

Littoral Habitat Heterogeneity and Shifts in Plant Composition Relative to a Fall Whole-Lake Fluridone Application in Perch Lake, Michigan

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ABSTRACT

Dense stands of Eurasian watermilfoil (*Myriophyllum spicatum* L.) can alter aquatic habitat by decreasing structural heterogeneity in littoral zones critical to fish habitat. Evidence suggests that the herbicide fluridone (1-methyl-3-phenyl-5-[3-(trifluoromethyl) phenyl]-4(1H)-pyridinone) can be used to selectively target monotypic stands of invasive aquatic plants, while leaving native plant species and the habitat heterogeneity intact. We evaluate efficacy of a fall, low-dose treatment of fluridone on a Eurasian watermilfoil-infested Michigan Lake to enhance multi-species growth and habitat heterogeneity. In October 2000, approximately three liters of Sonar® AS (fluridone) were injected subsurface, covering the entire 15-ha lake to provide a whole-lake target application rate of 8 µg/L. A second application was applied 40 days after initial treatment to boost the rate back to the original target level. Habitat heterogeneity was defined as biomass, stem density, relative abundance, diversity and species richness. Pre- and post-treatment measurements (N = 3) were made at 24 sites in the lake littoral zone. Total plant biomass decreased after treatment, due to the removal of Eurasian watermilfoil. Shifts in the plant community resulted in increased native plant abundance and stem density for two years following initial herbicide treatments suggesting enhancement in habitat heterogeneity within the littoral zone potentially important to the fishery.

Key Words: Sonar AS, invasive species, aquatic plant control, *Myriophyllum spicatum*.

INTRODUCTION

Native aquatic vegetation is an important regulator of community dynamics in a lake. Fish generally prefer vegetated sites to non-vegetated sites, with intermediate stem densities harboring the greatest fish densities (Savino and Stein 1982, Killgore et al. 1989). Many families such as Centrarchidae show preferences for complex, species-rich macrophyte beds, which provide refuge habitat from the effects of

predation (Gilinsky 1984, Keast 1985, Poe et al. 1986, Mittelbach and Chesson 1987, Engel 1988). The habitat heterogeneity provided by diverse aquatic plant beds can also support a significant increase in diversity and biomass of macroinvertebrates (Gerking 1957, McCafferty 1981, Watkins et al. 1983). Innate architecture differences among aquatic plant species provide structural heterogeneity in habitat important to fishes and their prey (Dionne and Folt 1991, Lillie and Budd 1992, Wyckera et al. 1993, Dibble et al. 1996a). Water bodies with limited or no plant growth and aquatic systems with large-scale invasive monocultures lack critical habitat heterogeneity important to maintaining a viable fishery.

A littoral zone characterized by a diverse aquatic plant bed provides greater structural heterogeneity than a monoculture of a prolific and invasive species, i.e. Eurasian watermilfoil. Prolific monocultures can be detrimental to a fishery by interfering with trophic interactions, feeding behaviors, water quality and individual growth (Colle and Shireman 1980, Crowder and Cooper 1982, Maceina and Shireman 1985). Whereas a littoral zone diverse in native plant species provides greater heterogeneity and may provide a more beneficial habitat (Engel 1984, Dibble et al. 1996b, Weaver et al. 1996, Valley and Bremigan 2002). Given enough time, structural heterogeneity within a habitat may mediate stability and biodiversity of a community (Stenseth 1980, Freitas et al. 2005).

Herbicides are a common method for removing invasive, canopy-forming submersed macrophytes (Madsen 2000). The herbicide fluridone has been widely used for nearly 20 years to control the invasive plant Eurasian watermilfoil (hereafter referred to as milfoil) in northern tier states of the U.S. Recently, a unique method of application is being used, in which the entire water body is managed to selectively remove an invasive species, rather than merely spot-treating sections of the lake (Getsinger et al. 2002a). The efficacy of fluridone against milfoil in this whole-lake treatment method is dependent upon both the initial treatment rate and the duration of exposure time (Hall et al. 1984, Netherland 1992, Netherland et al. 1993, Netherland et al. 1997). Field investigations have shown that maintaining low-dose (5-8 µg/L), long-exposure (>60 days) treatments of this herbicide have provided milfoil control for one or more growing season (Getsinger et al. 2002a, Getsinger et al. 2002b, Madsen et al. 2002).

Milfoil and curlyleaf pondweed (*Potamogeton crispus* L.) are exotic plants to the U.S. and have prolonged growing seasons that may be beneficial to fish and macroinvertebrate

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populations by increasing forage and refuge habitat in the late fall and early spring when native plant species are dormant (Nichols et al. 1988). Studies have shown their submerged leafy structure to be more densely populated with macroinvertebrates than emergent, non-leafy types of aquatic plants (Krecker 1939). However, milfoil is generally considered undesirable because its dense vegetative mats eventually crowd out native plant populations and destroy the aesthetic and ecological value of a lake system (Madsen et al. 1991, Boylen et al. 1999). The surface canopies that are characteristic of milfoil can be detrimental to structural heterogeneity. Dense matted vegetation that forms at the surface acts in a somewhat similar fashion as would a floating-leaved plant, hindering growth of submersed plants by blocking available light. Removal of competitive exotic species that exhibit this growth form creates an environment for better colonization by less aggressive native plant species, promoting native plant density and diversity (Madsen et al. 2002). The selective removal of nuisance vegetation with minimal harm to non-target plants is a desirable goal when managing lake systems (Netherland et al. 1997).

A system dominated by a single plant species can lack the beneficial effect provided by the structure created in a multi-species system, where lake managers frequently look for effective ways to enhance littoral zone habitat by increasing structural heterogeneity. Some efforts include the introduction of various species of native aquatic plants after invasive species are controlled (Smart et al. 1996, Dibble et al. 2001). Previous studies conducted in Michigan and Vermont have shown that springtime whole-lake fluridone treatments using aqueous concentrations of 5 to 6 µg/L provided ≥85% control of milfoil during the year of treatment with little injury to many non-target plants (Getsinger et al. 2002a, 2002b, Madsen et al. 2002). These results suggest fluridone has potential as a habitat management tool that may be used to convert a simple system (where the invasive plant dominates the canopy and provides little heterogeneity) to a multi-species complex that occupies different levels within the littoral zone. After such treatment, the new condition may represent a system with increased heterogeneity even though biomass has been greatly reduced. This is due to the increased value that each of the other individual species contributes as components to the overall habitat. As with springtime applications, whole-lake treatments of fluridone in the early fall—extending through the winter months—may provide another window of opportunity to selectively remove milfoil and increase habitat heterogeneity.

We investigate whether a whole-lake herbicide treatment to control a submersed plant community dominated by milfoil during the fall/winter can accomplish a shift from a dominant single plant species low in habitat heterogeneity to a multi-species native plant community high in habitat heterogeneity. This portion of a larger study evaluates the effect of a fall low-dose, whole-lake fluridone application on the aquatic plant community in a milfoil-infested lake in south-central Michigan. Pre- and post-treatment measurements were recorded for plant biomass, species composition, plant diversity, and stem density. Differences between exotic and native plant responses were evaluated, as well as how these changes may potentially affect habitat heterogeneity and the aquatic community.

MATERIALS AND METHODS

Herbicide Treatment

Perch Lake, a 15-ha spring-fed water body located in Hillsdale County, Michigan, was chosen for this study due to its small size, limited watershed, and its high infestation of milfoil mixed with some curlyleaf pondweed. On 18 October 2000, 2.84 L (3 quarts) of Sonar® AS (SePRO Corporation, Carmel, IN) were injected subsurface (~0.5 m depth) using weighted hoses mounted on an airboat, covering the entire lake to provide a nominal application rate of 8 µg/L fluridone. Since fluridone is primarily degraded by photolysis, aqueous levels were expected to persist and remain above 4 µg/L beneath the ice and snow cover through the winter months making the herbicide biologically available to the milfoil in the early spring as it is actively photosynthesizing. The non-target native plants begin actively growing later in the spring than does milfoil (Dale and Gillespie 1977), and herbicide levels by that time could be too low (<3 µg/L) to significantly affect growth of some species. The timing of this treatment strategy was designed to evaluate a fall application window for selective control of milfoil. In addition, the early-growing curlyleaf pondweed would also be susceptible to low levels of fluridone in the spring, prior to active growth of non-target native plants. Aqueous fluridone residue levels were monitored at three evenly spaced locations in the lake through 337 days after treatment (DAT). Samples were analyzed after immunoassay techniques, described in Netherland et al. (2002), by the analytical laboratory at SePRO Corporation (Carmel, IN). By 27 DAT, the measured fluridone concentration in the water had declined to 3 µg/L (Figure 1). This unexpectedly rapid decline in water residues precipitated a follow-up booster application of Sonar® AS at 40 DAT to re-establish a nominal whole-lake aqueous concentration of 8 µg/L fluridone, which did occur.

Sampling Design and Techniques

Pre-treatment samples were collected between 8:00 and 18:00 hr on 18-21 September 2000 and post-treatment samples between 8:00 and 18:00 hr on 12-16 June 2001, 16-19 September 2001, and 11-13 June 2002 to evaluate changes in the plant community structure occurring as a result of the removal of exotic vegetation. Twenty four sites were evenly spaced along the periphery of the lake in the littoral zone to ensure adequate coverage of the shoreline. The littoral zone was defined by depths ranging from 0.3 to 2.0 m. A 0.09-m² PVC quadrant was randomly placed on the bottom within each site at a depth <1 m.

Plant structure was measured as biomass, stem density, relative abundance, diversity and species richness of plants at each site. Plants within the quadrant were uprooted by hand, identified (Prescott 1979), and enumerated. Stems were sorted by species and totaled within each quadrant to obtain densities for all species at the site level within the littoral zone. All stems measuring ≥5 cm in length were included in our sample. Plants were preserved in 10% formalin, transported to the laboratory, dried for two weeks in a PowerOMatic dryer (Blue M Electric Company, IL) and weighed to

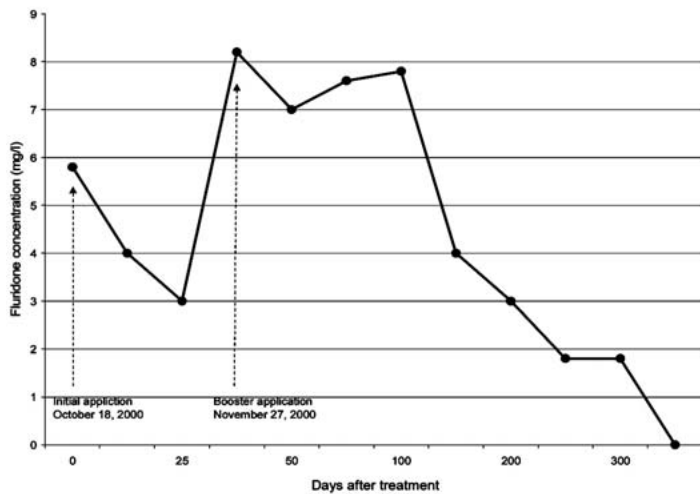


Figure 1. Fluridone concentrations from a fall whole-lake herbicide application on Perch Lake, Michigan (initial application 18 October, a booster application 27 November 2000, and the final water residue sample 25 September 2001).

the nearest 0.01 g to obtain dry weight (DW) biomass (Pringle 1984). Dry weight and density values were extrapolated to a square meter basis for analyses and reporting.

Data Analyses

Aquatic plant diversity was calculated using the Shannon Index (H'). Relative abundance was expressed as a percentage of total stems counted and richness represented total number of species recorded at the 24 sites within the littoral zone. A Chi-square (χ^2) was used to measure for overall differences in abundance among the aquatic plants, and a one-way ANOVA with a Bonferroni comparison of means was used to compare changes in biomass, stem density, and plant diversity over time. All statistical analyses were conducted using STATISTIX (Version 4.0, Tallahassee, FL).

RESULTS AND DISCUSSION

By early spring, fluridone residues had declined to levels of approximately 3 $\mu\text{g/L}$, and continued a slow decline through the remainder of the growing season to an approximate level of 0 $\mu\text{g/L}$ by 25 September 2001 (Figure 1). The herbicide treatment had a significant impact on the plant community in the littoral zone at Perch Lake by facilitating a decrease in the abundance of the dominant species (milfoil) and an increase in the abundance of native plants (Figure 2). Prior to the herbicide treatment, milfoil was the most common and widespread species collected in September 2000, comprising 79% of all plants recorded (Table 1). After the herbicide treatment, milfoil was reduced significantly ($F = 22.44$, $p < 0.001$) during each sampling period, comprising 8%, 0%, and <1%, respectively. While the treatment was highly successful in removing milfoil from the lake, abundance of the other invasive species, curlyleaf pondweed, gradually increased during the post-treatment sampling period, reaching a level of 12% by June 2002. Even though curlyleaf pondweed control was very good following the ini-

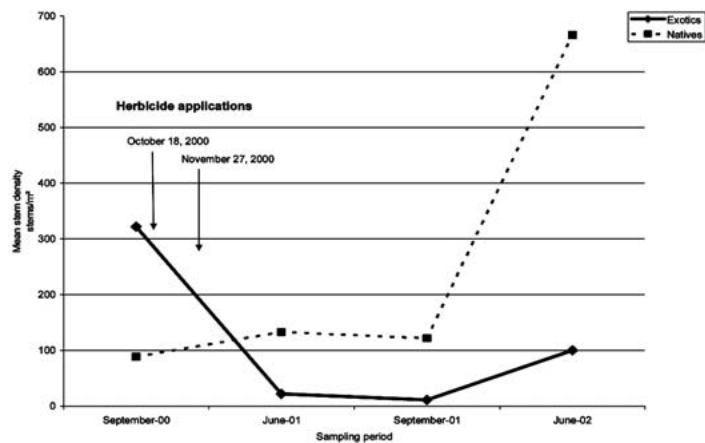


Figure 2. Mean stem densities for exotic and native plants sampled at 24 sites before (September 2000) and after (June 2001, September 2001, and June 2002) a whole-lake fluridone application in Perch Lake, Michigan.

tial fall treatment, its relatively low recovery was most likely due to sprouting of dormant turions in the sediment.

Natives comprised approximately 20% of the total species composition before the herbicide treatment, and increased to approximately 90, 93, and 87% in successive sampling periods after the treatment (Table 1). Canopy forming water-shield (*Brasenia schreberi* L.) and white water lily (*Nymphaea odorata* Aiton), and the macroalgae muskgrass (*Chara* spp.) that can provide excellent bottom cover were the most abundant species following the treatment in June 2001, September 2001, and June 2002, respectively. The greatest total stem densities occurred in June 2002, twice as high as pre-treatment, and constituted primarily of native species (Figure 2). We noted a significant difference ($\chi^2 = 42$, $p < 0.01$) in relative abundance of the native plant species during the study (Table 1). In June 2001, watershield was most common (35%) closely followed by muskgrass (27%) and white water lily (23%). White water lily was the most common aquatic plant species in September 2001 (53%) and muskgrass was most common the following June (81%). This represented a shift in the dominant canopy forming milfoil to a more complex under story dominated by muskgrass. Muskgrass is important because its high stem numbers provide habitat important as fish cover and macroinvertebrate attachment. Furthermore, since it is not a canopy forming species it does not hinder light penetration into the water column that is required for new growth and colonization of submersed native plants. Two native species not previously collected were recorded in post-herbicide treatment samples: wild celery (*Valisneria americana* L.) and bladderwort (*Utricularia* spp.). Wild celery was present in all post-treatment samples, and bladderwort was very common in September 2001, where the abundance of the two native species, *Potamogeton gramineus* and *Najas* spp. was reduced (Table 1). Mean plant biomass was significantly greater ($F = 26.34$, $p < 0.001$) in September 2000 (pre-herbicide treatment) compared to post-treatment samples, ranging from 214 g/m^2 to a low of 39.8 g/m^2 in June 2001 of the post-treatment sampling period immediately following the herbicide treatment (Table 2). Likewise, we noted significant treatment effects on mean stem densities of the lit-

TABLE 1. TOTAL NUMBER OF STEMS AND RELATIVE PERCENTAGE OF AQUATIC PLANT SPECIES MEASURED IN THE LITTORAL ZONE AT PERCH LAKE MICHIGAN DURING PRE- AND POST-TREATMENT SAMPLING.

Species	Pre-treatment ^a		Post-treatment	
	Sep 2000 (no.) (%)	June 2001 (no.) (%)	Sep 2001 (no.) (%)	June 2002 (no.) (%)
<i>Myriophyllum spicatum</i> ^b	709 (79) ^c	27 (8)	0 (0)	3 (<1)
<i>Nymphaea odorata</i>	55 (6)	75 (23)	148 (53)	52 (3)
<i>Potamogeton gramineus</i>	19 (2)	2 (<1)	2 (<1)	0 (0)
<i>Najas</i> spp.	86 (7)	3 (<1)	0 (0)	1 (<1)
<i>Brasenia schreberi</i>	22 (2)	111 (35)	9 (3)	6 (<1)
<i>Chara</i> spp.	6 (1)	87 (27)	1 (<1)	1,361 (81)
<i>Nuphar advena</i>	1 (<1)	6 (2)	0 (0)	0 (0)
<i>Utricularia</i> spp.	0 (0)	0 (0)	86 (31)	5 (<1)
<i>Vallisneria americana</i>	0 (0)	0 (0)	13 (5)	37 (2)
<i>Potamogeton crispus</i> ^b	0 (0)	4 (<1)	20 (7)	208 (12)
<i>Potamogeton illinoensis</i>	1 (0)	2 (<1)	0 (0)	3 (<1)
Total	899 (100)	315 (100)	279 (100)	1,646 (100)

^aTreatment = fall, low-dose whole-lake fluridone application.

^bIndicates exotic species.

^cPercentages are rounded to the nearest whole number.

toral zone plants (Table 2). Means ranged from a low of 144 and 133 stems m² during the two sampling periods immediately after the herbicide treatment, lower than the stems counted before the treatment, to a high of 778 stems m² in June 2002 after the treatment (Table 2). Mean plant diversity and species richness did not change significantly (Table 2).

Our data suggest that a fall, low-dose whole-lake herbicide treatment can serve as a management tool to enhance spatial heterogeneity within the littoral zone habitat of lakes. The treatment successfully targeted milfoil and significantly decreased its biomass, density, and abundance while maintaining growth of a diverse plant bed of native species within the littoral zone. In addition, this operational application verifies results of small-scale evaluations of the species-selective potential of fluridone (Netherland et al. 1997). Several major shifts occurred in the aquatic plant community of Perch Lake after the whole-lake fluridone treatment that potentially influenced habitat heterogeneity in the littoral zone. Within one year following treatment, the dominant stand of milfoil was absent, with a slight recurrence of that species the following June.

Since, milfoil forms dense vegetative mats that contribute greatly to the biomass of an aquatic system (Madsen et al. 1991), once these mats are removed, a reduction in overall

plant biomass is not unexpected. Less than one year after milfoil removal, native plants had firmly re-established themselves in Perch Lake, and within almost two years, native species biomass and density levels increased. In fact, the highest stem density of all sampling periods was recorded in June 2002, due to dense beds of muskgrass (>3000 stems m²) recorded at three sites. Stems in milfoil beds, like other submerged aquatic plants provide substrate for attachment and predator protection for the epiphytic organisms that constitute a prey resource for small and young fishes (Keast 1984). Plant stems can contain significantly higher levels of macroinvertebrates and epiphytic fauna than open water littoral areas (Purdue and Webb 1985). Thus increasing stem density can increase biomass of a forage base for fish (Pardue 1973).

However, even though the monoculture of milfoil provided stem density important to epiphytic organisms and fish, it does not provide the heterogeneity required to support a more diverse food web. Architecture in plants differs significantly by species (Dibble et al. 1996a, Lillie and Budd 1992) and a diverse bed of native plants exhibit high heterogeneity due to these innate differences in form. This heterogeneity provides interstices and a suite of different habitats important to colonization of a diverse macroinvertebrate commu-

TABLE 2. MEAN^a BIOMASS, STEM DENSITY, DIVERSITY, AND SPECIES RICHNESS OF AQUATIC PLANTS MEASURED IN THE LITTORAL ZONE AT PERCH LAKE, MICHIGAN DURING PRE-AND POST-TREATMENT SAMPLING.

	Pre-treatment		Post-treatment	
	September 2000	June 2001	September 2001	June 2002
Biomass (g/m ²)	214.0 A ^b	39.8 B	47.3 B	64.4 B
Stem density (no./m ²)	411.0 AB	144.0 B	133.0 B	778.0 A
Total diversity (<i>H</i>)	1.7 A	2.3 A	1.4 A	2.3 A
Species richness	8.0 A	9.0 A	7.0 A	9.0 A

^aN = 24 sites.

^bValues in each column with letters in common are not significantly.

nity (Jefferies 1993). Gaps among stems and plants in beds with heterogeneity provide foraging space to fishes. Too much stem density may reduce this heterogeneity, interfere with efficient foraging, and hinder fish growth and condition (Eklove and Diehl 1994, Macina and Shirman 1985).

In addition to increased native species abundance and stem densities, two new native species were collected in post-treatment samples, bladderwort and wild celery. These species may have been present among milfoil, but in very low abundance, explaining why they were not collected in pre-treatment samples. The increase in native species composition may be the result of dramatic reductions in competition due to the removal of milfoil. The native bladderwort is similar in structure to milfoil, and grew with little competition to become the second, most abundance species in September 2001.

Several studies have found increases in native plant diversity following herbicide treatments to remove milfoil (Getsinger et al. 1997, Getsinger et al. 2001). While this study does not support those findings, no significant differences were found among seasonal sampling periods with respect to native plant diversity. The diversity differences between fall and summer sampling periods are most likely due to seasonality. Post-treatment evaluations continued only for one year (June 2001 to June 2002), which may not have been sufficient time for late-summer native species to fully establish themselves.

Additional heterogeneity may have been introduced into our study system due the seasonal succession of the growth in the native species. For example, the muskgrass and water-shield that dominated our samples early in the growing season were later replaced by the water-lily and bladderwort in September. This seasonal succession of growth in the native plants added another element of heterogeneity within the littoral zone. Similar shifts and increases in native plants have been noted in other systems after the removal of an invasive species (Maceina and Slipke 2004).

A monoculture of milfoil exhibits little difference in form because the seasonal progression of biomass lacking different growth stages (Grace and Wetzel 1978). Milfoil can dominate an area early in the spring with an architecture relatively uniform growing throughout the year and lasting into late fall and early winter. On the contrary, growth and form of native plants exhibit seasonality and vary within the same growing season (Madsen 1997). This provides temporal heterogeneity not provided by a monoculture and different structural habitat due to the different life forms of plant present in the lake at any given time during the season. For example, *Valisineria* provides a short stem and root mass on the bottom during early life stages and later provides long ribbon like leaves that project into the water column. Spring growth of some *Potamogetons* may fill the water column with a branching matrix of small leaves and stems, yet these same plants later in the summer may form a surface canopy of leaves over now spindly stems.

While we were unable to collect data on an untreated reference lake, results in our study were consistent with spring-time whole-lake fluridone treatments previously conducted and compared to such controls (Getsinger et al. 2002a, 2002b, Madsen et al. 2002). Like these studies, a significant decrease in overall aquatic plant biomass was noted after the removal of milfoil. However, this biomass reduction repre-

sents a shift from a monotypic vegetative condition dominated by a single invasive species, to an enhancement of native species richness and habitat heterogeneity. Our data shows that the vegetative community was transformed from a milfoil-dominated system (i.e., early, widespread, and persistent surface canopy with a suppressed understory of native plants) to a chara-dominated system (low-growing and highly branched growth form) with native plants emerging through the chara meadows. The small and gradual increase of curlyleaf pondweed following the treatment in 2002 most likely reflects the sprouting of dormant turions and suggests that *Potamogetons* can rely on vegetative structures to recover from stresses such as herbicide applications. Increases in curlyleaf pondweed following low-dose, whole-lake fluridone treatments targeted at milfoil have been reported in other Michigan lakes (Getsinger et al. 2001), but these increases were often more dramatic than measured in this study.

This herbicide treatment was unique because the application occurred in the fall, with herbicide residue remaining in the water column throughout winter, targeting exotic species as they grew in early spring. Since the littoral zone plant composition shifted significantly during our study from a near monoculture to a multi-species community, we hypothesized that both spatial and temporal heterogeneity was increased and improved the quality of habitat within the littoral zone in Perch Lake at the expense of eradicating the invasive plant monoculture. Such a shift in structural heterogeneity within a lake is generally accepted by community ecologists and managers as beneficial, yet little is known about the underlying ecological mechanisms. Future work is required to investigate this hypothesis and to better understand how aquatic organisms (i.e., fish and their prey) respond to changes in structural heterogeneity of habitat and the role herbicides can play in lake management to enhance littoral zone habitat.

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