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Krisan Marie Webb

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EVALUATION OF BLUEGILL (*LEPOMIS MACROCHIRUS*) FEEDING HABITS
AFTER ERADICATION OF EURASIAN WATERMILFOIL
(*MYRIOPHYLLUM SPICATUM*)

By

Krisan Marie Webb

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Mississippi State University
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in Wildlife and Fisheries Science
in the Department of Wildlife and Fisheries

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The objectives of this study were to determine effects of Eurasian watermilfoil (*Myriophyllum spicatum*) removal on bluegill feeding habits relative to diet composition, size, and feeding selectivity. Data were collected from 2003 through 2007 in four Minnesota lakes during June and September using boat electrofishing. Two lakes received an herbicide application of Endothall 2, 4-D, whereas remaining lakes were untreated and used as a reference. Bluegill diet composition, diets relative to size, and feeding selectivity were unaffected by vegetation removal, but varied seasonally with macroinvertebrate availability. Therefore, removal of Eurasian watermilfoil had minimal effects on bluegill feeding habits.

DEDICATION

This thesis is dedicated to my husband, Stephen Webb; without his encouragement this thesis would not have been completed.

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CHAPTER I

INTRODUCTION

Aquatic plants are important to fish, macroinvertebrates and zooplankton, providing spawning sites, forage habitat, structural attachment, and refuge (Cheruvilil et al.; 2002Valley et al. 2004). When compared to unvegetated areas, vegetated sites contain a greater abundance of fish, as well as macroinvertebrates and zooplankton (Borawa et al. 1979; Keast 1984). Most important, fish depend on this vegetation to forage on macroinvertebrates and zooplankton that provide energy to grow, but when an invasive plant takes over, high stem densities are created, decreasing foraging ability of fish (Crowder and Cooper 1982; Harrel and Dibble 1991).

Eurasian watermilfoil (*Myriophyllum spicatum* L), hereafter referred to as watermilfoil, was introduced into the U.S in the 1940's and first reported in Minnesota in 1987. Watermilfoil can form extensive homogeneous canopies that displace native macrophytes, and at high stem densities, act as barriers to fish movement (Keast 1984). These barriers, created by dense stems and foliage can reduce foraging success (Savino and Stein 1982; Dionne and Folt 1991). This effect is due to a decrease in search, encounter, and capture times (Anderson 1984; Diehl 1988), which can possibly affect bluegill (*Lepomis macrochirus*) life history processes (e.g., ontogenetic niche shift) and feeding habits (e.g., feeding selectivity).

Bluegills experience a shift in habitat and resource use several times during their life history, where juveniles typically feed in the littoral zone on macroinvertebrates and zooplankton, whereas larger bluegill feed in the pelagic zone on zooplankton (Werner and Hall 1988). This ontogenetic niche shift may be compromised as the habitat becomes increasingly complex (e.g., high stems densities), limiting bluegill optimal foraging (Werner and Hall 1974). Prey selection within these high stem densities also may be compromised when the ability to search and encounter prey is limited (Anderson 1984). Watermilfoil provides concealment for many macroinvertebrate and zooplankton (Cheruvilil et al. 2002) species, limiting foraging opportunities. Limited studies are available on effects of vegetation removal on bluegill feeding habits which is important for growth, but removal of vegetation and its effects on bluegill growth has been studied extensively.

Studies such as Pothoven et al. (1999), Unmuth et al. (1999), Olson et al. (1998), and Savino et al. (1992), have examined removal of vegetation and its effects on bluegill growth rates, but specifically Pothoven et al. (1999) and Unmuth et al. (1999) looked at removal effects of watermilfoil. Both studies indicated that removal of watermilfoil was necessary to improve bluegill growth rates, but how much vegetation needs to be removed? Studies such as Unmuth et al. (1999) and Olson et al. (1998), used models to evaluate how much vegetation needed to be removed to improve bluegill growth, they both studies concluded that the littoral zone should not include more than 20 to 40 % vegetation.

All studies mentioned are good examples of the effects of vegetation removal on bluegill growth. However, most were conducted over brief time periods, used few

specimens of a single age-class, and were implemented on a small scale. Thus, there is a need for long term studies on bluegill feeding habits and life history. To this end, in chapter II, I investigated the hypothesis that a temporary release of food would be available for bluegill after plant removal, thus increasing certain food items in their diets. I examined bluegill diet composition before and after plant removal, and three years post-treatment. In chapter III, I investigated the hypothesis that plant removal would influence bluegill diets relative to fish size based on Werner and Hall's (1988) hypothesis of habitat switching. I looked at changes and differences in diets of bluegill 40-70 mm and 80-160 mm standard length. I identified potential habitat shifts after plant removal according to Werner and Hall's (1988) hypothesis. I also investigated the hypothesis that removal of plants will affect diet selectivity of bluegill, allowing foraging on other types of invertebrates not available before vegetation removal. I identified preferred prey items selected by bluegill and identified any changes before and after plant removal.

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CHAPTER II

SHORT AND LONG TERM EFFECTS OF BLUEGILL FEEDING HABITS AFTER ERADICATION OF EURASIAN WATERMILFOIL

ABSTRACT

Little is known about how changes in plant communities influence diet of foraging fishes. I evaluated diet of bluegill (*Lepomis macrochirus*) in four Minnesota lakes selected for having 80% coverage of Eurasian Watermilfoil (*Myriophyllum spicatum* L.). In 2004, a low-dose of endothall/2, 4-D treatment was applied to two lakes and used as an experimental manipulation to shift plant composition. Pre-treatment data were collected in 2003 and post-treatment data in 2004-2007. Fish were collected during summer (June) and autumn (September) using electrofishing. Fish specimens were preserved and transported to the laboratory where stomach contents were analyzed. All macroinvertebrates were enumerated and identified to taxonomic order. Dietary composition was compared before and after herbicide application (2003-2004) and three years post treatment (2005-2007). My results suggested removal of invasive plants and restoration to native plants had minimal influence on diet composition of bluegill. However, I noted temporal variations in abundance of a number of dietary items, which may be related directly to seasonal availability of macroinvertebrate prey.

INTRODUCTION

Aquatic plants provide many functions including primary production, stabilizing sediments and maintaining water clarity, and habitat for zooplankton, macroinvertebrates and numerous fish species (Carpenter et al. 1997; Dibble et al. 1996; Diehl and Kornijow 1998). Many juvenile and adult fish have been reported in habitats containing aquatic vegetation, when compared to unvegetated areas and these vegetated areas often harbor greater fish densities (Dibble et al. 1996). Killgore et al. (1989) found up to seven times more fish in areas with plants than in areas without. Moreover, younger and smaller fish become more abundant as plant density increases (Barnett and Schneider 1974; Borawa et al. 1979; Moxley and Langford 1985). Macroinvertebrate abundances and diversity are greater in aquatic plants than in unvegetated areas, because leaves and stems provide substrate for attachment and protection from predators (Gilinsky 1984; Keast 1984; Beckett et al. 1992). However, invasive plants such as Eurasian watermilfoil (*Myriophyllum spicatum* L.) can alter fish and macroinvertebrate habitat.

Eurasian watermilfoil (hereafter referred to as watermilfoil) was introduced into the U.S in the 1940's and first reported in Minnesota in 1987 in Lake Minnetonka; as of summer 2004 it had spread to 159 lakes, most in the Twin Cities metro area (Valley et al. 2004). Establishment of watermilfoil can lead to extensive homogeneous canopies that can displace native macrophytes (Madsen et al. 1991), affect fish foraging abilities (Crowder and Cooper 1979; Harrel and Dibble 2001), and affect macroinvertebrate biomass (Keast 1984; Menzie 1980; Cheruvilil et al. 2002). When watermilfoil forms these extensive homogeneous beds throughout the littoral zone, these macrophytes act as barriers to fish movement (Keast 1984), and these barriers can reduce foraging success

(Heck and Thoman 1981; Savino and Stein 1982; Dionne and Folt 1991). This reduction effect is due to an increase in search, encounter, and capture times (Anderson 1984; Diehl 1988). Crowder and Cooper (1982) found that fish in presence of high macrophyte densities (177 ± 10 stems/m²) experienced reduced prey capture rates and slower growth rates despite the greater biomass of prey available. In another study, prey capture rates declined as a result of structural complexity, decreasing foraging efficiency as habitat became more spatially complex (Dibble et al. 1996) and affected macroinvertebrate availability.

Eurasian watermilfoil, a highly dissected plant, has greater surface to plant mass ratio and therefore may provide more habitat for macroinvertebrates (Krull 1970; Gilinsky 1984; Pardue and Webb 1985). However, studies have shown that watermilfoil supports fewer macroinvertebrates per gram of plant than native plant species, despite its greater surface area (Soszka 1975; Dvorak and Best 1982; Keast 1984). Cumulative species richness significantly decreases with increasing percentage cover of watermilfoil, and macroinvertebrate density and biomass significantly decrease with increasing percentage cover of watermilfoil (Cheruvilil et al. 2002).

Several techniques have been evaluated to reduce high density of aquatic plants, and aquatic herbicides are high on the list. Use of aquatic herbicides in aquatic plant management have been assessed (Pothoven et al. 1999; Valley and Bremigan 2002), and found to cause major shifts in vegetative habitats and fish communities. Removal of aquatic vegetation can produce a temporary release of food in the environment, thus changing the fish community (Bettoli et al. 1993), but studies are limited on the impacts of vegetation removal on bluegill (*Lepomis macrochirus*) foraging habitat, conducted on

a long term scale. I investigated the hypothesis, that as a result of vegetation removal, there would be a temporary release of prey items into the environment, reflected by an increase in bluegill diets. I measured bluegill diets before and after herbicide removal of Eurasian watermilfoil and evaluated potential changes in bluegill diets three years after watermilfoil removal.

METHODS

My experiment constituted four eutrophic lakes located in the Minneapolis, Minnesota metropolitan area: Auburn, Pierson, and Zumbra (Carver Co.), and Bush (Hennepin Co.). These lakes ranged in area from 66 to 106 ha and had a max depth from 8.53 to 25.6 m (Table 2.1). Lakes were all dominated by watermilfoil with a surface coverage of at least 80% of the littoral zone, and a similar fish assemblage dominated by bluegill. In spring of 2004, an herbicide application of low-dose endothall/2, 4-D was used to control the watermilfoil and a small percentage of curly leaf pondweed (*Potamogeton crispus*) in Bush and Zumbra lakes. Auburn and Pierson lakes were not treated and used as reference.

Pre-treatment data were collected in 2003 prior to herbicide application; the post-treatment period included 2004 to 2007. Macrophyte abundance was sampled using 1.0 m² popnets, each popnet was placed within a macrophyte bed at water depths of 0.5 to 1.25 m, and parallel to the shore at 1.0 to 5.0 m (Slade et al. 2005). Macrophyte measurements were conducted by placing a 1.0 m long PVC pipe and counting all stems touching the pipe along 1.0 m transects at the surface and 0.4 m below the surface.

Abundance was defined as the average of these two readings and results were expressed as stems/m² (Slade et al. 2005).

Bluegills were sampled in each lake, twice a year during June and September for five years (2003-2007) using boat mounted electrofishing. A minimum of twenty bluegills were selected randomly from the field collection and preserved in 70% ethanol. Specimens were transported to the laboratory at Mississippi State University where stomachs were removed, dissected, and contents preserved again in 70% ethanol and stored until analysis (Bowen 1983). Macroinvertebrates, zooplankton and all other stomach contents were enumerated during analysis and identified to a specific taxonomic order using Merritt and Cummins (2007) and Thorp and Covich (1991).

Statistical analysis

I used a multi-variate analysis of variance (MANOVA) to analyze frequency of occurrence of certain taxa in bluegill diets. MANOVA is robust against deviation from normality and violations of homogeneity of covariance matrices (Zar 1999). I tested for significant differences in short term changes in diet composition before and after plant removal (2003-2004) and long term changes, three years after plant removal (2005-2007). Each analysis tested for possible interactions between year, season, and treatment. Taxa that represented <5% of bluegill diets were excluded from analyses. Data did not meet normality criteria and were log transformed; I assumed a p-value of 0.05 to be statistically significant.

A MANOVA measures predictor variables on multiple criterion variables and assigns a Wilk's lambda to specified interactions (Hatcher and Stepanski 1994). Wilk's

lambda values can range from 0 to 1 and are interpreted differently from an R^2 value. Small values (near zero) are relatively strong relationships whereas larger values (near one) are relatively weak relationships between the predictor variable and multiple criterion variables. For example; if the Wilk's lambda is 0.01, this represents a strong relationship and accounts for 99% of the variability (e.g., $0.01 - 1 = 0.99$). When the Wilk's lambda is 0.88, then the relationship between the predictor variable and multiple criterion variables is weak, and accounts for only 12% of the variability ($0.88 - 1 = 0.12$) (Hatcher and Stepanski 1994).

RESULTS

Shift in vegetated habitat

Application of endothall and 2,4-D was effective in the removal of watermilfoil and curly-leaf pondweed. After the herbicide application in spring 2004, number of exotics (stems/m²) decreased, whereas native plants increased (Figure 2.1). Three years after plant removal, native plants in treatment lakes continued to increase in relative abundance with a decrease in exotic plants. Once exotic plants were removed from the lakes, native species returned one year after treatment (Table 2.2). Many species, such as *Elodea canadensis* Rich., *Sagittaria graminea* Michx., *Potamogeton Illinoensis* Morong., *Typha* sp., and *Scirpum* sp. were examples of species that were not detected in surveys before watermilfoil removal and were established after removal (Table 2.2). Reference lakes remained unaltered while retaining a high composition of exotic plants (Figure 2.1).

Short term effects on diet

Of all 18 taxa found in bluegill diets (Table 2.3), only six taxa orders composed \geq 5% of diets within treatment and reference lakes (Table 2.4). A year*season*treatment interaction (Wilk's lambda = 0.94, $p = 0.009$) was found between treatment and reference lakes for amphipoda (Table 2.3). However, only 6% of the variability in bluegill diets could be explained by this interaction. The remaining 94% of the variability in bluegill diets was possibly due to natural changes in macroinvertebrate abundances.

Long term effects on diet

Bluegill diet composition from 2005 to 2007 revealed a year*season*treatment interaction (Wilk's lambda = 0.88, $p < 0.01$) for treatment and reference lakes, one changed occurred in zooplankton consumption; cladocera and three changes in macroinvertebrate consumption; hymenoptera, trichoptera, and ephemeroptera, accounting for 12% of the variability in bluegill diets (Table 2.5). The remaining 88% of the variability of macroinvertebrate composition in bluegill diets could possibly be explained by seasonal changes in macroinvertebrate abundances.

DISCUSSION

This study did not support the hypothesis that a temporary release of food in the environment, after vegetation removal, would be reflected in bluegill diets. Failure to support this hypothesis may be due to small sample size that precluded detection of statistical differences. Only one prey item exhibited a change relative to year, treatment and season. Potential long term effects of vegetation removal revealed that only six prey

items changed, relative to year, treatment, and season. This study did not find the same effects as Bettoli et al. (1993); however, my study allowed the replacement by the native plant communities (Table 2.2), whereas Bettoli et al. (1993) removed vegetation permanently. The quick replacement by native vegetation in my study possibly reduced the temporary effects of food released in the environment, thus only affecting one change in zooplankton consumption.

Changes that occurred in amphipoda (zooplankton) may have been associated with natural changes in macroinvertebrate abundance and habitat characteristics. Amphipoda consumption differed between year, treatments and seasons (Table 2.3) and could be associated with presence of watermilfoil in reference lakes. Menzie (1980) found more amphipods were associated with milfoil than any other plant, which would explain why this taxon was consumed more in reference lakes than in treatment lakes. However, the difference in consumption in treatment lakes may be associated with natural changes in macroinvertebrate abundances as indicated by Mittelbach (1981). The short term effects of vegetation removal revealed one change in zooplankton selection, but long term effects also revealed a change in another zooplankton species.

Cladocera were one of the most abundant zooplankton species, and were important to bluegill diets. Cladocera were one of the most consumed prey items in treatment lakes from 2005 to 2007 (Table 2.4); Robinson (1981) also reported that cladocera populations were five times more abundant in watermilfoil in Okanagan lakes. One possible explanation for an increase in zooplankton consumption may be diel vertical migration (DVM) by cladocera in the pelagic zone. DVM is well documented and the degree of DVM increases with increasing density of planktivorous fish and

decreasing plant density (Jeppesen et al. 1997). If bluegill density increased in the pelagic zone after watermilfoil was removed, DVM might explain why bluegills within the littoral zone were consuming more cladocera in treatment lakes. A possible shift of bluegill to the pelagic may have resulted due to faster growth rates of bluegill allowing them to forage in the pelagic zone at a large enough body size to avoid predation (Werner and Hall 1988). Not only did zooplankton consumption change 3 years post vegetation removal, but three different macroinvertebrates prey species changed.

I found changes in representations of hymenoptera, trichoptera, and ephemeroptera (Table 2.4) macroinvertebrate species in bluegill diets over time. Changes within the consumption of macroinvertebrates may be linked to the growth of the watermilfoil plant as well as natural changes in abundance over years and seasons. Keast (1984) found that in July, when watermilfoil is at full growth, it supports fewer ephemeroptera nymphs and trichoptera larvae than native plant communities of *Potamogeton vallisneria*. These nymphs and larvae also were more abundant in May in the community of *Potamogeton vallisneria*, as opposed to July when watermilfoil was in full growth. Changes from an exotic plant community to a more native community, led to an increase of these macroinvertebrates in bluegill diets. The remaining 88% of the variability of macroinvertebrate composition in bluegill diets within my treatment and reference lakes could possibly be due to seasonal changes in macroinvertebrate abundances as indicated by Mittelbach (1981). He author found that macroinvertebrate abundances within littoral vegetation can change throughout the year. Cheruvilil et al. (2002) also found macroinvertebrate density and biomass to be variable across lakes and months, which may be happening in my study lakes.

In conclusion, small changes in bluegill diets occurring immediately following plant removal were statistically significant, but may not represent biological significance. Long term effects only changed consumption of four prey items in bluegill diets and were statistically significant, but may not represent a significant biological change. Changes in diet composition were not affected by plant removal, but rather by natural changes in macroinvertebrate populations. Future research should evaluate how vegetation removal potentially affects bluegill life history and feeding selectivity, which may have been masked by my generic diet analysis.

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Table 2.1 Physical characteristics of study lakes. Data were obtained from Skogerboe and Getsinger (2006).

Lake	Lake Area (ha)	Max Depth (m)	Littoral Zone (ha)	% Littoral zone
Auburn	106	25.6	64	61
Bush	70	8.53	46	66
Pierson	95	12.19	48	50
Zumbra	66	17.68	37	57

Table 2.2 Relative abundance (stems/m²) of shift in plant species in bluegill foraging habitat in Bush and Zumbra lakes.

Plant species	Pre-treatment (2003)		Post-treatment (2004)	
	Mean ± SE	% Composition	Mean ± SE	% Composition
Exotic Plants				
<i>Myriophyllum spicatum</i> L.	11.43 ± 1.78	37.06	0.00 ± 0.00	0.00
<i>Potamogeton crispus</i> L.	0.53 ± 0.82	1.73	0.00 ± 0.00	0.00
Native Plants				
<i>Nymphaea odorata</i> Woodv.	5.97 ± 0.59	19.37	9.55 ± 0.85	41.65
<i>Ceratophyllum demersum</i> L.	4.51 ± 1.30	14.63	2.51 ± 0.74	10.93
<i>Ranunculus flammula</i> var. <i>reptans</i> (L.)	1.72 ± 0.75	1.78	0.00 ± 0.00	0.00
<i>Potamogeton foliosus</i> Raf.	0.55 ± 0.17	3.15	0.19 ± 0.08	0.47
<i>Potamogeton natans</i> L.	1.08 ± 0.37	2.75	0.54 ± 0.31	2.37
<i>Vallisneria americana</i> Michx.	0.85 ± 0.73	0.00	1.11 ± 0.61	4.88
<i>Elodea canadensis</i> Rich.	0.00 ± 0.00	0.00	0.12 ± 0.08	0.51
<i>Sagittaria graminea</i> Michx.	0.00 ± 0.00	0.00	0.89 ± 0.51	3.89
<i>Typha</i> sp.	0.00 ± 0.00	0.00	0.26 ± 0.26	1.14
<i>Scirpus</i> sp.	0.00 ± 0.00	0.00	3.14 ± 1.44	14.88
<i>Potamogeton illinoensis</i> Morong.	0.00 ± 0.00	0.00	0.21 ± 0.15	0.91
<i>Stuckenia pectinata</i> (L.) Böerner	3.02 ± 0.84	9.79	0.59 ± 0.59	2.59
<i>Potamogeton richardsonii</i> (Benn.) Rydb.	0.07 ± 0.07	0.25	0.00 ± 0.00	0.00
<i>Chara</i> sp.	0.00 ± 0.00	0.00	3.62 ± 1.56	0.00
<i>Najas flexilis</i> (Willd.) Rostk. and Schmidt	0.00 ± 0.00	0.00	0.00 ± 0.00	0.00

Table 2.3 Percentage composition of taxa found in bluegill stomachs (n = 327 and 349 from treatment and reference lakes, respectively) from 2004 to 2007 in treatment (Bush and Zumbra) and reference (Auburn and Pierson) lakes.

Taxa	Treatment	Reference
	% Composition	% Composition
Acari ¹	1.12	0.51
Amphipoda ^{1, 4}	3.32	2.74
Annelida ³	0.00	0.04
Cladocera ^{1, 4}	51.00	55.27
Coleoptera ¹	1.05	0.29
Copepoda ¹	0.20	0.00
Diptera ^{1, 4}	18.13	19.95
Ephemeroptera ^{1, 4}	1.10	2.11
Gastropoda ²	0.14	0.06
Hemiptera ¹	0.11	0.06
Hymenoptera ^{1, 4}	0.02	0.14
Nematoda ³	0.13	0.11
Nematomorpha ³	0.02	0.01
Odonata ¹	0.11	0.30
Ostracoda ¹	1.18	0.23
Pelecypoda ²	0.05	0.10
Plecoptera ¹	0.02	0.10
Trichoptera ^{1, 4}	0.91	1.79
Fish Parts	4.93	1.91
Plant Material	12.82	13.76
Other	2.55	0.39
Unknown	0.96	0.09

¹Represents Order

²Represents Class

³Represents Phylum

⁴Taxa that represented $\geq 5\%$ of bluegill diet, calculated from bluegill during each year

Table 2.4 Geometric means (\pm SE) for six taxa found ($>5\%$) in bluegill diets from 2003 to 2004 in June and September for treatment (Bush and Zumbra) and reference (Auburn and Pierson) lakes in Minnesota. n = number of bluegill examined.

Year	Season	Treatment	Taxa ¹	n	Mean \pm SE
2003	June	Treatment	Diptera	40	2.60 \pm 0.51
			Amphipoda ²	40	0.45 \pm 0.13
			Cladocera	40	0.67 \pm 0.21
			Trichoptera	40	0.16 \pm 0.07
			Hymenoptera	40	0.00 \pm 0.00
			Ephemeroptera	40	0.12 \pm 0.06
	June	Reference	Diptera	40	1.89 \pm 0.22
			Amphipoda ²	40	0.69 \pm 0.14
			Cladocera	40	0.66 \pm 0.26
			Trichoptera	40	0.42 \pm 0.12
			Hymenoptera	40	0.00 \pm 0.00
			Ephemeroptera	40	0.38 \pm 0.10
2003	September	Treatment	Diptera	40	2.32 \pm 0.18
			Amphipoda ²	40	0.55 \pm 0.15
			Cladocera	40	2.21 \pm 0.41
			Trichoptera	40	0.36 \pm 0.14
			Hymenoptera	40	0.11 \pm 0.09
			Ephemeroptera	40	0.12 \pm 0.05
	September	Reference	Diptera	40	2.61 \pm 0.16
			Amphipoda ²	40	2.16 \pm 0.32
			Cladocera	40	0.51 \pm 0.19
			Trichoptera	40	0.46 \pm 0.13
			Hymenoptera	40	0.30 \pm 0.16
			Ephemeroptera	40	0.30 \pm 0.08
2004	June	Treatment	Diptera	40	2.53 \pm 0.20
			Amphipoda ²	40	0.40 \pm 0.13
			Cladocera	40	1.44 \pm 0.34
			Trichoptera	40	0.16 \pm 0.05
			Hymenoptera	40	0.00 \pm 0.00
			Ephemeroptera	40	0.07 \pm 0.04
	June	Reference	Diptera	40	2.13 \pm 0.20

Table 2.4 Continued.

Year	Season	Treatment	Taxa ¹	n	Mean ± SE
2004	June	Reference	Amphipoda ²	40	0.71 ± 0.15
			Cladocera	40	2.71 ± 0.50
			Trichoptera	40	0.28 ± 0.09
			Hymenoptera	40	0.00 ± 0.00
			Ephemeroptera	40	0.45 ± 0.11
2004	September	Treatment	Diptera	40	2.74 ± 0.18
			Amphipoda ²	40	0.66 ± 0.17
			Cladocera	40	1.32 ± 0.23
			Trichoptera	40	0.24 ± 0.09
			Hymenoptera	40	0.06 ± 0.04
			Ephemeroptera	40	0.06 ± 0.04
	September	Reference	Diptera	40	3.02 ± 0.27
			Amphipoda ²	40	0.97 ± 0.19
			Cladocera	40	0.44 ± 0.14
			Trichoptera	40	0.24 ± 0.08
			Hymenoptera	40	0.08 ± 0.08
			Ephemeroptera	40	0.09 ± 0.04

¹MANOVA used to test for difference in year, season, and treatment; year*season*treatment interaction (Wilk's lambda = 0.94, $p = 0.009$)

²Univariate test conducted within MANOVA for individual taxa ($F_{1,312} = 12.50, p = 0.001$)

Table 2.5 Geometric means (\pm SE) for six taxa found ($\geq 5\%$) in bluegill diets from 2005 to 2007 for year, treatment, and season for treatment (Bush and Zumbra) and reference (Auburn and Pierson) lakes in Minnesota. n = number of bluegill examined.

Year	Treatment	Season	Taxa ¹	n	Mean \pm SE
2005	Treatment	June	Diptera	40	1.52 \pm 0.22
			Amphipoda	40	0.11 \pm 0.05
			Cladocera ²	38	0.76 \pm 0.21
			Trichoptera ³	40	0.48 \pm 0.13
			Hymenoptera ⁴	40	0.02 \pm 0.02
			Ephemeroptera ⁵	40	0.68 \pm 0.16
	Treatment	September	Diptera	41	2.57 \pm 0.20
			Amphipoda	41	1.06 \pm 0.22
			Cladocera ²	41	2.39 \pm 0.33
			Trichoptera ³	41	0.17 \pm 0.09
			Hymenoptera ⁴	41	0.00 \pm 0.00
			Ephemeroptera ⁵	41	0.06 \pm 0.04
2005	Reference	June	Diptera	40	1.95 \pm 0.19
			Amphipoda	40	0.53 \pm 0.14
			Cladocera ²	40	0.58 \pm 0.14
			Trichoptera ³	40	1.05 \pm 0.19
			Hymenoptera ⁴	40	0.03 \pm 0.02
			Ephemeroptera ⁵	40	0.55 \pm 0.10
	Reference	September	Diptera	46	2.50 \pm 0.18
			Amphipoda	46	0.35 \pm 0.09
			Cladocera ²	46	1.29 \pm 0.20
			Trichoptera ³	46	0.22 \pm 0.08
			Hymenoptera ⁴	46	0.00 \pm 0.00
			Ephemeroptera ⁵	46	0.22 \pm 0.09
2006	Treatment	June	Diptera	56	2.11 \pm 0.16
			Amphipoda	56	0.21 \pm 0.06
			Cladocera ²	56	0.42 \pm 0.13
			Trichoptera ³	56	0.58 \pm 0.10
			Hymenoptera ⁴	56	0.01 \pm 0.01
			Ephemeroptera ⁵	56	0.98 \pm 0.14

Table 2.5 Continued.

Year	Treatment	Season	Taxa ¹	n	Mean ± SE
2006	Treatment	September	Diptera	35	2.72 ± 0.23
			Amphipoda	35	0.42 ± 0.13
			Cladocera ²	35	2.99 ± 0.43
			Trichoptera ³	35	0.09 ± 0.06
			Hymenoptera ⁴	35	0.00 ± 0.00
			Ephemeroptera ⁵	35	0.00 ± 0.00
2006	Reference	June	Diptera	64	1.80 ± 0.16
			Amphipoda	64	0.92 ± 0.16
			Cladocera ²	64	1.79 ± 0.29
			Trichoptera ³	64	0.57 ± 0.10
			Hymenoptera ⁴	64	0.02 ± 0.02
			Ephemeroptera ⁵	64	1.28 ± 0.14
	Reference	September	Diptera	43	2.58 ± 0.19
			Amphipoda	43	0.56 ± 0.12
			Cladocera ²	43	0.15 ± 0.06
			Trichoptera ³	43	0.19 ± 0.62
			Hymenoptera ⁴	43	0.17 ± 0.09
			Ephemeroptera ⁵	43	0.24 ± 0.09
2007	Treatment	June	Diptera	46	1.59 ± 0.20
			Amphipoda	46	0.41 ± 0.14
			Cladocera ²	46	0.52 ± 0.13
			Trichoptera ³	46	0.40 ± 0.12
			Hymenoptera ⁴	46	0.01 ± 0.02
			Ephemeroptera ⁵	46	0.41 ± 0.10
	Treatment	September	Diptera	51	2.11 ± 0.18
			Amphipoda	51	0.70 ± 0.15
			Cladocera ²	51	1.37 ± 0.28
			Trichoptera ³	51	0.35 ± 0.10
			Hymenoptera ⁴	51	0.03 ± 0.03
			Ephemeroptera ⁵	51	0.27 ± 0.07
2007	Reference	June	Diptera	40	2.16 ± 0.21
			Amphipoda	40	0.50 ± 0.14
			Cladocera ²	40	0.25 ± 0.12

Table 2.5 Continued.

Year	Treatment	Season	Taxa ¹	n	Mean ± SE
2007	Reference	June	Trichoptera ³	40	1.36 ± 0.20
			Hymenoptera ⁴	40	0.07 ± 0.06
			Ephemeroptera ⁵	40	1.47 ± 0.20
2007	Reference	September	Diptera	20	2.05 ± 0.28
			Amphipoda	20	0.25 ± 0.10
			Cladocera ²	20	0.13 ± 0.13
			Trichoptera ³	20	0.24 ± 0.17
			Hymenoptera ⁴	20	0.00 ± 0.00
			Ephemeroptera ⁵	20	0.12 ± 0.07

¹MANOVA used to test for difference in year, season, and treatment; year*season*treatment interaction (Wilk's lambda = 0.88, $p < 0.001$)

²Univariate test within MANOVA for individual taxa ($F_{2, 508} = 15.18, P \leq 0.001$)

³Univariate test within MANOVA for individual taxa ($F_{2, 508} = 5.25, P = 0.001$)

⁴Univariate test within MANOVA for individual taxa ($F_{2, 508} = 3.74, P = 0.024$)

⁵Univariate test within MANOVA for individual taxa ($F_{2, 508} = 8.75, P \leq 0.002$)

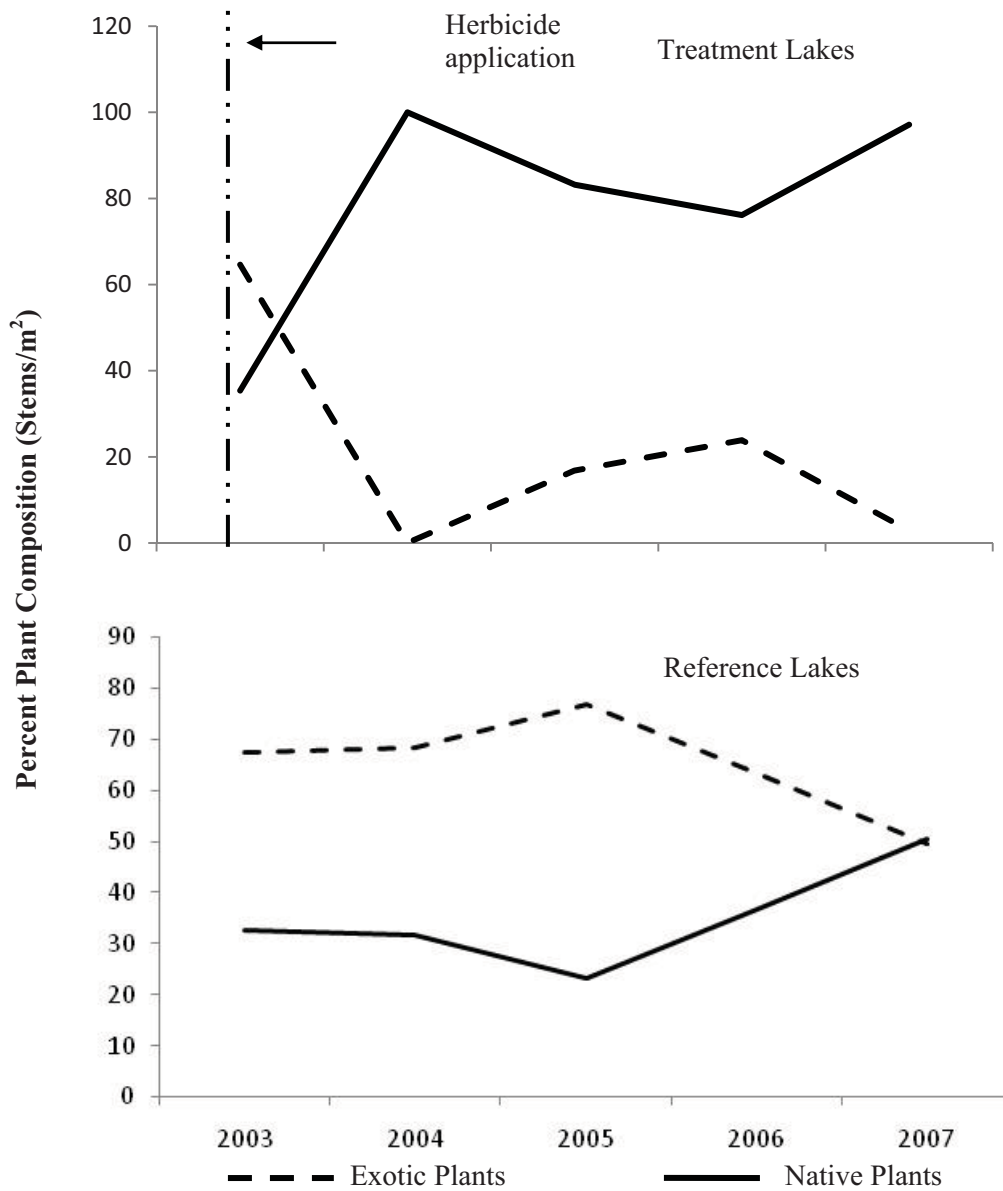


Figure 2.1 Percentage plant composition (stems/m²) of native and exotic plants from 2003-2007 for treatment lakes (Bush and Zumbra) and reference (Auburn and Pierson) lakes in Minnesota.

CHAPTER III
AFFECTS OF EURASIAN WATERMILFOIL REMOVAL ON BLUEGILL DIETS
RELATIVE TO FISH SIZE AND FEEDING SELECTIVITY

ABSTRACT

I investigated the hypothesis that removal of plants will influence bluegill diets relative to size three years after vegetation removal and that removal of plants will affect diet selectivity of bluegills by allowing foraging opportunities on other invertebrates not available before vegetation removal. I measured potential changes in bluegill diets based on Werner and Hall's (1988) hypothesis on habitat shifts in two different bluegill size classes and feeding selectivity before and after watermilfoil eradication. I used a multivariate analysis of variance to determine any significant difference between dominant prey items in each size class. Manly's alpha was used to determine feeding selectivity by bluegill, and a two sample t-test to determine any difference in selectivity values. An overall size difference in diets occurred in June (Wilks' lambda = 0.96, $p = 0.498$) and September (Wilks' lambda = 0.94, $p = 0.297$) but changes only occurred in three diet items. Eight different items were preferred by bluegills in treatment and reference lakes, with significant changes in three items during September. I did not detect any habitat shifts according to Werner and Hall's (1988) hypothesis and removal of watermilfoil with replacement of native plants did not affect bluegill diets relative to size, and feeding

selectively. Changes that did occur may reflect natural changes in macroinvertebrate populations.

INTRODUCTION

Fish growth occurs when the energy value of consumed food exceeds the energy expended to search, capture, and ingest food (Spotte 2007). However, high aquatic macrophyte stem densities also can affect a fish's foraging ability by reducing search, capture, and encounter rates with prey (Anderson 1984; Diehl 1988). Invasive plants, such as Eurasian watermilfoil (*Myriophyllum spicatum* L.), hereafter referred to as watermilfoil, can form these high stem densities. When evaluated as potential habitat for fish and macroinvertebrates, Keast (1984) found watermilfoil eliminated spawning sites for bluegill (*Lepomis macrochirus*) and reduced preferred prey species abundance. Effects of high stem density on bluegill foraging ability has been studied extensively and it has been concluded that low stem densities tend to increase foraging efficiency, thus increasing bluegill growth (Crowder and Cooper 1982)

Pothoven et al. (1999), Olson et al. (2003), and Unmuth et al. (1999) removed invasive watermilfoil to improve bluegill growth, but previous experiments that measured effects of macrophyte cover on foraging and growth of bluegill were conducted over short periods, used few specimens of a single age-class, and were implemented on a small scale (Spotte 2007). Long term studies are needed to measure effects of stem densities on bluegill foraging efficiency because little information is available on possible long-term effects of vegetation removal and how vegetation removal indirectly affects bluegill life

history processes (e.g., ontogenetic niche shift) and foraging abilities (e.g., prey selection).

Bluegills experience a shift in habitat and resource use several times during their life history, called ontogenetic niche shift (Werner and Hall 1988). Juvenile bluegill typically feed in the littoral zone on macroinvertebrates and zooplankton, whereas larger bluegill (> 80 mm standard length, SL) feed in the pelagic zone on zooplankton (Werner and Hall 1988). As the habitat becomes increasingly complex (e.g., high stem densities), the bluegill's ability to forage optimally or shift habitats may be compromised (Werner and Hall 1974). Werner and Hall (1988) evaluated the mechanism behind this ontogenetic niche shift and determined bluegill < 80 mm fed within the littoral zone to trade off optimal foraging for protection from predation. Conversely, bluegill > 80 mm SL, which are generally large enough to avoid predation, fed optimally in the open pelagic zone. This ontogenetic niche shift in bluegill shows their ability to maximize foraging opportunities to increase growth in response to predation.

Selecting larger prey, which is important for fish growth, offers a greater energy return and is determined by availability of prey in the environment (Wootton 1990). Watermilfoil has been found to support a high biomass of macroinvertebrates but bluegill foraging opportunities are limited because prey are not easily accessible due to increased stem densities which provide concealment for many macroinvertebrate and zooplankton species (Cheruvilil et al. 2002). Few studies have examined effects of bluegill feeding selectivity within high stem density habitats, but other studies on capture and encounter rates within high stem densities can provide insight on bluegill foraging and prey selection.

Given the importance of the effect of vegetation removal on bluegill life history processes and prey selection, my first objective was to investigate effects of plant removal on bluegill diets relative to size three years after vegetation removal. I hypothesized bluegill 40-79 mm SL would feed on macroinvertebrates and zooplankton, whereas bluegill ≥ 80 mm SL would feed exclusively on zooplankton species, indicating a habitat shift in lakes that have been treated. I hypothesized no habitat shift would be detectable in bluegill foraging in reference lakes containing watermilfoil. My second objective was to determine if removal of plants would affect diet selectivity of bluegills by allowing foraging opportunities on other invertebrates not available before vegetation removal. I hypothesized that bluegill feeding selectivity would change in treatment lakes, while no changes would occur in reference lakes.

STUDY AREA

My experiment consisted of four eutrophic lakes located in the Minneapolis, Minnesota metropolitan area: Auburn, Pierson, and Zumbra (Carver Co.), and Bush (Hennepin Co.). Lakes were all dominated by watermilfoil with a surface coverage of at least 80% of the littoral zone (Table 2.1), and a similar fish assemblage dominated by bluegill.

METHODS

Plant removal and fish collection

In spring of 2004 an herbicide application of low-dose endothall/2, 4-D was applied to control the watermilfoil and a small percentage of curly leaf pondweed (*Potamogeton crispus*) in Bush and Zumbra lakes. Auburn and Pierson lakes were not treated and used as reference. Bluegills were sampled in each lake, twice a year during June and September for 5 years (2003-2007) using boat mounted electro-fishing. A minimum of twenty bluegills were randomly selected from the field collections.

Diets relative to size

Bluegill stomachs were removed, dissected, and contents preserved in 70% ethanol and stored until analysis (Bowen 1983). Macroinvertebrates, zooplankton and all other stomach contents were enumerated during analysis and identified to a specific taxonomic order according to Merritt and Cummins (2007) and Thorp and Covich (1991). I measured bluegill standard length and placed them in two size classes corresponding to length classes from Werner and Hall (1988); 40-79 mm SL and 80-160 mm SL.

Feeding selectivity

I used Manly's alpha for constant prey populations to determine what macroinvertebrate species, when available in the environment, were preferred by bluegill (Krebs 1989). Manly's alpha for constant prey population was used when number of prey

eaten was small in relation to the total available in the environment (Chesson 1978; Krebs 1989). When selective feeding does occur, $\alpha_i = 1/m$, if α_i is greater than $1/m$, prey species i is preferred in the diet, but if α_i is less than $1/m$, prey species i is avoided in the diet. The formula for estimating alpha may be computed as:

$$\alpha_i = r_i/n_i (1/\sum (r_j/n_j)) \quad (3.1)$$

Where:

α_i = Manly's alpha (preference index) for prey type i

r_i, r_j = Proportion of prey type i or prey type j in the diet (i and $j = 1, 2, 3, \dots, m$)

n_i, n_j = Proportion of prey type i or prey type j in the environment

m = Number of prey types possible

Methods for stomach removal and macroinvertebrate identification were described above. Availability of macroinvertebrates in the environment was sampled at each lake, from four different sites. Each site was then sampled five times during June and September from 2003 to 2004 for approximately 160 samples each year.

Macroinvertebrates were sampled using a d-framed net and were preserved in 70% ethanol and stored until analysis. Macroinvertebrate availability was expressed by taxon as a percentage of total abundance of all macroinvertebrates in that sample.

Macroinvertebrates that were found in the environment were used in the analysis, whereas zooplankton species were not sampled for availability in the environment and therefore were not evaluated.

Statistical analysis

Diets relative to size

I used a multi-variate analysis of variance (MANOVA) to analyze frequency of occurrence of certain taxa in bluegill diets. MANOVA is robust against deviations from normality and violations of homogeneity of covariance matrices (Hatcher and Stepanski 1994). I tested for significant differences in dominant prey items between size class, year, season and treatment, for 2005-2007. Data were sorted by season accounting for changes in macroinvertebrate abundances based on seasons (Mittelbach 1981). Taxonomic orders that composed $\geq 5\%$ of the diet of all fish for each year were analyzed; any order that composed $< 5\%$ of the diet was excluded from the analysis. I assumed a p-value of 0.05 to be statistically significant.

A MANOVA measures a predictor variable on multiple criterion variables and assigns a Wilk's lambda to specified interactions (Hatcher and Stepanski 1994). Wilk's lambda values can range from 0-1 and are interpreted differently from an R^2 value. Small values (near zero) are relatively strong relationships whereas larger values (near one) are relatively weak relationships between the predictor variable and multiple criterion variables (Hatcher and Stepanski 1994). For example; if the Wilk's lambda is 0.01, this represents a strong relationship and accounts for 99% of the variability (e.g. $0.01 - 1 = 0.99$). When the Wilk's lambda is 0.88, then the relationship between the predictor variable and multiple criterion variables is weak, and accounts for only 12% of the variability ($0.88 - 1 = 0.12$) (Hatcher and Stepanski 1994).

Feeding selectivity

I used a two-sample t-test, which is robust against deviations from normality (Zar 1999), to assess any significant difference before and after plant removal for preferred macroinvertebrates in bluegill diets among treatment and reference lakes. A Satterthwaite approximation was used when variances were not equal (Zar 1999).

RESULTS

Diets relative to size

Results indicated that there was no significant difference between year, treatment season and size groups for June (Wilks' lambda = 0.96, $p = 0.498$) or September (Wilks' lambda = 0.94, $p = 0.297$). During June, a year by treatment interaction was present (Wilks' lambda = 0.82, $p = 0.001$) accounting for 18% of the variability in macroinvertebrate consumption (Table 3.1), whereas an overall size difference (Wilks' lambda = 0.88, $p = 0.003$), accounted for 12% variability in size specific diets (Table 3.2). The remaining 70% of the variability in bluegill diets was possibly related to changes in macroinvertebrate abundances. During September, a treatment effect was present (Wilks' lambda = 0.84, $p < 0.001$) where two diet items, cladocera and plant material, accounted for 16% of the variability in macroinvertebrate consumption. Cladocera were 294% more abundant ($F_{1, 224} = 5.52$, $p = 0.02$) in bluegill diets from treatment lakes (2.44 ± 0.22) than reference lakes (0.62 ± 0.10), whereas consumption of plant material was 34% greater ($F_{1, 224} = 5.60$, $p = 0.02$) in reference lakes (2.64 ± 0.13) than treatment lakes (1.97 ± 0.16). An overall size difference (Wilks' lambda = 0.88, $p =$

0.002) accounted for 12% of the variability in size specific diets (Table 3.2). The remaining 72% of the variability in bluegill diets could be explained by natural changes in macroinvertebrate abundances. Removal of plants did not influence bluegill diets relative to size, but removal of plants did influence consumption of certain taxa categories, such as cladocera, ostracoda, and acari. Even though these taxa changed, there was a weak relationship within each taxa based on year, treatment, season, and size group. A category that is not considered a food item, plant material, was influenced by treatment and differed between small and large fish, but again the relationship was weak based on the above mentioned independent variables.

Feeding selectivity

Eight of the twelve taxa evaluated were preferred food items in treatment and reference lakes (Table 3.3). When evaluated seasonally, only September had significant differences in 2003 to 2004 in three different taxa categories for treatment and reference lakes (Table 3.4). However, two taxa, diptera (midges) and acari (water mites), differed in selectivity before and after plant removal in reference lakes, but were not considered preferred food items based on alpha values, suggesting changes in macroinvertebrate selectivity were based on seasonal availability of macroinvertebrates. A taxa category that was not evaluated for selectivity that may have been actively selected for was cladocera (zooplankton). This was not evaluated because my project mainly focused on the macroinvertebrates consumed by bluegill.

DISCUSSION

Diets relative to size

This study did not support the hypothesis that bluegill will switch from feeding in the littoral zone at ~80 mm SL, to feeding in the pelagic zone exclusively on zooplankton as indicated by Werner and Hall's (1988) original hypothesis. A size specific difference occurred when treatment and reference lakes were combined. Small bluegill (<79 mm) consumed primarily zooplankton, while larger bluegill (≥ 80 mm) consumed a significant amount of plant material. Even though size specific diets occurred, removal of vegetation in treatment lakes did not indicate a size specific diet shift as expected. The consumption of zooplankton by small bluegill may be attributed to a specific zooplankton species.

A shift in size specific diets may not be indicated by a shift in the composition of bluegill diets, but by a specific zooplankton species. *Daphnia galeata*, a species commonly consumed by small bluegill (Werner and Hall 1988), were highly abundant within the littoral vegetation, where *Daphnia pulex*, a larger species of zooplankton, was commonly found in the pelagic zone and consumed by larger bluegill (Werner and Hall 1988). Further analysis of the zooplankton community may relate diet shifts to certain species of zooplankton as indicated by Werner and Hall (1988), but analysis of diet composition in larger bluegill, indicates otherwise.

Similar to previous research (Sadzikowski and Wallace 1976; Spotte 2007), I found large bluegill (111-160 mm) consumed chironomides, cladocera, and many hymenopterans (bees, wasps, and ants) and a considerable amount of plant material.

However, size specific results indicated by Spotte (2007) with Sadzikowski and Wallace (1976) data suggested this type of diet composition as a shift in diets. This would then indicate a size-specific diet shift in my treatment lakes (Figure 3.1), but based only on percentage of consumption. Large bluegill in Sadzikowski and Wallace's (1976) and my study were considerably larger (40-160 mm) than bluegill in Werner and Hall (1988) (30-110 mm), possibly indicating a shift at a much larger size. The considerable amount of plant material found in large bluegill diets possibly represents a shift to feeding in different parts of the littoral zone on macroinvertebrates.

Reportedly, bluegill 200 mm leave zooplankton and feed on macroinvertebrates and fish (Moffett and Hunt 1945). Conversely, the significant amount of plant material that I found in large bluegill (80-160 mm) diets may indicate otherwise. Plant material is common in larger bluegill and has been described by Gerking (1962), Etnier (1971), Sadzikowski and Wallace (1976) and Seaburg and Moyle (1964). Many suggestions have been made to explain the occurrence of plant material in bluegill diets. Gerking (1962) suggested that plant material aids in digestion, but Etnier (1971) found an association of plant material with Lepidoptera larvae and trichoptera larvae. Sadzikowski and Wallace (1976) suggest the occurrence of plant material in the stomach is possibly due to damselflies in the diet, suggesting accidental ingestion of plant material, whereas Seaburg and Moyle (1964) found associations of plant material with decreased feeding on insects. Although I found bluegill stomachs that contained plant material had a low volume of insects, use of plant material by fish is still unexplained. The associations of plant material with macroinvertebrates may again indicate shifts at a different size, but changes

in macroinvertebrate consumption in relation to plant removal is possibly related to natural fluctuations in macroinvertebrate communities.

Seasonal variation in macroinvertebrate abundances can be identified with changes in bluegill consumption, as indicated by the year by treatment interaction I found in June (Table 3.1). When the macroinvertebrate populations were high it was likely those bluegills were able to consume more macroinvertebrate species. Conversely, when populations were low, bluegill were not able to consume as much. Similarly, Mittelbach (1981b) indicated that macroinvertebrate biomass tended to decline from May to August within littoral vegetation. However changes in diet composition were different for certain taxa in September compared with June indicated by a treatment effect.

A treatment effect was evident in amount of cladocera and plant material that was consumed by bluegill in September. Cladocera were consumed mainly in treatment lakes compared to reference, which may be attributed to the removal of watermilfoil. The majority of cladocera consumption takes place during the summer, and watermilfoil tended to decrease cladocera abundance (Menzie 1980). However, cladocera were more abundant in August-September in the presence of watermilfoil (Menzie 1980). Although watermilfoil was removed in treatment lakes, a possible increase in cladocera abundance during this month would allow for an increase in their consumption. Not usually a food of choice, plant material was consumed mainly by bluegill within reference lakes. This was not a surprise; reference lakes contained watermilfoil throughout the study, and this would explain why these bluegills contained more plant material in their diets than treatment lakes, but use of plant material in the diet was discussed earlier and is still unexplained.

Feeding selectivity

Plant removal did not affect bluegill feeding selectivity as predicted. Selectivity only varied seasonally, with changes occurring from September 2003 to September 2004. However, all species of macroinvertebrates that were found in bluegill diets were not evaluated for availability in the environment, and important prey species may have been overlooked.

Cladocera were one of the most important prey species to bluegill optimal foraging and was suggested to be actively selected (Werner and Hall 1988). I did not evaluate selection of zooplankton species because I was mainly concerned with changes in macroinvertebrates. However, Olson et al. (2003) evaluated selectivity of cladocera and found them to be unimportant in bluegill diets, but limited studies on bluegill feeding selectivity offers little plausibility to this statement. Changes that I found in bluegill selectivity were possibly related to macroinvertebrate emergences and availability within changing macrophyte densities.

Life histories of macroinvertebrate species can be compared with seasonal changes found in selectivity values. Selectivity indicated that trichoptera larvae were the most commonly selected item in treatment and reference lakes. However, changes in selectivity for trichopteran (caddisflies) larvae occurred in September in one reference lake (Table 3.3). This may be attributed to the emergence of trichopteran larvae, which begins in early June and is complete by the third week of July. Macrophyte density at this time would provide some protection from fish predation in June (Keast 1984), suggesting why it was not preferred. When the watermilfoil starts to slow growth in the fall (e.g., September) (Keast 1984), it may have allowed for more consumption of trichopterans.

This growth in watermilfoil also may have contributed to the consumption of Coleoptera in another reference lake. The reduction of watermilfoil in treatment lakes may also have accounted for changes in selection of acari in one treatment lake. Most acari were brown and could be concealed by watermilfoil, once watermilfoil was removed, visual acuity of bluegill for this prey species may have increased.

One taxa order that changed in both treatment and reference lakes by bluegill was diptera. These changes probably represent natural fluctuations in macroinvertebrate availability in the environment. In the presence of watermilfoil, dipterans had the greatest abundance in June-July; the population slightly decreased in August, but increased during September-October (Menzie 1980). Natural changes of macroinvertebrate abundances within watermilfoil changed from year to year, explaining the changes in selectivity in reference lakes. This same pattern in dipteran abundances also was found in native littoral vegetation (Mittelbach 1981), and selectivity within treatment lakes possibly corresponded with reduction in native vegetation during fall.

Conclusions

Difference is size-specific diets and prey selectivity was not affected by removal of vegetation. All changes in diets were indicated as natural changes of macroinvertebrate availability in the environment. Prey selectivity needs to be expanded to a long term analysis to evaluate possible changes over time as well as size specific changes in selectivity. Results of this study provide insight into the effects of vegetation removal on bluegill feeding habits, but needs to be expanded on how these small changes in

macroinvertebrate consumption may possibly effect bluegill growth in relation to vegetation removal.

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Table 3.1 Geometric means (\pm SE) for changes in selected taxa indicated by year and treatment for June in treatment (Bush and Zumbra) and reference (Auburn and Pierson) lakes. n = 291 bluegill examined for treatment lakes. n = 231 bluegill examined for reference lakes.

Year	Treatment	Taxa ¹	Mean \pm SE ²
2005	Treatment	Diptera ³	1.52 \pm 0.22
		Cladocera ⁴	0.73 \pm 0.21
		Trichoptera ⁵	0.48 \pm 0.13
		Ephemeroptera ⁶	0.68 \pm 0.16
	Reference	Diptera ³	1.96 \pm 0.20
		Cladocera ⁴	0.58 \pm 0.14
		Trichoptera ⁵	1.05 \pm 0.20
		Ephemeroptera ⁶	0.56 \pm 0.11
2006	Treatment	Diptera ³	2.11 \pm 0.16
		Cladocera ⁴	0.42 \pm 0.14
		Trichoptera ⁵	0.59 \pm 0.10
		Ephemeroptera ⁶	0.99 \pm 0.14
	Reference	Diptera ³	1.81 \pm 0.16
		Cladocera ⁴	1.79 \pm 0.30
		Trichoptera ⁵	0.57 \pm 0.10
		Ephemeroptera ⁶	1.29 \pm 0.15
2007	Treatment	Diptera ³	1.96 \pm 0.20
		Cladocera ⁴	0.53 \pm 0.13
		Trichoptera ⁵	0.41 \pm 0.12
		Ephemeroptera ⁶	0.41 \pm 0.11
	Reference	Diptera ³	2.16 \pm 0.21
		Cladocera ⁴	0.26 \pm 0.12
		Trichoptera ⁵	1.36 \pm 0.21
		Ephemeroptera ⁶	1.47 \pm 0.21

¹Items that comprised $\geq 5\%$ of bluegill diets for each year 2005-2007, Univariate test conducted for each individual taxon within MANOVA

²Calculated from transformed data from 2005-2007

³($F_{2, 274} = 4.61, p = 0.0107$)

³($F_{1, 274} = 11.05, p = 0.0010$)

⁵($F_{2, 274} = 3.95, p = 0.0204$)

⁶($F_{2, 274} = 6.19, p = 0.0023$)

Table 3.2 Geometric means (\pm SE) for changes in selected taxa indicated by overall difference in size-specific diets for June and September in Minnesota. Overall differences are indicated by a combination of treatment and reference lakes (Bush, Zumbra, Auburn and Pierson). n = 522 bluegill examined for treatment and reference lakes combined.

Season	Size group ¹	Taxa ²	Mean \pm SE ³
June	40-79 mm	Diptera	2.14 \pm 0.20
		Amphipoda	0.53 \pm 0.15
		Coleoptera	0.20 \pm 0.09
		Cladocera ⁴	1.32 \pm 0.28
		Acari	0.50 \pm 0.11
		Trichoptera	0.17 \pm 0.15
		Ephemeroptera	0.94 \pm 0.18
		Ostracoda ⁵	0.72 \pm 0.19
		Copepoda	0.02 \pm 0.02
		Plant ⁶	0.69 \pm 0.18
		Other	0.09 \pm 0.06
		June	80-160 mm
Amphipoda	0.47 \pm 0.06		
Coleoptera	0.10 \pm 0.02		
Cladocera ⁴	0.70 \pm 0.09		
Acari	0.28 \pm 0.04		
Trichoptera	0.71 \pm 0.07		
Ephemeroptera	0.91 \pm 0.07		
Ostracoda ⁵	0.19 \pm 0.03		
Copepoda	0.01 \pm 0.01		
Plant ⁶	1.84 \pm 0.10		
Other	0.27 \pm 0.05		
September	40-79 mm		
		Amphipoda	0.86 \pm 0.16
		Coleoptera	0.08 \pm 0.05
		Cladocera ⁷	2.80 \pm 0.36
		Acari ⁸	0.49 \pm 0.13
		Trichoptera	0.32 \pm 0.12
		Ephemeroptera	0.05 \pm 0.03
		Ostracoda	0.03 \pm 0.02
		Copepoda	0.09 \pm 0.08
		Plant ⁹	1.35 \pm 0.20
		Other	0.04 \pm 0.03

Table 3.2 Continued.

Season	Size group ¹	Taxa ²	Mean \pm SD ³
September	80-160 mm	Diptera	2.45 \pm 0.09
		Amphipoda	0.53 \pm 0.07
		Coleoptera	0.21 \pm 0.04
		Cladocera ⁷	1.12 \pm 0.13
		Acari ⁸	0.22 \pm 0.03
		Trichoptera	0.20 \pm 0.04
		Ephemeroptera	0.20 \pm 0.04
		Ostracoda	0.10 \pm 0.03
		Copepoda	0.01 \pm 0.01
		Plant ⁹	2.57 \pm 0.11
	Other	0.11 \pm 0.02	

¹Calculated from transformed data from 2005-2007

²Standard length

³Items that comprised $\geq 5\%$ of bluegill diets for each year 2005-2007, Univariate test conducted for each individual taxon within MANOVA

⁴Overall MANOVA for June ($F_{1,274} = 11.05, p \leq 0.001$)

⁵Overall MANOVA for June ($F_{1,274} = 15.63, p \leq 0.001$)

⁶Overall MANOVA for June ($F_{1,274} = 8.25, p = 0.004$)

⁷Overall MANOVA for September ($F_{1,224} = 31.71, p \leq 0.001$)

⁸Overall MANOVA for September ($F_{1,224} = 6.72, p = 0.010$)

⁹Overall MANOVA for September ($F_{1,224} = 6.73, p = 0.010$)

Table 3.3. Feeding selectivity (alpha values) of preferred food items for treatment (Bush and Zumbra) and reference (Auburn and Pierson) lakes from June 2003 to 2004 and September 2003 to 2004. n = 20 bluegill examined for each lake in June and September.

Lake	Year	Season	Treatment	Taxa	Alpha value ¹ α_i
Bush	2003	June	Treatment	Trichoptera	0.7212
		September		Coleoptera	0.8431
				Hemiptera	0.0887
	2004	June		Pelecypoda	0.7846
				Odonata	0.1744
		September		Coleoptera	0.9699
Zumbra	2003	June	Treatment	Pelecypoda	0.6658
				Trichoptera	0.2219
		September		Coleoptera	0.3501
				Pelecypoda	0.4201
				Trichoptera	0.2100
		2004	June		Coleoptera
			Trichoptera	0.7233	
		September		Diptera	0.5174
				Amphipoda	0.0949
				Acari	0.2483
Auburn	2003	June	Reference	Trichoptera	0.2287
				Hemiptera	0.7622
		September		Trichoptera	0.8375
	2004	June		Trichoptera	0.8767
			Hemiptera	0.1096	
	September		Pelecypoda	0.8607	
Pierson	2003	June	Reference	Pelecypoda	0.1712

Table 3.3 Continued.

Lake	Year	Season	Treatment	Taxa	Alpha value ¹ α_i
Pierson	2003	June	Reference	Trichoptera	0.7419
				Coleoptera	0.4975
Pierson	2003	September	Reference	Trichoptera	0.2669
				Hemiptera	0.1906
	2004	June		Diptera	0.0868
				Coleoptera	0.6227
				Acari	0.1245
		September		Coleoptera	0.9537

¹Calculated using Manly's alpha, if $\alpha_i = 1/12$ ($1/12 = 0.0833$) selectivity occurred, if $\alpha_i \geq 1/12$, then item is preferred in diet.

Table 3.4 Summary of treatment effects of preferred food items from September 2003 to 2004 in treatment (Bush and Zumbra) and reference (Auburn and Pierson) lakes. n = 20 bluegill examined in September 2003 and 2004 for each lake.

Lake	Season	Taxa	DF	t-value	p-value
Auburn	September	Diptera	36	-2.36	0.0189
		Trichoptera	18	3.39	0.0031
Pierson	September	Coleoptera	38	-2.04	0.0481
Bush	September	Diptera	38	2.38	0.0225
Zumbra	September	Acari	23	-2.96	0.0071

CHAPTER IV
SYNTHESIS AND MANAGEMENT IMPLICATIONS

SYNTHESIS

This study answered questions that were lacking in others by examining the effects of vegetation removal on bluegill feeding habits and life history processes. Although it has been concluded that high stem densities affect bluegill foraging efficiency (Harrel and Dibble 1991; Crowder and Cooper 1982), certain aspects of bluegill feeding habits and life history processes were unaffected by removal of vegetation.

Immediately following plant removal, bluegill diet composition revealed a change in consumption of one prey item, whereas diet composition three years after plant removal indicated change in consumption of four prey items. Although changes were statistically significant relative to year, treatment, and season, they were not indicative of plant removal alone. While these changes may not have been biologically significant, life history process that indicates diet shifts relative to size may have been masked by this generic analysis.

Bluegill diets relative to size in treatment lakes did not indicate any size specific diet shifts. Changes in diets relative to size were indentified with the combination of treatment and reference lakes, where small bluegill were consuming a majority of the

zooplankton species and larger bluegill consuming macroinvertebrates and plant material. There were changes that were indicative of season, but not size specific. In June, changes occurred between year and treatment in three macroinvertebrates and one zooplankton species. September indicated changes in plant and zooplankton consumption relative to treatment.

Prey selection also was not affected by plant removal and any changes that did occur seem to take place during September. Changes in prey selection occurred in treatment and reference lakes, with selection differing in two macroinvertebrate species. However changes also occurred in items that were not preferred by bluegill, overall plant removal did not affect bluegill feeding habits and all changes in bluegill diets were related to natural changes in macroinvertebrate availability. However, these small changes may have possibly affect bluegill growth.

MANAGEMENT IMPLICATIONS

Removal of invasive vegetation, influential of structural complexity of fish habitat, has been studied extensively, and it has been concluded that removal was necessary to improve bluegill foraging and growth (Pothoven et al. 1999; Keast 1984). The need for vegetation removal raises questions about the affects of vegetation removal on bluegill feeding habits and life history processes which were answered in this study. Bluegill feeding habits and ontogenetic niche shift were not affected by removal of vegetation, but it was important to note that vegetation was not permanently removed. After watermilfoil was removed, native plant communities were reestablished and littoral vegetation communities were necessary for bluegill, macroinvertebrate and zooplankton

habitat (Richardson et al. 1998; Keast 1984). Fishery managers need to take into consideration the type of vegetation that needs to be removed and the expenses involved, although watermilfoil was removed in one application in this study, spot treatment was necessary to keep the watermilfoil from coming back. Many techniques that are used to control watermilfoil are short-lived and expensive, indicating the expense of herbicide application (Smith and Barko 1990), which also needs to be taken into consideration.

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