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Relationships Among Shoreline Development, Nearshore Fish Communities, and Aquatic Macrophyte Communities in the Littoral Zone of Indiana Glacial Lakes

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Entitled

Relationships Among Shoreline Development, Nearshore Fish Communities, and Aquatic
Macrophyte Communities in the Littoral Zone of Indiana Glacial Lakes

For the degree of Master of Science

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For the degree of Master of Science

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RELATIONSHIPS AMONG SHORELINE DEVELOPMENT, NEARSHORE FISH COMMUNITIES, AND
AQUATIC MACROPHYTE COMMUNITIES IN THE LITTORAL ZONE OF INDIANA GLACIAL LAKES

A Thesis

Submitted to the Faculty

of

Purdue University

by

Kelly D. Boatright

In Partial Fulfillment of the

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of

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ABSTRACT

Boatright, Kelly D. M.S., Purdue University, May 2012. Relationships Among Shoreline Development, Nearshore Fish Communities, and Aquatic Macrophyte Communities in the Littoral Zone of Indiana Glacial Lakes. Major Professor: Robert B. Gillespie.

The relationship among shoreline development, fish and aquatic plant communities was assessed in five glacial lakes in Indiana. Contrary to results reported in previous studies, vegetation abundance was significantly higher at sites along developed shorelines than along undeveloped shorelines. Vegetation abundance differed significantly among lakes, but was better explained by Secchi depths than by shoreline development. There was no consistent relationship between shoreline development and species richness of fishes and vegetation. This study suggests that shoreline development alone may not adequately explain vegetation and fish species richness and abundance.

The usefulness of pop nets for sampling fishes and vegetation was assessed in the littoral zone of five glacial lakes in Indiana. Pop nets captured 11 species of fish not previously accounted for in surveys completed by the Indiana Department of Natural Resources (IDNR). Five of these fish species are considered intolerant by the Michigan Department of Natural Resources and may be important for assessing the ecological integrity of lakes. Thirteen aquatic macrophyte species found in pop net samples were not previously accounted for in IDNR Tier II vegetation surveys, one of which is considered threatened in Indiana. Because of their ability to target littoral zone macrophytes and small-bodied littoral zone fish species pop nets may provide a supplemental tool to sample lakes more extensively than current practices.

INTRODUCTION

Resulting from the last retreat of the Erie Lobe of the Wisconsin Glacier approximately 12,000 years ago, glacial lakes in Indiana are recognized as a substantial resource providing recreational benefits, educational opportunities, and economic possibilities. (Fleming and Rupp, 2011). Lakes and surrounding land are utilized for various purposes (e.g., housing, angling, boating), and to suit these uses lakes have been altered through residential construction and addition of seawalls, beaches, piers and boat ramps. The negative impacts of lake shoreline development on the physical and ecological characteristics of lakes have been demonstrated in multiple studies. Lakes in Wisconsin and Minnesota with a higher amount of development possessed a lower abundance of emergent and floating vegetation than lakes with less development (Radomski and Goeman 2001). The developed edges of Spirit Lake in Iowa had a lower abundance and diversity of aquatic macrophytes and fish species than areas which still had natural shoreline (Bryan and Scarnecchia 1992). Growth rates of bluegill (*Lepomis microchirus*) and productivity of largemouth bass populations (*Micropterus salmoides*) were both lower in highly developed Wisconsin and Michigan lakes than in lakes with no development (Schindler, Geib, and Williams 2000).

Although extensively studied in Iowa, Michigan, Minnesota, and Wisconsin lakes, the impact of shoreline development on lakes in Indiana has not been examined. These lakes are distinctively different from these northern lakes simply by being farther south. Indiana's glacial lakes have greater mean water temperatures than those in Iowa, Michigan, Minnesota, and Wisconsin making them prime spots for boating, swimming, fishing, and year-round living (Table 0.1). Glacial lakes farther north are often excellent for fishing but too cold for swimming. These nearby states also have lower population densities than Indiana, and Indiana has a relatively low percent of its surface area covered by water. In short, in Indiana there are more people using less water.

The purpose of this study was to determine if lakes with varying degrees of shoreline development differ in vegetation and fish community structure and abundance. Based on past studies, we hypothesized that fish and vegetation species richness and abundance would be negatively associated with amount of shoreline development.

Table 0.1: Comparison of urbanization, percent of state covered by water, average temperature, and southernmost latitude by state. ^aUnited States Census Bureau, 2011b, ^bPerlman, 2011, ^cNational Oceanic and Atmospheric Administration, Physical Sciences Division, n.d., ^dSault Sainte Marie, MI yearly temperature (“Sault Ste. Marie,” n.d.).

State	Population density ^a (km ²)	Percent of state covered by water ^b	Average yearly temperature (C) ^c
Indiana	468.8	0.9	10.9
Iowa	141.2	0.7	8.8
Michigan (UP)	452.7(49.8)	2.8 (54.3)	6.9 (4.3 ^d)
Minnesota	172.5	6	5.1
Wisconsin	271.9	3.4	6.2

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CHAPTER 1

RELATIONSHIPS AMONG SHORELINE DEVELOPMENT, FISH AND AQUATIC MACROPHYTE COMMUNITIES IN INDIANA GLACIAL LAKES

Introduction

Nearshore aquatic vegetation in lacustrine systems is often seen as a hindrance to recreational activities such as boating or swimming and is frequently removed by land owners. Removal of macrophytes reduces the ability of the riparian zone and littoral zone to filter sediments and capture nutrients entering the lake (White et al. 2000). Removal of vegetation can be directly linked to development; lakes with a higher density of development have a lower abundance of emergent and floating vegetation than lakes with no or less development (Jennings et al. 2003, Radomski and Goeman 2001). In addition, developed edges of a lake have a lower abundance and diversity of aquatic macrophytes than areas which still have natural shoreline (Bryan and Scarnecchia 1992). Areas along the shoreline of a lake where vegetation has been removed are subjected to additional stress from waves. Furthermore, partial removal of aquatic vegetation can induce changes in the natural macrophyte species that remain because of increased wave energy (Wilson and Keddy 1986).

Lake littoral zones are important for juvenile fish because they provide ample forage areas and protection from predators. Savino and Stein (1982) showed that the predatory success of largemouth bass on bluegill decreased as stem density of aquatic vegetation increased; therefore a decrease in aquatic vegetation density will increase the predation rate of largemouth bass on bluegill. Bluegill at risk of predation are able to select densities which afford them the most protection, avoiding areas where the vegetation is either too scant to adequately hide them or too thick to allow quick movements for escape (Gotceitas and Colgan 1987, Johnson et al. 1988, Lynch and Johnson 1989). Aquatic vegetation density also affects the diet of

bluegills, with fish experiencing the most energetically profitable diet in intermediate macrophyte density (Crowder and Cooper 1982).

Shoreline development was listed as one reason for a decline in native fish species in Spirit Lake, IA (Pierce et al. 2001). Decreased aquatic macrophyte richness and shifts in fish community composition toward more tolerant species have been shown in littoral zones along altered shorelines (Poe et al. 1986, Jennings et al. 1999, Hatzenbeler et al. 2004). Radomski (2006) noted a decrease in aquatic macrophyte abundance as shoreline development increased.

While the impact of shoreline development on fish and aquatic macrophyte communities has been studied in northern glacial lakes, similar studies in more southern glacial lakes (e.g., Indiana lakes) are limited. The primary intent of this study was to compare species richness and abundance of fish and aquatic vegetation from the littoral zone of lakes with varying levels of shoreline development. The expectation was that lakes with more development would have fewer macrophyte and fish species and lower macrophyte and fish abundance than lakes with less development.

Methods

Lakes were selected based on the amount of shoreline development as reported by the Indiana Department of Natural Resources, Division of Fish and Wildlife in general survey reports for each lake. Shoreline development was categorized as none (0% of the shoreline developed), low (up to 33% of the shoreline developed), medium (34% to 66% developed), or high (over 66% developed). Channels extending from the main lake body were not considered part of the shoreline.

Five natural glacial lakes were selected as study lakes. All lakes are dimictic and located within Kosciusko, Noble, or Whitley counties, Indiana (Figure 1.1). Crooked Lake has a maximum depth of 33 m and surface area of 88.4 hectares. Robinson, High, Knapp, and Cree Lakes are no more than 18 m at maximum depth and have a surface area less than 40.1 hectares (Table 1.1). Robinson Lake has an undeveloped shoreline with only a small gravel public access site (Braun 2004). High Lake in Noble County had very little development that was mostly on the south end of the lake except a small area owned by Goshen College that has turf grass and a pier on the northeast shore (Pearson, 1978). The shoreline of Knapp Lake is approximately 50% developed (Pearson, 1999). This lake also has small channels which connect it to Harper and Moss Lakes.

Cree Lake is highly developed; approximately 95% of the shoreline is single-family residences that include a pier (Fink, 2004). Crooked Lake on the Noble/Whitley County border does not fit size or depth constraints. This lake has approximately 75% shoreline development (Pearson, 2000).

Pop nets were constructed according to Killgore et al. (1989) with some modifications. Frames were made with 2.5 cm diameter PVC pipe painted black to reduce visibility. The bottom frame was weighted with steel rebar, and the top was filled with foam to increase buoyancy. Corners were glued together and made of PVC elbows. Nets were 1.2 x 2.4 x 1.2 m and fitted with 0.5 cm black nylon mesh. The release mechanism consisted of two eyebolts on each side, one attached to the top frame and one to the bottom frame (Figure 1.2). Another eyebolt, attached to a 6.1 m length of rope with a buoy at the end, was pushed through the top and bottom eyebolts to hold the top frame to the bottom frame until the release eyebolts were removed by quickly pulling the rope. Pop nets were set and left for two hours before deployment to allow adequate time for fish to return after disturbance.

Nearshore fish and vegetation were collected with pop nets during day and night in spring and summer in 2009 and 2010. For day sampling, nets were set in early morning so that collection took place between 11:00 am and 1:00 pm. For night sampling, nets were set approximately 2 hours before dark so gear was pulled after sunset. Spring sampling was conducted from May 28 to July 13 in 2009 and from June 15 to July 1 in 2010. Summer sampling was conducted from August 5 to August 23 in 2009 and from August 10 to September 9 in 2010. Vegetation was removed, stored, and taken back to the lab for drying and identification. Fish were removed from pop nets, identified, counted, measured, and released at the capture site. Surface temperature, pH, dissolved oxygen, and Secchi depth were measured at the deepest point of the lake at the end of each day sampling session and at the beginning of each night sampling session (excluding Secchi depth).

Fish were collected with pop nets at four different collection sites at the 1.2 m depth contour. Sites were located so that they were representative of the entire shoreline. Site selection was somewhat limited as pop nets need to be set in water less than 1.2 m deep. Sites within each lake were categorized as developed or undeveloped based on adjacent shoreline. A site was considered developed if the adjacent shoreline contained a house, pier, parking lot, or

beach. When set on the lakebed before deployment, the pop nets had a total height of only 5 cm to reduce introduction of shadows or artificial structure that might attract fish.

Macrophytes were removed from within the pop nets with ten pulls of a standard double-headed aquatic vegetation rake. The rake was dropped into the pop net at specific points within the enclosed area, pulled for approximately 0.3 m, and lifted straight up out of the water.

Fish were removed from pop nets using a long-handled dip net with 0.6 cm mesh. After each swipe, fish were removed from the dip net and stored in a large bucket. The dip net was used to scoop out fish from the pop net until it consistently came out empty. At that point, the pop net was removed in a manner that allowed the net to gather any fish that may have been missed during dipnetting. All fish were then identified by species, measured to the nearest 0.1 cm, and released. Any fish that were unable to be identified in the field were euthanized using 400 mg/L MS222, preserved in 10% formalin, and brought back to the lab for identification.

Because there was a strong possibility that the dependent variables (fish and macrophyte richness and abundance) were associated enough that they might be affected together by the independent variables (year, season, time, and lake), a MANOVA was performed on fish and vegetation data. Fish less than 0.3 m were excluded because they were able to freely move through the 0.6 cm mesh. An ANOVA was used to determine if there were differences in vegetation biomass or species richness between developed and undeveloped site categories, and Kruskal-Wallis was used to discern differences between water chemistry data. SPSS was used to perform all MANOVA and ANOVA tests, and Kruskal-Wallis tests were conducted using Systat.

Results

Mean temperatures ranged from 23.1° C in Cree Lake to 26.9° C in High Lake (Table 1.2). The lowest mean dissolved oxygen was 7.61 mg/L at Cree Lake while High Lake had the highest average dissolved oxygen level at 9.80 mg/L. Average pH ranged from 8.74 to 9.08. Kruskal-Wallis tests revealed no significant difference in temperature ($p = 0.495$), dissolved oxygen ($p = 0.233$), or pH ($p = 0.400$) among lakes. Tamhane's t_2 tests revealed that Secchi depth measurements were significantly greater in Crooked Lake than in Robinson Lake ($p < 0.001$),

High Lake ($p < 0.001$), and Cree Lake ($p = 0.011$) (Figure 1.3). Knapp Lake was not significantly different from any other lake.

A total of 23 aquatic plant species were collected from the five study lakes. Five vegetation species, chara (*Chara* spp.), coontail (*Ceratophyllum demersum*), curlyleaf pondweed (*Potamogeton crispus*), and sago pondweed (*Potamogeton pectinatus*), were found in all five study lakes. Chara (*Chara* spp.) was the most prevalent vegetation species, comprising 78% of all vegetation collected (Table 1.3).

Robinson, High, and Cree Lakes had significantly less vegetation per rake pull than Crooked Lake (Figure 1.4). Knapp Lake had significantly greater amounts of vegetation than Robinson, High, and Cree Lakes, and it had significantly lower amounts of vegetation than Crooked Lake. The MANOVA detected a lake*year interaction for vegetation biomass which indicates the lake impact on vegetation biomass was modified by the year of sampling (Figure 1.5). Vegetation species richness did not differ among lakes (Figure 1.6).

There was no significant difference in the number of vegetation species when sites were grouped according to presence or absence of development along adjacent shorelines ($p = 0.369$). Sites along undeveloped shorelines averaged 2.4 vegetation species, while sites along developed shorelines averaged 2.8 species (Figure 1.7). Vegetation biomass was significantly higher at sites along developed shorelines than undeveloped shores ($p = 0.038$). Sites along undeveloped shorelines had an average of 14.7 g/rake pull while sites along developed shorelines had an average of 33.7 g/rake pull (Figure 1.8).

A total of 17 fish species were collected from the five study lakes. Four fish species, bluegill (*Lepomis macrochirus*), warmouth (*Lepomis gulosus*), largemouth bass (*Micropterus salmoides*), and brook silverside (*Labidesthes sicculus*), were found in all 5 study lakes. Bluegill was the most abundant species, representing over 88% of fish collected (Table 1.4).

A MANOVA showed significant lake*year interaction for fish species richness which indicates the lake impact on vegetation biomass was modified by the year of sampling (Figure 1.9). Fish species richness ranged from 1.1 species in High Lake to 2.3 in Crooked Lake (Figure 1.10). Average fish abundance per site did not differ significantly among lakes (Figure 1.11).

Discussion

The expectation that vegetation richness and abundance would decline proportionally to an increase in development was not supported. Vegetation species richness did not differ among lakes, while vegetation biomass was lowest in lakes with no or very little development. Vegetation biomass values were lowest in lakes with low Secchi depth measurements, suggesting that sunlight penetrating the water might strongly influence aquatic vegetation biomass. Compared to the low development lakes, the highly developed lakes had few trees along the riparian zone. Shading from these riparian trees might limit the amount of light available to grow littoral zone vegetation in the less developed lakes. This could result in a positive relationship between development and littoral zone vegetation.

The significant lake*year interaction for total vegetation biomass within each lake indicates the difference in vegetation biomass between lake categories was modified by the year of sampling. The most likely explanation for this is the extreme change in the vegetation community and biomass in Knapp Lake between 2009 and 2010. Differences between estimated marginal means for 2009 and 2010 calculated using MANOVA varied only slightly for Robinson, High, Cree, and Crooked Lakes. Knapp Lake decreased by 208 g/rake pull between 2009 and 2010. The difference in vegetation biomass for this one lake creates a very different level and shape for the 2010 vector which is interpreted as a significant interaction. This interaction does not necessarily address the hypothesis one way or another but instead points out an interesting phenomenon in Knapp Lake.

Chara was the dominant vegetation in Knapp Lake in 2009. It grows in thick, dense mats that choke out most other species and yields high biomass numbers. In 2009, Knapp Lake averaged 246 grams of chara per rake pull compared to only 39 g/rake pull in 2010. The vegetation community in Knapp Lake in 2010 was still primarily chara, however the amount of chara collected was reduced by 85% in 2010. Naiad species increased from less than 0.61 g/rake pull to 7.66 g/rake pull, and although two pondweed species collected in 2009 were not observed in 2010, average pondweed biomass collected per rake pull was higher in 2010. These naiad and pondweed species that colonized in the absence of chara are much less dense and yield lower biomasses.

Several factors can affect growth of chara. Blindow (1992) noted that biomass of stoneworts such as chara can be reduced by high phosphorous levels which encourage growth

of phytoplankton and lessen light penetration. According to Secchi readings in 2009 and 2010 it is not likely that light penetration contributed to the reduction of chara. Bociag, et al. (2011) noted that lakes subjected to drainage of swamp forests and peatlands may collect acidic runoff that changes the conductivity of the water resulting in deposition of acidic sediment. Stoneworts thrive in more alkaline environments, and with their reduction other macrophytes are able to utilize the clear habitat. An increase in acidity would be reflected by a decrease in specific conductivity. Specific conductivity readings Knapp Lake in 2009 and 2010 show an increase and suggest that acidification was not a factor in the decline of chara. The reason for decreasing chara abundance in Knapp Lake is not clear.

Fish abundance and species richness were expected to decrease as development increased. However, fish abundance was not significantly different among lakes. Lakes with the lowest fish species richness coincided with lakes having the lowest vegetation biomass indicating vegetation could be a more influential factor than shoreline development. Eadie and Keast (1984) noted that in lakes with little habitat variation fish species richness was more closely related to prey availability and diversity. Jennings et al. (1999) found an increase in sampling effort (specifically the number of sites) was necessary to properly assess fish species richness at sites without structure (natural shoreline). The fish species richness reported here undoubtedly underestimates the actual number of species found in lakes with little or no development because only 4 sites were targeted.

An interaction between lake and year categories was seen when comparing the fish species richness at each site (Figure 1.11). Fewer fish species were caught in Robinson, High, and Cree Lakes in 2009 than in 2010. Fish species richness increased in Crooked Lake between 2009 and 2010, and increased greatly in Knapp Lake between 2009 and 2010. Similar changes among lakes in fish species richness between 2009 and 2010 would support a large-scale event that influenced all study lakes in the same way, e.g., an exceptionally warm spring. This year*lake interaction suggests mechanisms causing the differences seen in fish species richness were specific to each lake instead of one all-encompassing event. Knapp Lake had the greatest decrease in fish species richness and also had a significant decrease in vegetation biomass. The mechanism specific to Knapp Lake negatively impacting fish species richness may have been the amount of vegetation available for refuge.

Previous studies examining shoreline development have given evidence of the negative effects on fish and vegetation communities. This study has shown that these intertwined communities are shaped and controlled by more than one mechanism. While shoreline development has been determined as an important part of this complex system, this research demonstrates the importance of considering the overall state of each lake when considering shoreline alteration and fisheries management decisions.

Table 1.1: Characteristics of the 5 study lakes.

Lake	SA (ha)	Max depth (m)	Development category
Robinson	23.9	14	None
High	40.1	8	Low
Knapp	35.6	18	Medium
Cree	30.8	8	High
Crooked	83.4	33	High

Table 1.2: A summary of the means of water quality parameters at each lake.

Lake	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Conductivity (mS/cm)	Secchi (m)
Robinson	24.0	7.90	8.74	0.381	1.3
High	26.9	9.80	9.08	0.403	1.0
Knapp	26.0	9.04	8.98	0.468	2.3
Cree	23.1	7.61	8.76	0.414	1.8
Crooked	24.9	8.52	8.92	0.304	3.7

Table 1.3: Average aquatic plant species biomass per lake (g/rake pull). P = present (plant was observed, but collected in amounts lower than 0.00 g/rake pull). Data were pooled across sites and sampling events for each lake except Knapp Lake. Knapp Lake was not pooled across years due to the extreme differences in biomasses. Asterisks (*) indicate species not previously recorded in IDNR Tier II vegetation surveys.

Species	Lake					
	Robinson	High	Knapp		Cree	Crooked
			2009	2010		
Chara <i>Chara</i> spp.	0.03*	0.34*	244.94	34.65	63.96	184.26
Coontail <i>Ceratophyllum demersum</i>	32.66	19.6	6.51	2.81	10.22	3.72
Watermilfoil <i>Myriophyllum</i> spp.	1.04	0.88*			0.79	7.18
Eelgrass/Water celery <i>Vallisneria americana</i>			0.38	0.69	0.59	
Elodea/Waterweed <i>Elodea americana</i>	0.42*		0.02*		0.17*	
Common bladderwort <i>Utricularia macrorhiza</i>						0.05*
Leafy pondweed <i>Potamogeton foliosus</i>		P	0.02	1.69	0.07*	0.04
Richardson's pondweed <i>Potamogeton richardsonii</i>		3.58*		1.51*		0.87*
Curlyleaf pondweed <i>Potamogeton crispus</i>	0.22	0.28	2.76		0.19	0.2
Sago pondweed <i>Potamogeton pectinatus</i>	0.01	0.18	0.22*	1.39*	0.09*	0.24*
Flat-stemmed pondweed <i>Potamogeton zosteriformis</i>		0.06*	0.07*			0.14*
American pondweed <i>Potamogeton nodosus</i>		1.80*			0.01*	
Small pondweed <i>Potamogeton pusillus</i>		0.11*				0.84*
Largeleaf pondweed <i>Potamogeton amplifolius</i>						0.47
Floating-leaf pondweed <i>Potamogeton natans</i>						0.20*
White Water Lily <i>Nymphaea odorata tuberosa</i>	9.92	1.62			7.88	0.2
Spatterdock <i>Nuphar advena</i>					1.32	
Cattail <i>Typha latifolia</i>		0.03				
Arrow Arum <i>Peltandra virginica</i>					0.16	
Spiny naiad <i>Najas marina</i>		P*		4.92*	1.44*	
Slender naiad <i>Najas flexilis</i>		0.04*	0.61*	2.74*	0.68*	0.04*

Table 1.4: Fish species abundance per lake, total abundance, and relative abundance (RA; % of total catch). Data were pooled across sites and sampling events for each lake. Asterisks (*) indicate species not previously recorded in IDNR general surveys.

Species	Lake					Total	RA
	Robinson	High	Knapp	Cree	Crooked		
Bluegill <i>Lepomis macrochirus</i>	332	494	426	311	95	1658	88.4
Warmouth <i>Lepomis gulosus</i>	5	1	2	1	1	5	0.3
Redear sunfish <i>Lepomis microlophus</i>	2			1	1	4	0.2
Largemouth bass <i>Micropterus salmoides</i>	19	6	6	3	12	46	2.5
Rock bass <i>Ambloplites rupestris</i>				2*		2	0.1
Johnny darter <i>Etheostoma nigrum</i>	1*			1*	2*	4	0.2
Least darter <i>Etheostoma microperca</i>			36*		6*	42	2.2
Iowa darter <i>Etheostoma exile</i>			4*	3*	5*	12	0.6
Logperch <i>Percina caprodes</i>					1*	1	0.1
Yellow bullhead <i>Ameiurus natalis</i>		2	3	1	1	7	0.4
Brown bullhead <i>Ameiurus nebulosus</i>					1	2	0.1
Tadpole madtom <i>Noturus gyrinus</i>	2*		5*	2*	2*	11	0.6
Brook silverside <i>Labidesthes sicculus</i>	8	9*	5	7	4	33	1.8
Blacknose shiner <i>Notropis heterolepis</i>	1*		3*	1*	13*	18	1.0
Banded Killifish <i>Fundulus diaphanus</i>			1		26*	27	1.4
Central mudminnow <i>Umbra limi</i>		2*				2	0.1
Lake chubsucker <i>Erimyzon sucetta</i>			1*			1	0.1

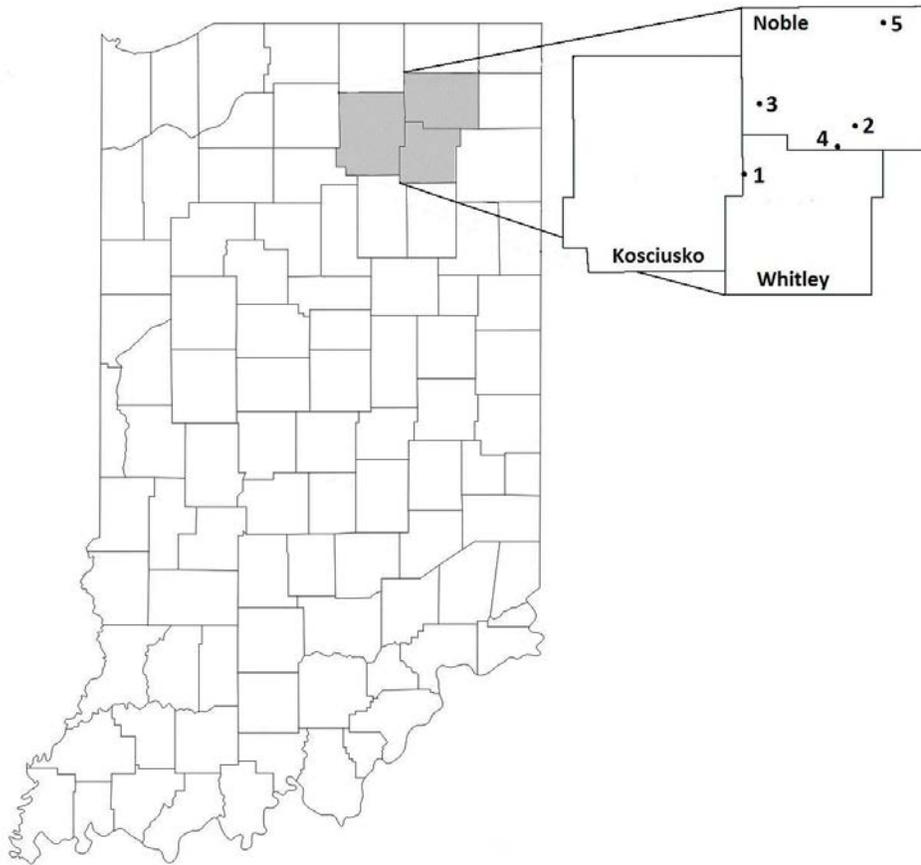


Figure 1.1: Site locations: 1) Robinson Lake, 2) High Lake, 3) Knapp Lake, 4) Crooked Lake, 5) Cree Lake.

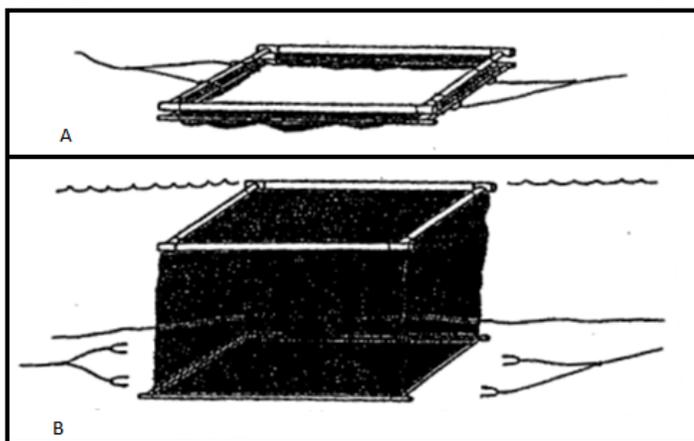


Figure 1.2: Illustration of a pop net, A) Pop net on bottom of lakebed ready to be deployed, B) Pop net after deployment, illustration from Serafy, Harrell, and Stevenson (1988).

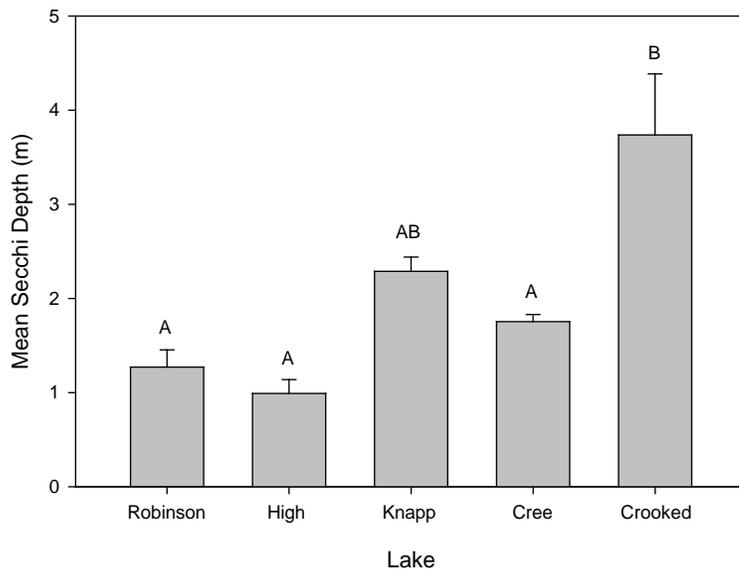


Figure 1.3: Average Secchi depth measurements for each lake. Different letters represent significant differences.

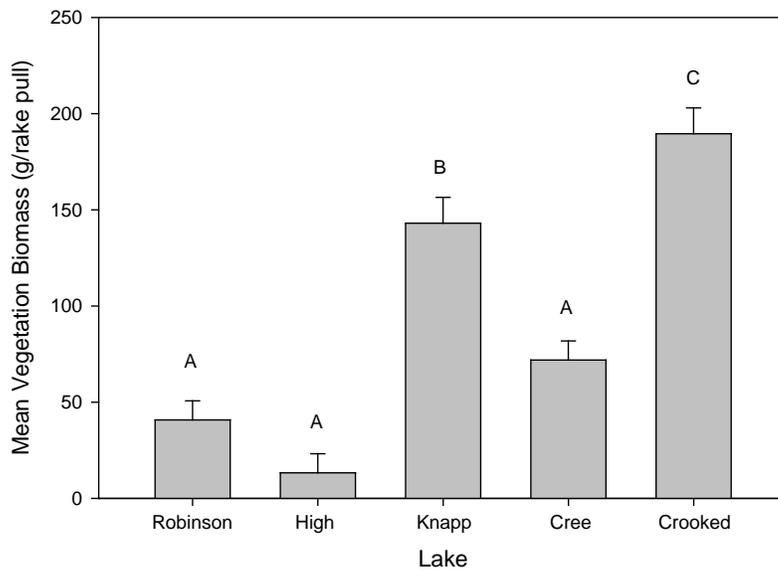


Figure 1.4: Average vegetation mass (g/rake pull) for sites within each lake. Different letters represent significant differences.

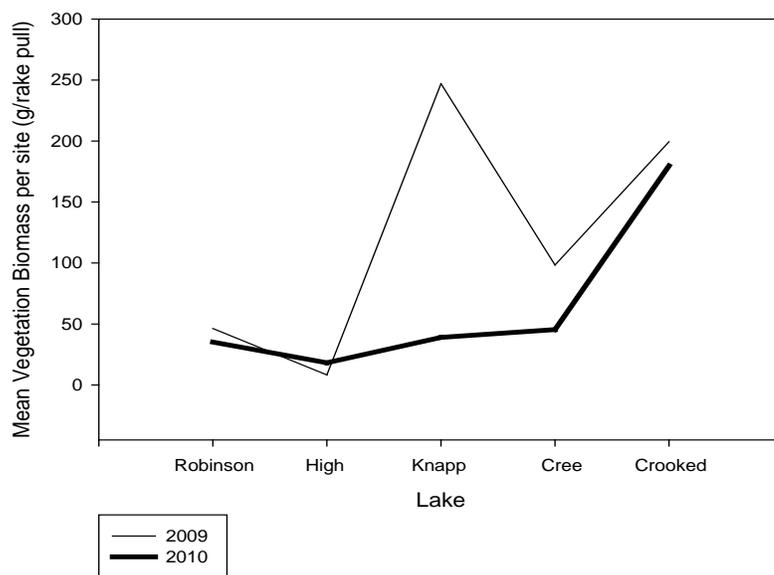


Figure 1.5: Vector plot for lake and year categories. MANOVA detected a significant interaction between lake and year groups for average vegetation biomass (g/rake pull).

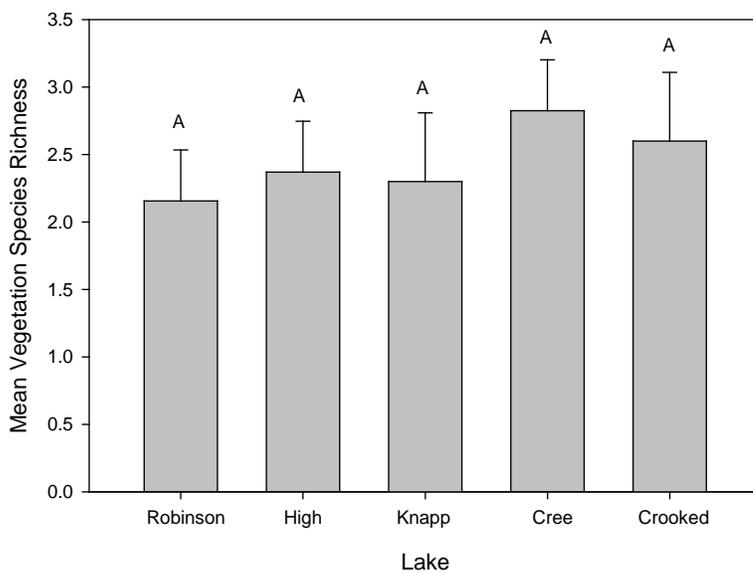


Figure 1.6: Average vegetation species richness of sites within each lake. Different letters represent significant differences.

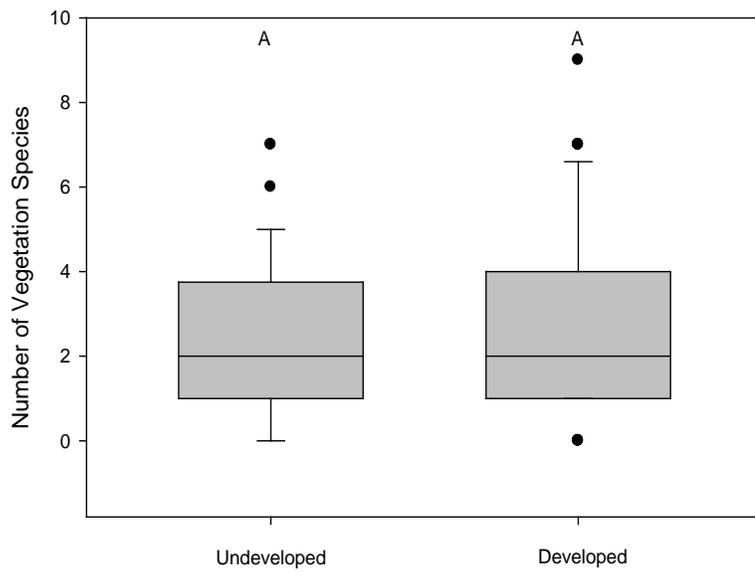


Figure 1.7: Vegetation species richness according to development category. Different letters indicate significant differences.

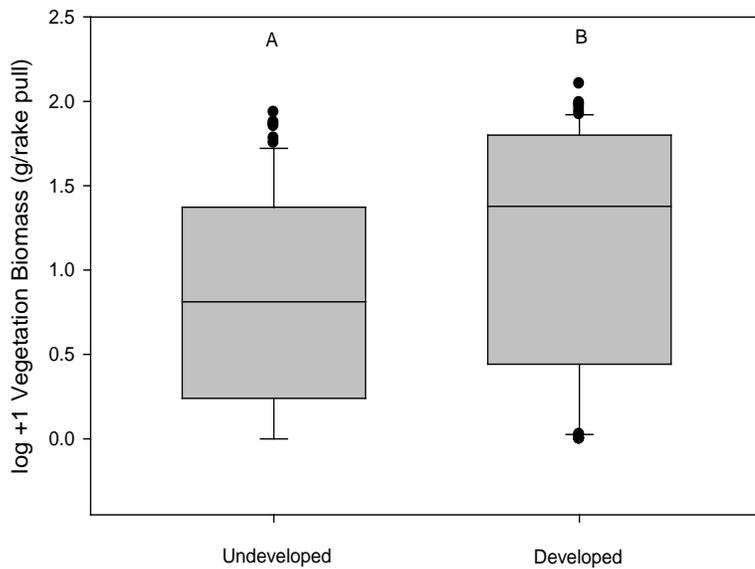


Figure 1.8: Grams of vegetation per rake pull (log + 1 transformed) according to development category. Different letters indicate significant differences.

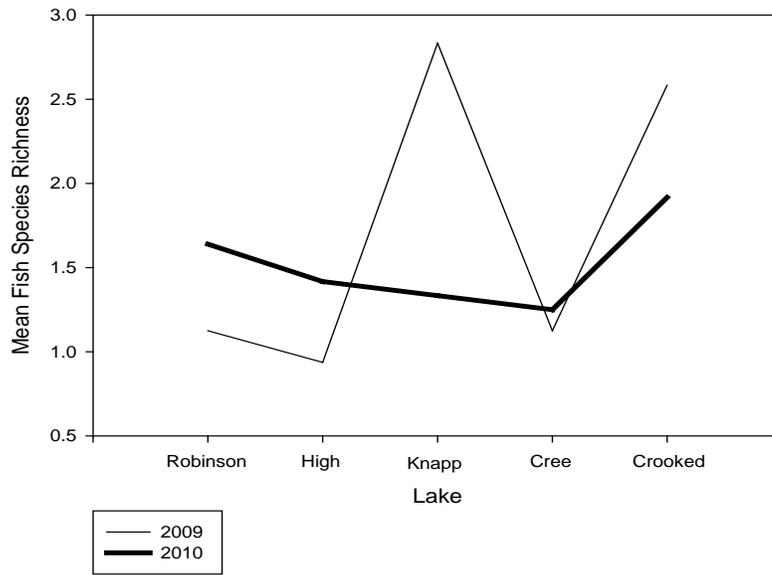


Figure 1.9: Vector plot for lake and year categories. MANOVA detected a significant interaction between lake and year groups for average fish species richness.

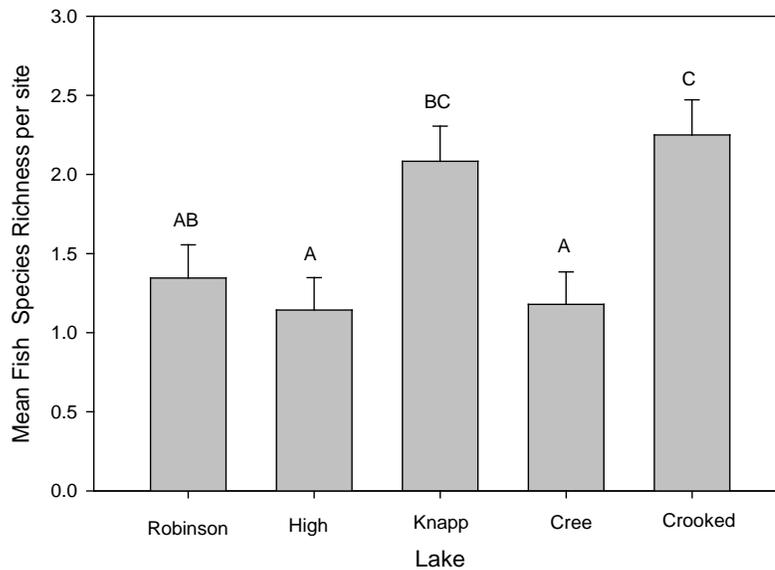


Figure 1.10: Average fish species richness for sites within each lake. Different letters represent significant differences.

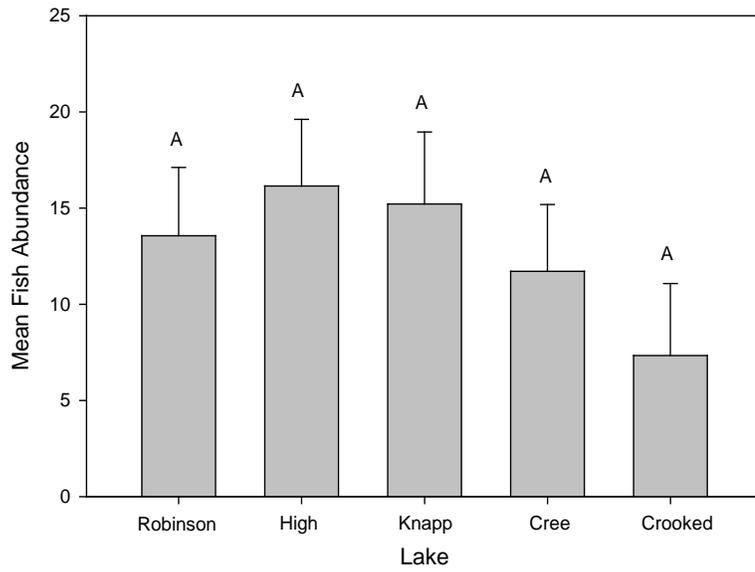


Figure 1.11: Average fish abundance for sites within each lake. Different letters represent significant differences.

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CHAPTER 2

POP NETS AS A LITTORAL ZONE SAMPLING GEAR

Introduction

Efficient tracking of abundance of fish populations and diversity of fish communities is critical for informing effective fisheries management. Because many fish populations utilize beds of aquatic macrophytes for refuge, forage grounds and spawning areas, understanding vegetation communities is also imperative. Fish sampling gear are selective in capturing fish of different sizes, locations and behaviors, and hence, are biased in their abilities to collect different fish species. To overcome such biases, multiple gear types are useful for sampling diverse fish communities. Collection of fishes in dense and highly diverse can be particularly difficult.

Aquatic macrophyte stands are important for many species of fish, with diverse macrophyte stands often being preferred to less diverse beds (Conrow et al. 1990). Presence and diversity of macrophytes can affect the species of fish found in a lake (Bettoli et al. 1997), fish species richness (Tonn and Magnuson 1982), fish species assemblages (Weaver et al. 1997), fish growth rates and production (Savino et al. 1992, Randall et al. 1996), the abundance of fishes (Chick and McIvor 1994), and fish behavior (Gotceitas and Colgan 1987, Savino and Stein 1982). In addition, macrophytes can impact the physical characteristics of a lake, influencing the availability of nutrients and chlorophyll a (Canfield et al. 1984, Hill 1979, Boyd 1971). Having an accurate description of the diversity and abundance of vegetation in a lake can allow biologists to make informed decisions regarding the ecological integrity of a lake as well as fish populations within that lake.

All common fish sampling gear show some type of selectivity. Electrofishing has a bias toward larger fish and samples can be affected by the selection imparted of the dip netting of shocked fish (Ruetz et al 2007 Tate et al 2003, and Hardin and Connor 1992). Some species of

fish are resistant to rotenone and collection can be difficult, especially for smaller fish (Beesley and Gilmour 2008). Fyke nets, trap nets, and drop nets can create artificial structure and shadows which introduce bias (Serafy et al. 1988). Drop nets also underestimate some benthic species (Beesley and Gilmour 2008). Sutela et al. (2008) found that gillnets did not successfully sample littoral fishes, even with mesh sizes as small as 5 mm. Seine nets are difficult to use in complex habitats such as dense vegetation, thus the highest efficiency is achieved in the least complex habitats (Dewey 1992). These biases mean multiple sampling gears are required for accurate characterization of fish communities (Vaux et al. 2000, Weaver et al. 1997).

Pop nets capture benthic species without damaging habitat. They can be set in dense vegetation flat on the ground to reduce introduction of artificial structure. By enclosing a known area, estimates of fish density are easily quantified (Beesley and Gilmour 2008). Additionally, they are appropriate for sampling small littoral zone fish and vegetation species present in low abundances. This study compared data obtained using pop nets to data from published reports to determine if they could be a supplemental tool used in more extensive sampling of nearshore fish communities.

Methods

Five glacial lakes were selected for sampling: Robinson, High, Knapp, Cree, and Crooked Lakes. Crooked Lake has a maximum depth of 33 m and surface area of 88.4 ha. Robinson, High, Knapp, and Cree Lakes are no more than 18 m at maximum depth and have a surface area less than 40.1 ha (Billig 2006, Table 2.1). All lakes are natural glacial lakes, are dimictic, and are within Kosciusko, Noble, or Whitley counties (Figure 2.1).

Pop nets were constructed according to Killgore et al. (1989) with some modifications. Frames were made with 2.5 cm diameter PVC pipe painted black to reduce visibility. The bottom frame was weighted with steel rebar, and the top was filled with foam to increase buoyancy. Corners were glued together and made of PVC elbows. Nets were 1.2 x 2.4 x 1.2 m and fitted with 0.5 cm black nylon mesh. The release mechanism consisted of two eyebolts on each side, one attached to the top frame and one to the bottom frame (Figure 2.2). Another eyebolt, attached to a 6.1 m length of rope with a buoy at the end, was pushed through the top and bottom eyebolts to hold the top frame to the bottom frame until the release eyebolts were

removed by quickly pulling the rope. Pop nets were set and left for two hours before deployment to allow adequate time for fish to return after disturbance.

Nearshore fish and vegetation were collected with pop nets during day and night in spring and summer 2009-2010. For day sampling, nets were set in early morning so that collection took place between 11:00 am and 1:00 pm. For night sampling, nets were set approximately 2 hours before dark so gear was pulled after sunset. Spring sampling was conducted from May 28 to July 13 in 2009 and from June 15 to July 1 in 2010. Summer sampling was conducted from August 5 to August 23 in 2009 and from August 10 to September 9 in 2010. Surface water temperature, pH, dissolved oxygen, and Secchi depth were measured at the deepest point of the lake at the end of each day's sampling session and at the beginning of each night sampling session (excluding Secchi depth).

Pop nets were set at four different collection sites per lake along the 1.2 m depth contour. Sites were located so that they were representative of the entire shoreline. Site selection was somewhat limited as pop nets had to be set in water less than 1.2 m deep. When set on the lakebed before deployment, the pop nets had a total height of only 5 cm to reduce introduction of shadows or artificial structure that might attract fish.

After pop net deployment, macrophytes were removed from within the pop nets with ten pulls of a standard double-headed aquatic vegetation rake. The rake was dropped into the pop net at specific points within the enclosed area, pulled for approximately 0.3 m, and lifted straight up out of the water. Vegetation was stored, and taken back to the lab for drying and identification.

Fish were removed from pop nets using a long-handled dip net with 0.6 cm mesh. After each swipe, fish were removed from the dip net and stored in a large bucket. The dip net was used to scoop out fish from the pop net until it consistently came out empty. At that point, the pop net was removed in a manner that allowed the net to gather any fish that may have been missed during dipnetting. All fish were then identified by species, measured to the nearest 0.1 cm, and released. Any fish that were unable to be identified in the field were euthanized using 400 mg/L MS222, preserved in 10% formalin, and brought back to the lab for identification.

Results

A total of 23 aquatic plant species were collected from the five study lakes. Five species, chara (*Chara* spp.), coontail (*Ceratophyllum demersum*), curlyleaf pondweed (*Potamogeton crispus*), and sago pondweed (*Potamogeton pectinatus*), were found in all five study lakes. Chara (*Chara* spp.) was the most prevalent vegetation species, comprising 78% of all vegetation collected (Table 2.3).

The usefulness of pop nets as a fishing gear can be determined by comparing data from published Tier II Indiana Department of Natural Resources (IDNR), Division of Fish and Wildlife vegetation reports. The lists of species collected during vegetation surveys were compared to those collected in this study to determine if pop nets captured species not previously recorded. The number of species collected from pop nets that were not accounted for ranged from 2 species in Robinson Lake to 8 species in High Lake. In total, 13 vegetation species were collected in this study but not listed in the latest Tier II vegetation survey reports. Seven of the novel species were pondweeds, and two were naiads.

A total of 17 fish species were collected from the five study lakes. Four species, bluegill (*Lepomis macrochirus*), warmouth (*Lepomis gulosus*), largemouth bass (*Micropterus salmoides*), and brook silverside (*Labidesthes sicculus*), were found in all 5 study lakes. Bluegill comprised 88% of fish collected (Table 2.4). Novel fish species netted by the pop nets that were not accounted for on IDNR general surveys ranged from 2 species in High Lake to 7 species in Crooked Lake. In total, 11 fish species were collected in this study but were not listed in the latest IDNR general survey report. The majority of novel species were those with smaller adult sizes, such as darters, madtoms, killifishes, shiners, and mudminnows.

Discussion

Pop nets collected species not previously recorded in IDNR vegetation reports and could supplement vegetation sampling. Currently the IDNR uses Tier II sampling to estimate aquatic vegetation which was designed to evaluate species found at all depths of the littoral zone, including the shoreline. Submerged, emergent and riparian vegetation are measured using one rake pull at multiple sites and visual assessment of riparian vegetation. One rake pull at a designated depth could easily miss one or several of the macrophytes found in the surrounding area. Pop net vegetation sampling was done within a quantifiable area and was a thorough

examination of the aquatic vegetation species found in one spot. As opposed to using a quadrat to quantify an area, pop nets can be set, deployed, and retrieved from a boat, and do not require diving.

Tier II sampling is one way to take a sweeping survey of the most abundant vegetation in and around a lake, and a general overview of the vegetation in a lake can provide important information regarding densities and dominant species. Pop net sampling, however, allows for an in-depth investigation of all of the vegetation found in concentrated areas of a lake.

Richardson's pondweed (*Potamogeton richardsonii*), listed as a threatened species in Indiana, was identified in pop net vegetation samples in 3 of the 5 study lakes. There was no previous record of Richardson's pondweed for any of these lakes.

While pop nets could not replace electrofishing, gill nets, or trap nets, they could augment the current sampling procedures. In this study pop nets captured fish species with small adult body sizes that hide in vegetation. These species are too small for gill and trap nets and would be difficult to see in dense vegetation at night while electrofishing. Five species captured by pop nets but not reported in reports that used traditional methods are considered to be relatively intolerant species (Schneider 2002). Banded killifish were listed as intolerant of turbidity and edge modification, least darters and tadpole madtoms are strongly dependent on macrophytes, logperch and blacknose shiners are acid intolerant, and blacknose shiners are silt intolerant. Tadpole madtoms and blacknose shiners were collected from Robinson, Knapp, Cree, and Crooked Lakes. Least darters and banded killifish were collected from Knapp and Crooked Lakes. Logperch were captured from Crooked Lake. Because these species have maximum lengths under 6 inches they are less likely to be sampled using traditional gear. Including them as additional target species may allow fisheries biologists to recognize problems regarding habitat degradation before they become severe enough to impact more tolerant species.

The ecological integrity of a lake is vital to managing the populations of fish that thrive within it. Knowing the status and composition of the littoral fish and vegetation communities is an essential part of the picture. Samples from pop nets detected differences in littoral zone communities among lakes. Surveys including pop nets can supplement information gathered by general fish surveys and vegetation surveys by providing a method for detailed vegetation sampling and collecting fish species that may be missed by more traditional methods.

Table 2.1: Characteristics of the 5 study lakes.

Lake	SA (ha)	Max depth (m)	Development category
Robinson	23.9	14	None
High	40.1	8	Low
Knapp	35.6	18	Medium
Cree	30.8	8	High
Crooked	83.4	33	High

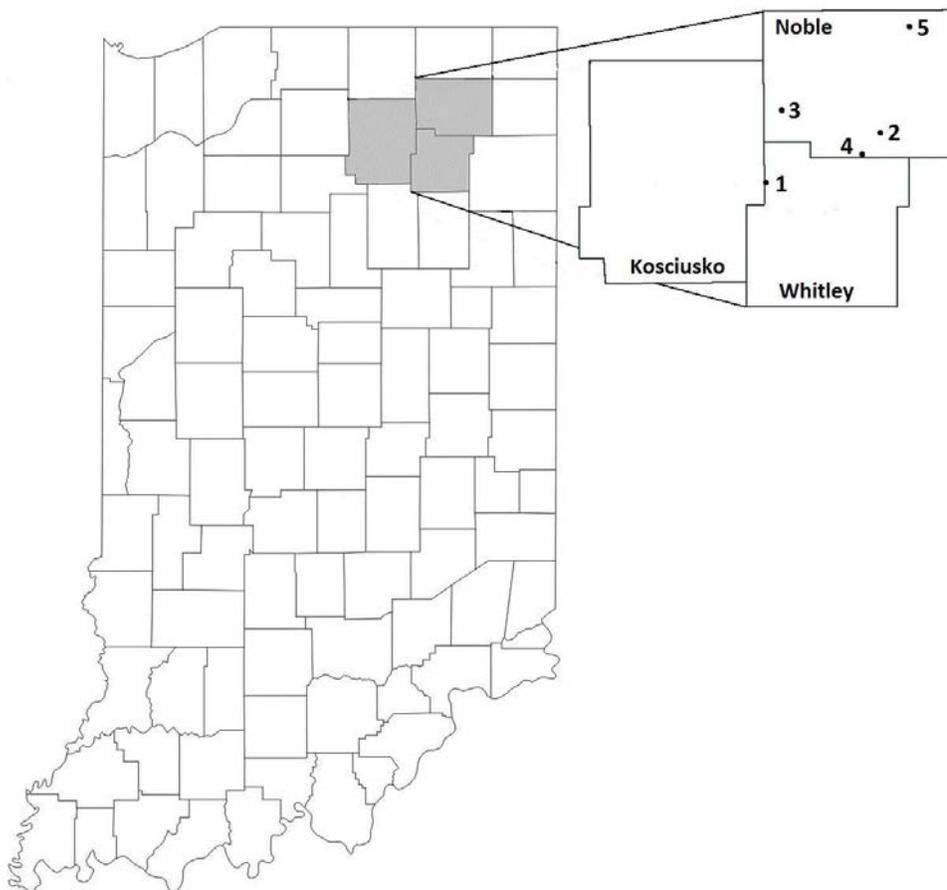


Figure 2.1: Site locations: 1) Robinson Lake, 2) High Lake, 3) Knapp Lake, 4) Crooked Lake, and 5) Cree Lake.

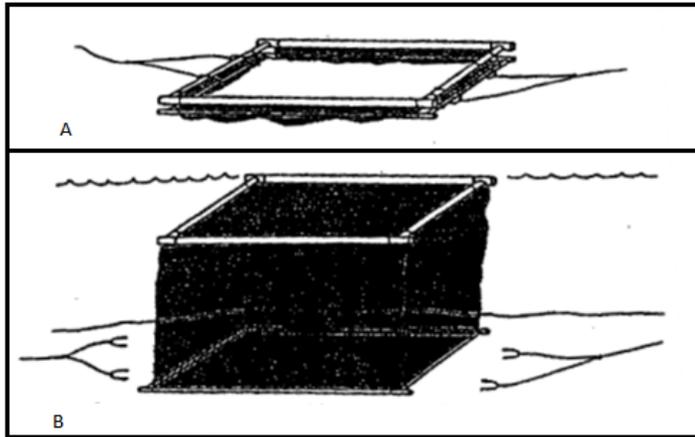


Figure 2.2: Illustration of a pop net, A) Pop net set on the bottom of a lakebed ready to be deployed, B) Pop net after deployment, illustration from Serafy, Harrell, and Stevenson (1988).

Table 2.2: A summary of the means of water quality parameters at each lake.

Lake	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Conductivity (mS/cm)	Secchi (m)
Robinson	24.0	7.90	8.74	0.381	1.3
High	26.9	9.80	9.08	0.403	1.0
Knapp	26.0	9.04	8.98	0.468	2.3
Cree	23.1	7.61	8.76	0.414	1.8
Crooked	24.9	8.52	8.92	0.304	3.7

Table 2.3: Average aquatic plant species biomass per lake (g/rake pull). P = present (plant was observed, but collected in amounts lower than 0.00 g/rake pull). Data were pooled across sites and sampling events for each lake except Knapp Lake. Knapp Lake was not pooled across years due to the extreme differences in biomasses. Asterisks (*) indicate species not previously recorded in IDNR Tier II vegetation surveys.

Species	Lake					
	Robinson	High	Knapp		Cree	Crooked
			2009	2010		
Chara <i>Chara</i> spp.	0.03*	0.34*	244.94	34.65	63.96	184.26
Coontail <i>Ceratophyllum demersum</i>	32.66	19.6	6.51	2.81	10.22	3.72
Watermilfoil <i>Myriophyllum</i> spp.	1.04	0.88*			0.79	7.18
Eelgrass/Water celery <i>Vallisneria americana</i>			0.38	0.69	0.59	
Elodea/Waterweed <i>Elodea americana</i>	0.42*		0.02*		0.17*	
Common bladderwort <i>Utricularia macrorhiza</i>						0.05*
Leafy pondweed <i>Potamogeton foliosus</i>		P	0.02	1.69	0.07*	0.04
Richardson's pondweed <i>Potamogeton richardsonii</i>		3.58*		1.51*		0.87*
Curlyleaf pondweed <i>Potamogeton crispus</i>	0.22	0.28	2.76		0.19	0.2
Sago pondweed <i>Potamogeton pectinatus</i>	0.01	0.18	0.22*	1.39*	0.09*	0.24*
Flat-stemmed pondweed <i>Potamogeton zosteriformis</i>		0.06*	0.07*			0.14*
American pondweed <i>Potamogeton nodosus</i>		1.80*			0.01*	
Small pondweed <i>Potamogeton pusillus</i>		0.11*				0.84*
Largeleaf pondweed <i>Potamogeton amplifolius</i>						0.47
Floating-leaf pondweed <i>Potamogeton natans</i>						0.20*
White Water Lily <i>Nymphaea odorata tuberosa</i>	9.92	1.62			7.88	0.2
Spatterdock <i>Nuphar advena</i>					1.32	
Cattail <i>Typha latifolia</i>		0.03				
Arrow Arum <i>Peltandra virginica</i>					0.16	
Spiny naiad <i>Najas marina</i>		P*		4.92*	1.44*	
Slender naiad <i>Najas flexilis</i>		0.04*	0.61*	2.74*	0.68*	0.04*

Table 2.4: Fish species abundance per lake, total abundance, and relative abundance (RA). Data were pooled across sites and sampling events for each lake. Asterisks (*) indicate species not previously recorded in IDNR general surveys.

Species	Lake					Total	RA
	Robinson	High	Knapp	Cree	Crooked		
Bluegill <i>Lepomis macrochirus</i>	332	494	426	311	95	1658	88.4
Warmouth <i>Lepomis gulosus</i>	5	1	2	1	1	5	0.3
Redear sunfish <i>Lepomis microlophus</i>	2			1	1	4	0.2
Largemouth bass <i>Micropterus salmoides</i>	19	6	6	3	12	46	2.5
Rock bass <i>Ambloplites rupestris</i>				2*		2	0.1
Johnny darter <i>Etheostoma nigrum</i>	1*			1*	2*	4	0.2
Least darter <i>Etheostoma microperca</i>			36*		6*	42	2.2
Iowa darter <i>Etheostoma exile</i>			4*	3*	5*	12	0.6
Logperch <i>Percina caprodes</i>					1*	1	0.1
Yellow bullhead <i>Ameiurus natalis</i>		2	3	1	1	7	0.4
Brown bullhead <i>Ameiurus nebulosus</i>					1	2	0.1
Tadpole madtom <i>Noturus gyrinus</i>	2*		5*	2*	2*	11	0.6
Brook silverside <i>Labidesthes sicculus</i>	8	9*	5	7	4	33	1.8
Blacknose shiner <i>Notropis heterolepis</i>	1*		3*	1*	13*	18	1.0
Banded Killifish <i>Fundulus diaphanus</i>			1		26*	27	1.4
Central mudminnow <i>Umbra limi</i>		2*				2	0.1
Lake chubsucker <i>Erimyzon sucetta</i>			1*			1	0.1

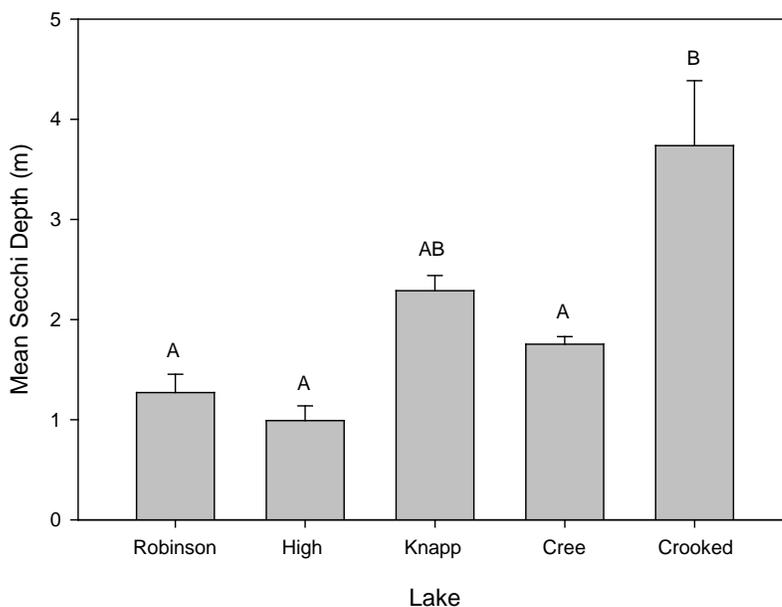


Figure 2.3: Average Secchi depths for each lake. Different letters represent significant differences.

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APPENDIX

APPENDIX

ADDITIONAL FISH SAMPLING GEAR

To overcome the sampling biases of pop nets, including selectivity toward vegetation-oriented fish and against structure-oriented fish, minnow traps and light traps were also set during sampling events. Minnow traps and light traps were chosen because they are small, passive gear that can be easily set by one person.

Six baited minnow traps were set along the lake shoreline within the 1.2 m depth contour. Because only four pop nets were available for sampling, baited minnow traps were set at additional sites to increase the portion of shoreline directly sampled. Double-funnel minnow traps (Frabill model 1271) with .6 cm black vinyl-coated mesh and a 2.5 cm opening were set during day and night sampling. Minnow traps were set before sundown and fished 3 hours later. Captured fish were removed, identified by species, counted, and released. Data from minnow trap night sampling were not used in overall statistical analyses (Table A.1).

Quatrefoil light traps (Aquatic Research, Inc.) were set during night sampling (Figure A.1). Only two light traps were set during night sampling sessions in 2009 to test efficacy of the traps. Six light traps were used during summer night sampling in 2010. Light traps were set at two (in 2009) or four (in 2010) sites additional to the 10 sites set with minnow traps and pop nets. Light traps had 10 mm wide entrance slots, and were set with Cyalume green 12-hour chemical light sticks and deployed for 3 hours (Marchetti et al. 2004). Night sampling was conducted during the new moon phase to minimize interference from other light sources (Hickford and Schiel 1999). Data from light trap night sampling were not used in overall statistical analyses because the majority of fish captured were under 2.5 cm (Table A.2).

Table A.1: Total catches for minnow traps pooled across sites and sampling events.

Species	Robinson	High	Knapp	Cree	Crooked
Bluegill <i>Lepomis macrochirus</i>	43	107	32	31	4
Warmouth <i>Lepomis gulosus</i>	4	6	0	0	0
Redear sunfish <i>Lepomis microlophus</i>	1	0	0	0	0
Largemouth bass <i>Micropterus salmoides</i>	0	0	1	0	0

Table A.2: Total catches for light traps by sites and sampling events.

Lake	Species	Abundance	Size Range (mm)
Robinson	Bluegill <i>Lepomis macrochirus</i>	5	10-81.2
	Blacknose shiner <i>Notropis heterolepis</i>	1	71
High	Bluegill <i>Lepomis macrochirus</i>	354	15-41, 61
	Brown bullhead <i>Ameiurus nebulosus</i>	21	15
	Brook silverside <i>Labidesthes sicculus</i>	1	48
	Least darter <i>Etheostoma microperca</i>	1	15
	Johnny darter <i>Etheostoma nigrum</i>	1	15
	Bluegill <i>Lepomis macrochirus</i>	91	15-38, 64
Knapp	Brook silverside <i>Labidesthes sicculus</i>	1	76
	Blacknose shiner <i>Notropis heterolepis</i>	1	33
	Largemouth bass <i>Micropterus salmoides</i>	1	58
	Bluegill <i>Lepomis macrochirus</i>	18	15-28
Cree		1	56
		1	64
		1	66
	Bluegill <i>Lepomis macrochirus</i>	442	8-27.9
Crooked		6	64-95
	Yellow perch <i>Perca flavescens</i>	1	112
	Largemouth bass <i>Micropterus salmoides</i>	2	74-89
	Brook silverside <i>Labidesthes sicculus</i>	1	51
	Iowa darter <i>Etheostoma exile</i>	1	33
	Blacknose shiner <i>Notropis heterolepis</i>	2	23-25
	Johnny darter <i>Etheostoma nigrum</i>	1	20

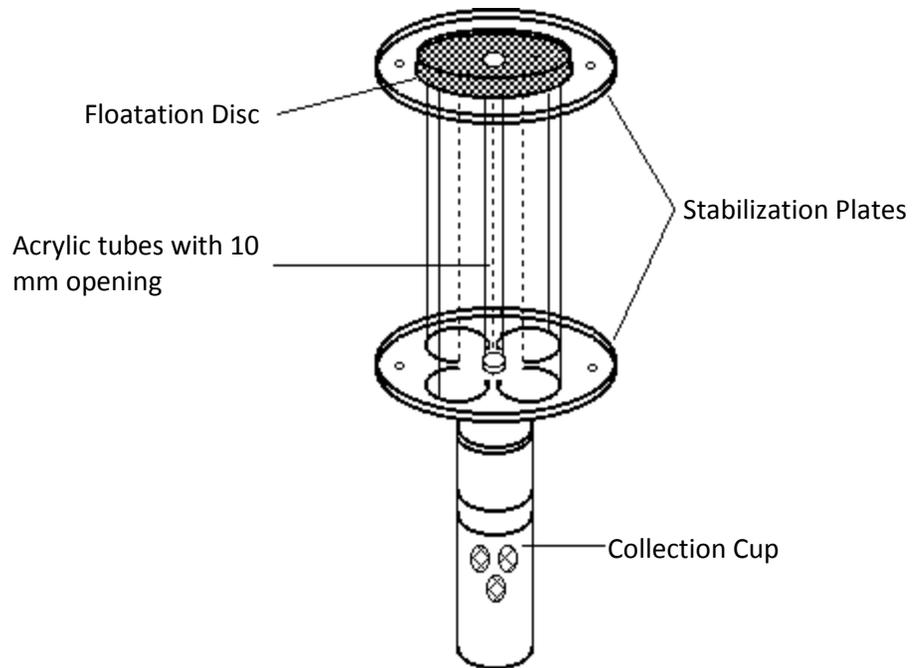


Figure A.1: Quatrefoil light trap with 10 mm opening. Illustration from Aquatic Research Instruments (2006).

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