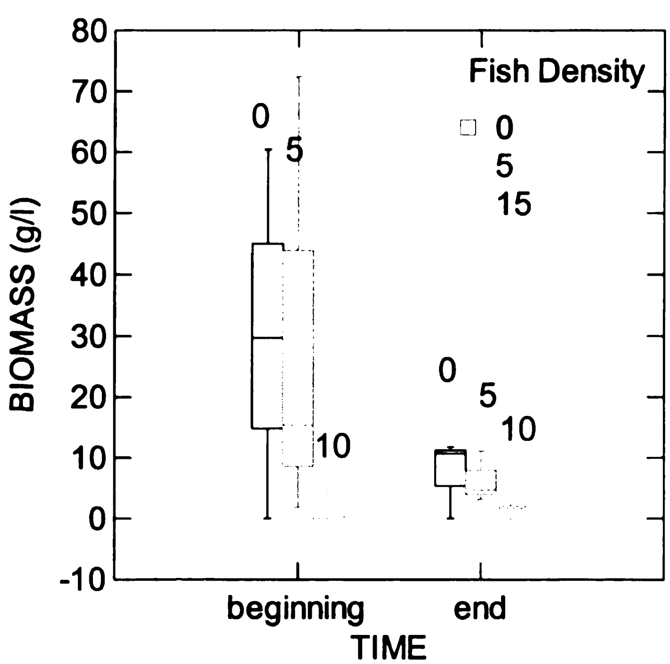


Figure 3.18: Mean biomass (g/l ± 2×standard error) of macroinvertebrates in enclosures located in A) open water and B) submersed vegetation during experiment two.

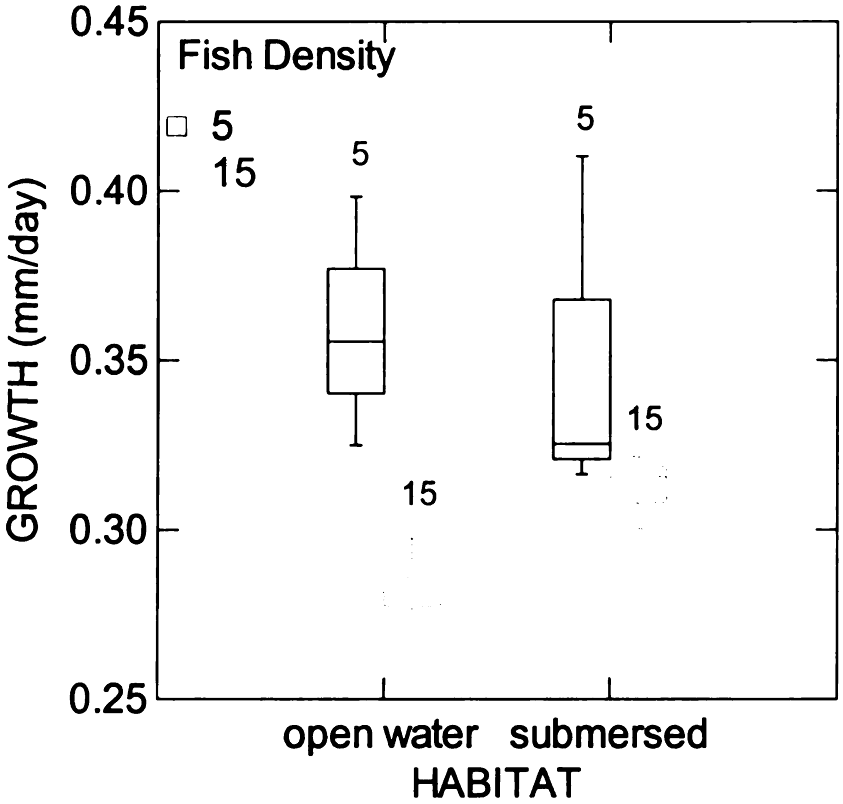


Figure 3.19: Growth of YOY bluegill (mm/day) in experiment two enclosures located in different habitats, and stocked with different densities of fish.

FISH DIET

Weights of bluegill stomachs ranged from 0.00347 g to 0.09146 g (Figure 3.20). There were no differences observed in the way stomach weight varied with fish density between open water and submersed vegetation ($F_{1,8} = 2.26$, $p = 0.1708$). Bluegill stomach weights were similar in both habitats ($F_{1,9} = 0.16$, $p = 0.6991$), and fish densities ($F_{1,9.} = 0.30$, $p = 0.5945$).

The diet of bluegill in all habitat types was numerically dominated by zooplankton, both cladocerans and copepods (Table 3.3). Macroinvertebrates from the order Diptera were also abundant within the bluegill stomachs, with means raging from 5 to 12 dipterans per stomach.

The main contributor to biomass within the stomachs of bluegill was macroinvertebrates from the order Diptera (Table 3.4). Cladocerans and copepod zooplankton, and macroinvertebrates from the order Odonata also made up high proportions of the biomass of items within bluegill stomachs, when compared to Ephemeroptera and Hemiptera.

To compare bluegill diet among habitat types, prey items were classified as macroinvertebrates and zooplankton. Mean zooplankton biomass in bluegill from different enclosures ranged from 3.8 to 53 µg per stomach (Figure 3.21). No interaction between habitat and fish density in predicting the biomass of zooplankton within the bluegill stomachs was observed ($F_{1,8} = 0.14$, $p = 0.7196$). Additionally, no differences in zooplankton biomass in the stomachs of bluegill harvested from enclosures located in different habitat types ($F_{1,9} = 0.12$, $p = 0.7359$) or different fish densities ($F_{1,9} = 0.19$, $p = 0.6743$) were observed.

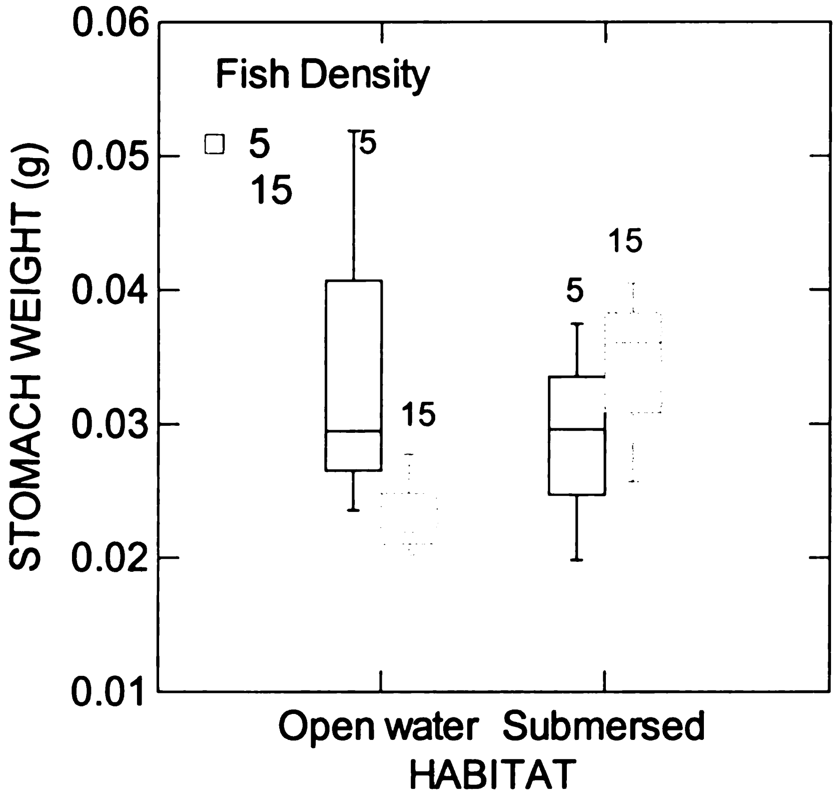


Figure 3.20: Stomach weights (g) from harvested bluegill within experiment two enclosures.

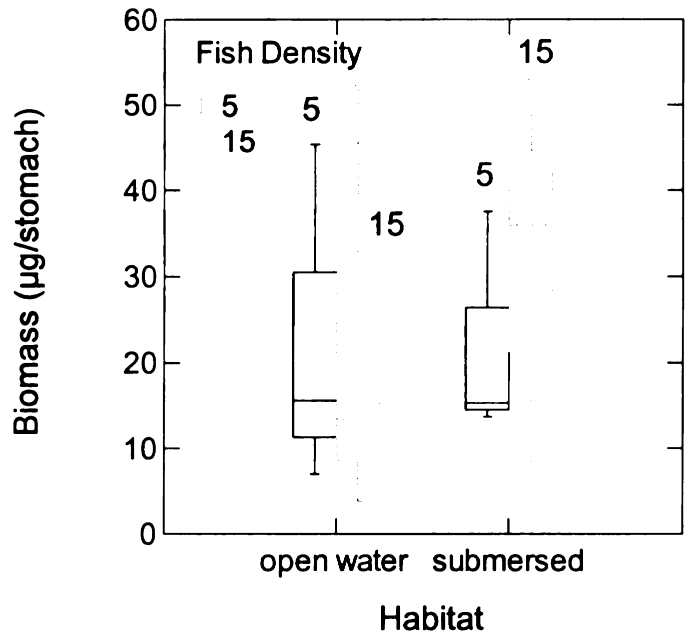
Table 3.3: Mean number (± 2 standard error) of organisms found within the stomach of YOY bluegill harvested from experiment two enclosures. Cla = Cladocera, Cop = Copepod, Dip = Diptera, Eph = Ephemeroptera, Hem = Hemiptera, Odo = Odonata.

	Cla	Cop	Dip	Eph	Hem	Odo
Open Water, 5	3.13 ± 2.89	7.48 ± 9.58	11.91 ± 10.19	0.06± 0.11	0.06 ± 0.11	0.66 ± 1.15
Open Water, 15	6.20 ± 1.85	7.07 ± 13.15	4.80 ± 0.69	0.07 ± 0.13	0.07 ± 0.13	0.07 ± 0.13
Submersed, 5	7.53 ± 1.64	3.40 ± 4.39	6.40 ± 0.23	0.07 ± 0.13	0 ± 0	1.07 ± 1.54
Submersed, 15	25.60 ± 44.14	6.60 ± 8.05	8.73 ± 6.59	0.13 ± 0.13	0.07 ± 0.13	1.53 ± 1.04

Table 3.4: Mean biomass (μg ± 2 ×standard error) of organisms found within the stomach of YOY bluegill harvested from experiment two enclosures. Cla = Cladocera, Cop = Copepod, Dip = Diptera, Eph = Ephemeroptera, Hem = Hemiptera, Odo = Odonata.

	Cla	Cop	Dip	Eph	Hem	Odo
Open Water, 5	4.510 ± 6.580	19.58 ± 54.40	1992 ± 2928	0.8684 ± 4.011	1.498 ± 6.920	46.42 ± 185.5
Open Water, 15	8.972 ± 10.99	14.22 ± 45.19	898.4 ± 1035	7.557 ± 33.80	23.20 ± 103.8	0.8923 ± 3.991
Submersed, 5	14.36 ± 19.56	7.803 ± 15.76	1203 ± 977.4	7.257 ± 32.46	0	13.09 ± 39.29
Submersed, 15	19.24 ± 57.48	12.53 ± 23.73	1621 ± 1746	77.90 ± 34.59	1.598 ± 7.147	18.20 ± 28.89

A. Zooplankton



B. Macroinvertebrates

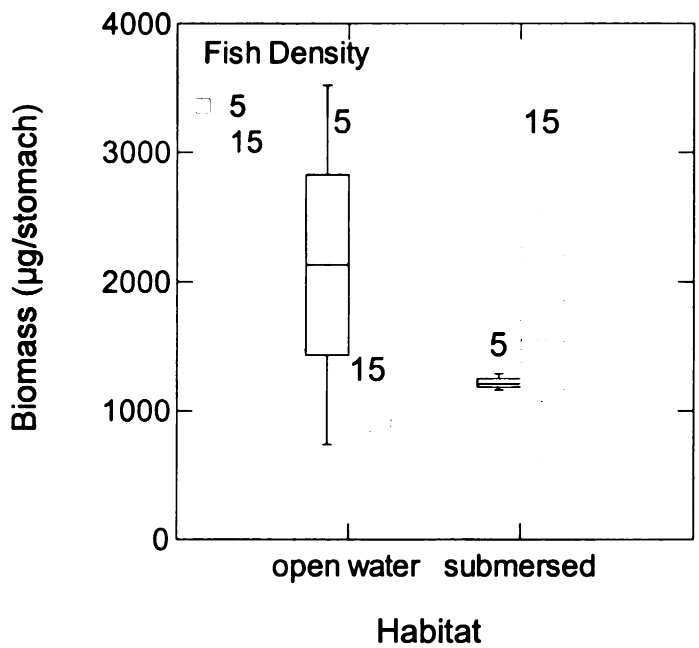


Figure 3.21: Biomass (µg/stomach) of A) zooplankton and B) macroinvertebrates dissected from YOY bluegill stomachs in experiment two enclosures located in different habitats.

Mean macroinvertebrate biomass in bluegill stomachs ranged from 612 to 3520 μg per enclosure (Figure 3.21). No interaction between habitat and fish density was observed ($F_{1,8} = 2.54$, $p = 0.1498$). Additionally, there were no differences in the amount of macroinvertebrate biomass in the stomachs of bluegill from different habitat types ($F_{1,9} = 0.01$, $p = 0.9215$) or different fish densities ($F_{1,9} = 0.37$, $p = 0.5565$).

DISCUSSION

YOY Bluegill Growth and Habitat

In experiment one, the growth rates of YOY bluegill stocked into enclosures located in emergent vegetation were slower than the growth rates of bluegill in enclosures located in open water or submersed vegetation. However, dissolved oxygen levels were significantly lower in emergent vegetation enclosures, with levels often falling below 3.0 mg/l. These low oxygen concentrations may have caused the decline in growth rate observed in YOY bluegill within these enclosures. Low oxygen concentrations in emergent vegetation compared to open water habitats have been documented in other studies (e.g., Rose and Crumpton 1996). More research is needed to determine if growth rates of YOY bluegill would be slower in areas of emergent vegetation that did not experience similarly low oxygen concentrations.

Bluegill in Saginaw Bay, Lake Huron were more likely to be sampled in areas with submersed vegetation than in areas of emergent vegetation or open water (see Chapter 2). One objective of this study was to examine if a habitat preference for submersed vegetation may lead to faster growth rates of bluegill. This study provides some evidence that submersed vegetation may have a positive impact on YOY bluegill growth rates. While no differences in bluegill growth rates were found between open water and submersed vegetation in experiment one, or at low densities in experiment two, at high densities bluegill located in submersed vegetation grew faster than those located in open water.

One possible explanation for the difference in growth rates between habitat types is that there are differences in food resource levels among emergent vegetation, submersed vegetation, and open water habitats. I found some differences in food resource levels among the different habitats in experiment one and two. The macroinvertebrate community in both experiments was dominated by ephemeropterans, gastropods, hemipterans, trichopterans, and odonates, which is consistent with macroinvertebrate communities reported in other studies of wetland and pond areas (e.g. Crowder and Cooper 1982, Schramm and Jirka 1989, Belk 1993). Macroinvertebrate food resources may have been greater in vegetated habitats than in open water in both experiments. Higher densities of macroinvertebrates were measured in enclosures located in emergent vegetation compared to open water and submersed vegetation in experiment one. In experiment two, higher densities of macroinvertebrates were found in submersed vegetation than in open water. However, no differences in macroinvertebrate biomass among the habitat types were observed in either experiment. The pattern of higher densities of macroinvertebrates in vegetated areas than in open water has been documented in other studies of wetland systems (e.g. Schramm et al. 1987, Belk 1993). Crowder and Cooper (1982) also documented increases in macroinvertebrate biomass with macrophyte density.

While there is some evidence of higher macroinvertebrate food resources in the submersed vegetation enclosures compared to open water, there is less evidence for differences in zooplankton levels among habitat types. Copepod density and biomass did not vary among habitat types in either experiment. Cladoceran biomass also did not vary among habitats; however, in experiment one there was a significantly greater density of cladocerans in enclosures located in submersed vegetation compared to emergent vegetation and open water. Belk (1993) also documented higher abundances of zooplankton in vegetated areas compared to open water in a South Carolina reservoir.

One other possible explanation for the differences in growth rates between submersed vegetation and open water habitats in experiment two is that there are differences in the feeding behavior and diet of bluegill between the two habitats. YOY bluegill in this study fed on a combination of zooplankton and macroinvertebrate food resources. In both experiments, bluegills fed on more cladocerans than copepods, even though copepods were found in higher densities and biomass levels. Bluegill also fed on macroinvertebrate food resources, with dipterans, ephemeropterans, and odonates making up large proportions of the biomass of food items within their stomachs. Similar types of macroinvertebrate prey have been found in the diet of older bluegill in other studies (Crowder and Cooper 1982, Mittelbach 1984, Mittelbach 1988, Schramm and Jirka 1989).

Diet analysis of bluegill in experiment one enclosures indicated that YOY bluegill fed on more macroinvertebrates in submersed and emergent vegetation habitats that in open water. Bluegill also fed on more zooplankton in open water enclosures than in the other habitat types. This pattern of feeding on macroinvertebrates in vegetated areas and zooplankton in areas of open water is consistent with results of other studies (Werner and Hall 1977, 1988, Mittelbach 1981, 1984, Crowder and Cooper 1982, Schramm and Jirka 1989); however, this pattern was not observed in experiment two enclosures. In experiment two there were no significant differences in the zooplankton or macroinvertebrate biomass from the stomachs of bluegill from enclosures located in open water compared to submersed vegetation. Under low resource conditions like those in experiment two, bluegill may switch from feeding on zooplankton to macroinvertebrates, or from macroinvertebrates to zooplankton depending upon resource levels, allowing them to maximize energy intake, at any given time (Mittelbach 1981, Werner 1983, Schramm and Jirka 1989). While studying age one and older bluegill, Werner (1983) demonstrated that to maximize energy intake, fish should feed on zooplankton when zooplankton populations are high, but then switch to macroinvertebrates as zooplankton populations decrease. Since resources of both macroinvertebrates and zooplankton were low in experiment two enclosures compared to experiment one enclosures, bluegill may have been feeding on both types of food resources rather than specializing on one resource.

Although I did not identify differences in the biomass of zooplankton and macroinvertebrates in bluegill stomachs from different habitats in experiment two, diet was only sampled at the end of the experiment, and may not be representative of the feeding behavior of bluegill throughout the experiment. If the bluegill were actually feeding more on zooplankton in open water and macroinvertebrates in submersed vegetation, there may have been differences in the energy YOY bluegill derive from those different food sources. Bluegill feeding on zooplankton in open water environments spend little time searching and handling prey, but the small prey size makes each item's overall profitability low (Mittelbach 1981). Bluegill feeding on macroinvertebrates in vegetated habitats may have to spend more time searching for and handling prey; however due to the increased prey size, they capture greater biomass per feeding event (Mittelbach 1981). In addition to capturing greater biomass food items in vegetated habitats, the overall caloric content per gram dry weight is typically higher for macroinvertebrates belonging to the orders diptera and odonata (the most common prey items consumed in this study) compared to cladoceran and copepod zooplankton (Cummins and Wuycheck 1971). These differences in energy consumption and expenditure could impact bluegill growth rates, leading to faster growth in submersed vegetation.

While I found that at high densities, bluegill grew faster in submersed vegetation than in open water, other studies have suggested that the opposite pattern may occur. Bluegill may feed more optimally in open water environments, resulting in faster growth rates of bluegill in open water habitat compared to vegetated areas (e.g. Mittelbach 1981, Werner and Hall 1988). However these estimates of prey profitability were calculated using large bodied zooplankton such as *Daphnia* spp. in artificial tank environments (Mittlebach 1981). I found low abundances of daphnids in experiment two enclosures. The low abundance of daphnids is expected, as all enclosures (open water and submersed vegetation) were located in the shallow littoral zone, and daphnids are typically more abundant in the pelagic zone compared to the littoral edge (Gliwicz and Rykowska 1992, Hulsmann et al. 1999). The lack of large species of zooplankton may be one reason why YOY bluegill in this study grew slower in open water enclosures compared to enclosures located in submersed vegetation.

Fish Density and Bluegill Growth Rates

Fish density can have a negative effect on the growth rates of YOY bluegill. Growth rates of bluegill in the second experiment were significantly slower in enclosures stocked with 15 fish compared to those stocked with 5 fish. This result is not entirely surprising, as intraspecific competition has been shown to have negative impacts on the growth rates of older bluegill (Mittelbach 1988, Osenberg et al. 1988, Belk 1993); however this is the first study to document negative impacts of high fish densities on the growth of small YOY bluegill.

Fish density can have a negative impact on growth rates through exploitative competition. If there is exploitive intraspecific competition among the bluegills used in this study, then a decline in the density and biomass of zooplankton and macroinvertebrates over time, and a stronger decline with increased fish density would be expected. Other studies have shown that bluegill can have significant negative impacts on cladoceran density (Turner and Mittelbach 1990), macroinvertebrate biomass (Crowder and Cooper 1982), macroinvertebrate size (Crowder and Cooper 1982, Mittelbach 1988) and macroinvertebrate density (Mittelbach 1988); however these studies involved the use of older bluegill and were longer in duration. Diet analysis of bluegill in this study did not indicate any significant differences in the biomass of zooplankton or macroinvertebrates harvested from the stomachs of bluegill in enclosures stocked with different densities of fish. However, measurements of zooplankton abundance and biomass over time show some evidence of resource depletion at high fish densities. While there were no significant differences in the abundance or biomass of zooplankton from the start date to the end date of the experiment, there were differences in the pattern of zooplankton variation over time among the different fish densities. There was an increase in cladoceran abundance and biomass in open water enclosures stocked with 0 or 5 fish measured on day 8 of the experiment. This increase in zooplankton may have been a result of release from predation pressure from existing populations of fathead minnows, sunfish, and sticklebacks within the pond. There was not an increase in density or biomass of cladocerans observed in enclosures stocked with 15 fish. Stocking 15 bluegill into enclosures may have maintained sufficient predation pressure on zooplankton to prevent the resource from growing. The increase in zooplankton resources on day eight of the experiment was not observed in enclosures placed in submersed vegetation; however zooplankton populations have been shown to persist under fish predation in vegetated areas because macrophytes can serve as a refuge from fish predation (Stansfield et al. 1997).

Growth Rates of Bluegill in Experiments 1 and 2

There was a large difference in mean growth rates of YOY bluegill between the two experiments. In experiment one, growth rates of YOY bluegill averaged approximately 0.523 ± 0.103 mm/day, which is within the range (0.343 to 0.957 mm/day) of mean growth rates of YOY bluegill sampled in wetland areas in Saginaw Bay, Lake Huron in 2001 (see chapter one). Growth of YOY bluegill was considerably slower in experiment two, averaging approximately 0.327 ± 0.042 mm/day.

The slower growth rates of YOY bluegill in experiment two may be a result of the considerably lower food resources available in experiment two enclosures compared to experiment one. Experiment one was conducted in a wetland with abundant populations of zooplankton. Mean cladoceran density in experiment one enclosures was 300 organisms/l, and mean copepod density was 882 organisms/l. The densities of cladocerans and copepods measured in experiment one are within the range of zooplankton densities reported in other wetland environments (Belk 1993, Sandilands and Hann 1996, Stansfield et al. 1997). The density of zooplankton was much lower in experiment two enclosures, with a mean cladoceran density of 8 organisms/l and mean copepod density of 81 organisms/l. With a mean density of 422 macroinvertebrates/m^3, enclosures in experiment one also had higher densities of macroinvertebrates compared to experiment two enclosures where mean density was 61 macroinvertebrates/m^3.

Growth rates of bluegill have been shown to be correlated with prey availability, with slower growth rates in areas with lower densities of large macroinvertebrates (Mittelbach 1988). This study did not show differences in the biomass or density of macroinvertebrates and zooplankton between enclosures stocked with fish and those without fish at the end of the experiment one, but there were differences in cladoceran biomass in experiment two. This indicates that food resources may have been limiting in experiment two. Therefore, managers concerned with bluegill growth may need to monitor zooplankton and macroinvertebrate community dynamics to ensure abundant food supplies for YOY fish.

Future Research

This study demonstrated that fish density has an impact on the individual growth rates of YOY bluegill. Therefore managers should be concerned with the density of YOY bluegill if they desire to maximize growth rates. Although lower fish densities may produce fewer numbers of fish, the fish should have faster growth rates. It is not yet known how large of an impact bluegill density may have on growth rates of small YOY bluegill. Additionally, this study only examined three levels of bluegill density, 0, 5, and 15 fish per square meter. While this study indicated that there is a relationship between bluegill growth rate and fish density, the nature of this relationship is not known, and requires further study.

Results of the second experiment indicated that at high fish densities, YOY bluegill grow faster in submersed vegetation than in open water. This study did not identify the mechanism driving this pattern. There are several possible explanations for why small YOY bluegill may grow better in submersed vegetation than in open water. One potential explanation is that there are differences in the feeding behavior and diet of small YOY bluegill between submersed vegetation and open water habitat. Although, this study did not find any significant differences in the diet of YOY bluegill between the two habitats in experiment two, the diet of bluegill was only sampled once at the end of the experiment. More research is needed on the potential feeding behavior and diet of small YOY bluegill in these habitats to determine if differences in growth rates are due to feeding.

LITERATURE CITED

Balcer, M.D., N.L. Korda, and S.I Dodson. 1984. Zooplankton of the Great Lakes: A Guide to the Identification and Ecology of the Common Crustacean Species. The University of Wisconsin Press, Madison, WI.

Belk, M.C. 1993. Growth and mortality of juvenile sunfishes (*Lepomis* sp.) under heavy predation. Ecology of Freshwater Fish 2:91-98.

Cardinale, B.J., V.J. Brady and T.M. Burton. 1998. Changes in the abundance and diversity of coastal wetland fauna from the open water/macrophyte edge towards shore. Wetlands Ecology and Management 6:59-68.

Crowder, L.B. and W.E. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. Ecology 63:1802-1813.

Culver, D.A., M.M. Boucherle, D.J. Bean, and J.W. Fletcher. 1985. Biomass of freshwater crustacean zooplankton from length-weight regressions. Canadian Journal of Fisheries and Aquatic Sciences 42:1380-1390.

Cummins, K.W. and J.C. Wuycheck. 1971. Caloric equivalents for investigations in ecological energetics. Mitteilungen - Internationale Vereinigung für Theoretische und Angewandte Limnologie 18:1-

Diehl, S. 1988. Foraging efficiency of three freshwater fishes: effects of structural complexity and light. Oikos 53:207-213.

Dionne, M. and C.L. Folt. 1991. An experimental analysis of macrophytes growth forms as fish foraging habitat. Canadian Journal of Fisheries and Aquatic Sciences 48:123-131.

Fassett, N.C., 1985. A Manual of Aquatic Plants. The University of Wisconsin Press, Madison, WI.

Francis, R.I.C. 1990. Back-calculation of fish length: a critical review. Journal of Fish Biology 36:883-902.

Gerking, S.D. 1957. A method of sampling the littoral macrofauna and its application. Ecology 38:219-226.

Gliwicz, Z.M. and A. Rykowska. 1992. 'Shore avoidance' in zooplankton: a predator-induced behaviour or predator-induced mortality? Journal of Plankton Research 14: 1331-1342.

Gotceitas, V. 1990a. Plant stem density as a cue in patch choice by foraging juvenile bluegill sunfish. Environmental Biology of Fishes 29:227-232.

Gotceitas, V. 1990b. Foraging and predator avoidance: a test of a patch choice model with juvenile bluegill sunfish. Oecologia 83:346-351.

Houde, E.D. 1994. Differences between marine and freshwater fish larvae: implications for recruitment. ICES Journal of Marine Science 51:91-97.

Hulsmann, S., T. Mehner, S. Worischka, and M. Plewa. 1999. Is the difference in population dynamics of *Daphnia galeata* in the littoral and pelagic areas of a long-term biomanipulated reservoir affected by age-0 fish predation? Hydrobiologia 408/409:57-63.

Jacobsen, L. and S. Berg. 1998. Diel variation in habitat use by planktivores in field enclosure experiments: the effect of submerged macrophytes and predation. Journal of Fish Biology 53:1207-1219.

Jude, D.J. and J. Pappas. 1992. Fish utilization of Great Lakes coastal wetlands. Journal of Great Lakes Research 18:651-672.

Lillie, R.A. and J. Budd. 1992. Habitat architecture of *Myriophyllum spicatum* L. as an index to habitat quality for fish and macroinvertebrates. Journal of Freshwater Ecology 7:113-125.

Littell, R.C., R.J. Freund, and P.C. Spector. 1991. SAS System for Linear Models, Third Edition. SAS Institute Inc., Cary, NC.

Mittelbach, G.G. 1981. Foraging efficiency and body size: a study of optimal diet and habitat use by bluegills. Ecology 62:1370-1386.

Mittelbach, G.G. 1984. Predation and resource partitioning in two sunfishes (Centrarchidae). Ecology 65:499-513.

Mittelbach, G.G. 1988. Competition among refuging sunfishes and effects of fish density on littoral zone invertebrates. Ecology 69:614-623.

Osenberg,. C.W., E.E. Werner, G.G. Mittelbach, and D.J. Hall. 1988. Growth patterns in bluegill (*Lepomis macrochirus*) and pumpkinseed (*L. gibbosus*) sunfish: environmental variation and the importance of ontogenetic niche shifts. Canadian Journal of Fisheries and Aquatic Sciences 45:17-26.

Post, J.R., and A.B. Prankevicius. 1987. Size-selective mortality of young-of-the-year yellow perch (*Perca flavescens*): evidence from otolith microstructure. Canadian Journal of Fisheries and Aquatic Sciences 44:1840-1847.

Rose, C. and W.G. Crumpton. 1996. Effects of emergent macrophytes on dissolved oxygen dynamics in a prairie pothole wetland. Wetlands 16:495-502.

Rozas, L.P. and W.E. Odum. 1988. Occupation of submerged aquatic vegetation by fishes: testing the roles of food and refuge. Oecologia 77:101-108.

Sandilands, K.A. and B.J. Hann. 1996. Effect of fish and submersed macrophytes on the abundance of zooplankton in a prairie wetland. UFS (Delta Marsh) Annual Report 31:58-62.

Schramm, H.L. Jr., and K.J. Jirka. 1989. Epiphytic macroinvertebrates as a food resource for bluegills in Florida lakes. Transactions of the American Fisheries Society 88:416-426.

Schramm, H.L. Jr., K.J. Jirka, and M.V. Hoyer. 1987. Epiphytic macroinvertebrates on dominant macrophytes in two central Florida lakes. Journal of Freshwater Ecology 4:151-161.

Smock, L.A. 1980. Relationships between body-size and biomass of aquatic insects. Freshwater Biology 10:375-383.

Stansfield, J.H., M.R. Perrow, L.D. Tench, A.J.D. Jowitt and A.A.L. Taylor. 1997. Submerged macrophytes as refuges for grazing Cladocera against fish predation: observations on seasonal changes in relation to macrophyte cover and predation pressure. Hydrobiologia 342/343:229-240.

Tonn, W.M. and C.A. Paszkowski. 1987. Habitat use of the central mudminnow (*Umbra limi*) and yellow perch (*Perca flavescens*) in *Umbra-Perca* assemblages: the role of competition, predation, and abiotic environment. Canadian Journal of Zoology 65:862-870.

Turner, A.M. and G.G. Mittelbach. 1990. Predator avoidance and community structure: Interactions among piscivores, planktivores, and plankton. Ecology 71: 2241-2254.

Turner, R.E. 1988. Secondary production in riparian wetlands. Transactions of the 53rd North American Wildlife and Natural Resources Conference. 491-501.

Werner, E.E. and D.J. Hall. 1974. Optimal foraging and the size selection of prey by the bluegill sunfish (*Lepomis macrochirus*). Ecology 55:1042-1052.

Werner, E.E. and D.J. Hall. 1976. Niche shifts in sunfishes: experimental evidence and significance. Science 191:404-406.

Werner, E.E. and D.J. Hall. 1977. Competition and habitat shift in two sunfishes (Centrarchidae). Ecology 58:869-876.

Werner, E.E. and D.J. Hall. 1979. Foraging efficiency and habitat switching in competing sunfishes. Ecology 60:256-264.

Werner, E.E. and D.J. Hall. 1988. Ontogenetic habitat shifts in bluegill: the foraging rate-predation risk trade-off. Ecology 69:1352-1366.

Werner, E.E., G.G. Mittelbach, and D.J. Hall. 1981. The role of foraging profitability and experience in habitat use by the bluegill sunfish. Ecology 62:116-125.

Werner, E.E., J.F. Gilliam, D.J. Hall, and G.G. Mittelbach. 1983a. An experimental test of the effects of predation risk on hab itat use in fish. Ecology 64:1540-1548.

Werner, E.E., G.G. Mittelbach, D.J. Hall, and J.F. Gilliam. 1983b. Experimental tests of optimal habitat use in fish: the role of relative habitat profitability. Ecology 64:1525-1539.

Winfield, I.J. 1986. The influence of simulated aquatic macrophytes on the zooplankton consumption rate of juvenile roach, *Rutilus rutilus*, and perch, *Perca fluviatilis*. Journal of Fish Biology 29:37-48.

CONCLUSIONS

Results of this research suggest that not all wetlands are of equal value to young of the year fish. Along the coastal wetlands of Saginaw Bay, Lake Huron, the distribution and growth of YOY fish varies both within wetland environments and among wetland areas. The YOY fish community responded to both changes in the physical structure of the habitat (e.g. type of vegetation present, water depth), as well as changes in water quality (e.g. dissolved oxygen concentrations, and turbidity). Wetland habitat characteristics influenced the abundance, diversity, species composition, and distribution of YOY fish. Wetland habitat also has the potential to influence the growth of YOY fish at the macrohabitat and microhabitat scale. Because growth rates are critical in determining the probability of over winter survival and year class strength, small changes in the characteristics of wetland environments that may influence YOY fish growth rates may have large implications on fish population dynamics in the Great Lakes.

Due to the large impact that wetland habitat characteristics can have on the YOY fish community, not all wetland habitats are of equal value to YOY fish. By understanding which habitat characteristics may increase the success of YOY fish, we can make better decisions on which type of wetlands to protect for Great Lakes fisheries resources. For example, this study suggests that water depth had a large impact on the YOY fish community, with the growth, presence, and

diversity of YOY fish all increasing in wetlands with areas of deeper water within the 0 – 100 cm range sampled. Water levels within the Great Lakes are cyclical in nature, and were approximately 0.5 meters below the long term mean during this study period. As a result of the low water levels, within the wetlands sampled there were few wetland areas with water depths greater than 60cm that also had abundant vegetation growth. There are several reasons why having access to deeper water habitats adjacent to vegetation may be beneficial to young fish, including providing refuges with cooler water temperatures, higher oxygen concentrations, and reduced risk of avian predation. Protecting wetland areas with greater littoral slopes would help insure that during periods of low water levels in the Great Lakes, YOY fish still have access to both areas of deeper water and abundant wetland vegetation.

Another habitat characteristic that had a large impact on the YOY fish community at both the macrohabitat and microhabitat scale is the amount of vegetation cover within a wetland. Vegetation cover influenced species richness, diversity, community composition, and fish growth at the macrohabitat scale, while the type of vegetation present influenced the distribution of banded killifish, and the distribution and growth of bluegill at the microhabitat scale. Higher abundances of submersed vegetation may be particularly advantageous to the growth of YOY fish. In addition to the amount of vegetation present, YOY fish may prefer patchy vegetation communities, and wetland environments with high habitat heterogeneity. At the macrohabitat scale habitat complexity influenced which species of YOY fish were found within a wetland as well as the growth of

YOY spottail shiner. At the microhabitat scale, YOY bluegill showed a preference for patchy vegetation communities, preferring to be located along the edge of habitat patches where they may have easy access to more than one habitat type. As a result of the importance of wetland vegetation to the YOY fish community, Great Lakes fisheries managers may wish to protect wetlands with patchy, diverse, and abundant vegetation communities.

This study examined the YOY fish community in fifteen different wetland areas located throughout Saginaw Bay, Lake Huron. Six of these wetland areas had islands, sand bars, or gravel bars adjacent to the wetland. While the number and size of these structures varied among the wetland areas, these structures may help to shelter wetland areas from damaging wind and wave action. The presence of these structures had a large impact on the YOY fish community, with increased abundances of YOY fish, and higher species richness with one of these structures compared to those without. These presence of these structures also impacted species composition. Yellow perch, brown bullhead, spotfin shiner, green sunfish, and pumpkinseed were all more commonly found in wetlands with one or more of these structures than in wetlands without. Due to the importance of these structures to the YOY fish community, managers may wish to focus on wetlands with these types of structures when managing coastal habitats for YOY fish.

The shore of Saginaw Bay where a wetland area was located appeared to have an impact on species composition, with different fish communities associated with the eastern compared to the western shore of Saginaw Bay.

Gizzard shad, green sunfish, sand shiners, and yellow perch were more commonly present in wetlands on the eastern bank, while white suckers, rock bass, and bowfin were more commonly present in wetlands on the western bank of Saginaw Bay. Due to the change in species composition observed between wetlands on the eastern versus western shore of Saginaw Bay, it may be important to protect and manage wetland areas on both shores for the benefit of YOY fish.

Water quality parameters such as turbidity and dissolved oxygen may also be important to YOY fish. Both banded killifish and spottail shiner were more likely to be sampled in areas with higher water clarity. Increased turbidity may inhibit the ability of YOY fish to locate and capture prey, and as a result, YOY banded killifish and spottail shiners may select areas with increased water clarity. Dissolved oxygen concentrations influenced the distribution of spottail shiners within wetland areas. Additionally, results of the enclosure experiment indicated that the growth of YOY bluegill was slower in areas of emergent vegetation. Although the enclosures with emergent vegetation had larger macroinvertebrate populations and abundant zooplankton food resources, dissolved oxygen concentrations were significantly lower in these enclosures, and may have had a negative impact on YOY bluegill growth. The distribution of transient wetland species, or those species that are likely to move in and out of wetland areas, was largely impacted by changes in water quality compared to the importance of changes in the physical structure of wetland habitat. Therefore, managers may need to monitor and manage water quality characteristics such as turbidity and dissolved oxygen within wetland areas to maximize their value to and use by YOY fish.

Finally, the density of YOY fish can have a negative effect on their growth rates. Growth rates of bluegill in the second enclosure experiment were significantly slower in enclosures stocked with 15 fish compared to those stocked with 5 fish. Fish density can have a negative impact on growth rates through exploitative competition. While diet analysis of bluegill in this study did not indicate any significant differences in the biomass of zooplankton or macroinvertebrates harvested from the stomachs of bluegill in enclosures stocked with different densities of fish, measurements of zooplankton abundance and biomass over time show some evidence of resource depletion at high fish densities. Because fish density has an impact on the individual growth rates of YOY bluegill, managers should be concerned with the density of YOY bluegill if they desire to maximize growth rates. Although lower fish densities may produce fewer numbers of fish, the fish should have faster growth rates.