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Assessment of Herbicide Efficacy on Eurasian Watermilfoil and Impacts to the Native Submersed Plant Community in Hayden Lake, Idaho, USA

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ABSTRACT

The presence of Eurasian watermilfoil (*Myriophyllum spicatum* L.) in aquatic systems has resulted in adverse impacts to native plant communities, ecosystem function, and water resource uses. Eurasian watermilfoil in Hayden Lake, Idaho, has spread rapidly, impacting the native plant community and recreational uses of the lake. Point intercept surveys were conducted to determine the current composition of the plant community and to assess the efficacy of triclopyr and 2,4-D herbicide treatments on Eurasian watermilfoil during the year of treatment. Twenty-two aquatic plant species were identified during four surveys (two of the littoral zone and two focused on herbicide treated areas) conducted between June and September 2007. The presence of Eurasian watermilfoil was reduced in all treated areas by 88% ($p < 0.01$) 5 weeks after treatment. There was no difference ($p = 0.81$) in the efficacy between triclopyr and 2,4-D for control of Eurasian watermilfoil. The use of herbicides had no significant deleterious impacts on the native plant community. The percent occurrence of large-leaved pondweed (*Potamogeton amplifolius* Tuckerm.), Robbins' pondweed (*Potamogeton robbinsii* Oakes), and wild celery (*Vallisneria americana* Michx.) increased after treatment ($p < 0.01$). Future triclopyr and 2,4-D applications should have minimal to no negative impact on the native plant community in Hayden Lake due to the dominance of monocotyledon species among the native vegetation, which are generally tolerant to these herbicides.

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INTRODUCTION

Hayden Lake is located in northern Idaho and has been invaded and colonized by Eurasian watermilfoil (*Myriophyllum spicatum* L.) in the past decade. Eurasian watermilfoil was first identified in Hayden Lake in 1998 by the Kootenai County Noxious Weed Program, prompting an operational control program beginning in 1999. During the 1998-1999 growing season there was approximately 243 ha (600 ac) of Eurasian watermilfoil, which represented roughly 16% of the total surface area of Hayden Lake. The initial introduction, spread, and possible reintroduction of Eurasian watermilfoil is likely attributed to increased disturbance within the lake and watershed of Hayden Lake. The shoreline of Hayden Lake is becoming suburbanized with increases in houses, parks, beaches, and impermeable surfaces. This development results in greater runoff into the lake and greater use of the lake for recreation (Hayden Lake Watershed Association 2008). As lake shores become more developed and recreation on the water increases, the level of disturbance also increases, which may result in reductions in native species. Removal or reductions in native species opens a niche for fast-growing colonizing species like Eurasian watermilfoil (Davies et al. 2005, Lockwood et al. 2005, Capers et al. 2007). Also, in recent years, a growing tourist industry has attracted an estimated 800,000 people each year to the region (Hayden Lake Watershed Association 2008), further putting the lake at risk to potential invasion by non-native species.

The threats posed by Eurasian watermilfoil to Hayden Lake and other water bodies in the state have prompted the Idaho State Department of Agriculture (ISDA), in cooperation with the Idaho Invasive Species Council, to develop a Eurasian watermilfoil eradication program (ISDA 2007). As part of this program, suspected waterbodies are being monitored to detect the presence of Eurasian watermilfoil, and those already infested are being monitored to document the extent and spread of Eurasian watermilfoil. The point-intercept method was chosen as the sampling protocol for the program due to the simplicity of data collection and the ability to conduct a quantitative statistical assessment of plant control techniques.

Management of Eurasian watermilfoil from 1999 to 2009 in Hayden Lake included the use of herbicides, diver-operated suction dredging, and bottom barriers. Over the past 10 years, 583 ha (1441 ac) of Eurasian watermilfoil has been managed at an average cost of \$2074 ha^{-1} (\$838 $acre^{-1}$; Inland Empire Cooperative Weed Management Area, unpublished data). In 2007, the auxin-mimicking herbicides triclopyr (triethylamine (TEA) salt of [(3,5,6-trichloro-2-pyridinyl) oxy]acetic acid) and 2,4-D (Butoxyethyl ester of (2,4-dichlorophenoxy) acetic acid) were selected for controlling Eurasian watermilfoil in Hayden Lake. Triclopyr and 2,4-D have been used in small-plot and whole-lake management programs to control Eurasian watermilfoil and in many instances have shown considerable selectively in removing Eurasian watermilfoil with little to no impact on native plant communities (Getsinger et al. 1982, 1997, 2000, Parsons et al. 2001, Poovey et al. 2004).

While much is known about the use patterns of 2,4-D and triclopyr on an anecdotal basis, there are relatively few published accounts of case studies using these products. The objectives of this study were to (1) conduct early and late season surveys of the littoral zone of Hayden Lake to assess the current plant community and (2) conduct pre- and post-herbicide treatment surveys to assess the level of control of Eurasian watermilfoil and impacts on nontarget native plant species throughout the lake where treatments using triclopyr and 2,4-D were performed.

MATERIALS AND METHODS

Study Site

Hayden Lake (47°46'1.167"N; 116°42'24.165"W) is located in northern Idaho and is approximately 1568 ha in total area. Hayden Lake has a maximum depth of 54 m and mean depth of 28 m (Bellatty 1990). The major land use surrounding the lake is agriculture and grazing. There are approximately 43 km of shoreline, of which more than 85% is developed (Bellatty 1990). The primary uses of the lake are recreational including boating, skiing, and fishing. Hayden Lake is oligotrophic with water clarity (Secchi depths) exceeding 7 m, and the lake is considered to be nutrient poor with total nitrogen ($NO_2 + NO_3$) <0.01 mg/L and total phosphorus <0.009 mg/L (Bellatty 1990, Hayden Lake Watershed Association 2005, 2006). In 2006, chlorophyll *a* concentrations were <0.002 mg/L, and dissolved oxygen ranged from 8.4 to 11.7 mg/L (Hayden Lake Watershed Association 2006). Historically, conductance was recorded to be 56 to 60 μmhos, total alkalinity as $CaCO_3$ was approximately 24 to 26 mg/L, and water pH ranged from 7.0 to 7.7 (Bellatty 1990).

Littoral Zone Surveys

The point intercept survey method was used to determine the presence of aquatic plants in the littoral zone of Hayden Lake on a 200-m grid (Madsen 1999). The littoral zone was defined using the 5-m depth contour of the lake as determined by the Idaho State Department of Agriculture. An early season survey of the littoral zone consisting of 104 sample points was conducted in June of 2007 (Figure 1). These same sample points were revisited in September 2007 to assess late season changes in the plant community. The surveys were conducted by boat using a Trimble AgGPS106™ receiver connected to a Panasonic Toughbook computer to achieve 1-3 m survey accuracy. At each survey point, a weighted plant rake was deployed twice to determine the presence and identification of aquatic plant species. Additionally, the depth at each point was recorded using a depth finder mounted to the hull of the boat.

Spatial data collected during the surveys were recorded in the computer using FarmWorks Site Mate® software. Data were recorded in database templates using specific pick lists constructed for each survey. Site Mate® provided an environment for displaying geographic and attribute data and enabled navigation to specific locations on the lake (Wersal et al. 2006a, 2007). Survey data were reported as the percent occurrence for each plant species. Species richness was cal-

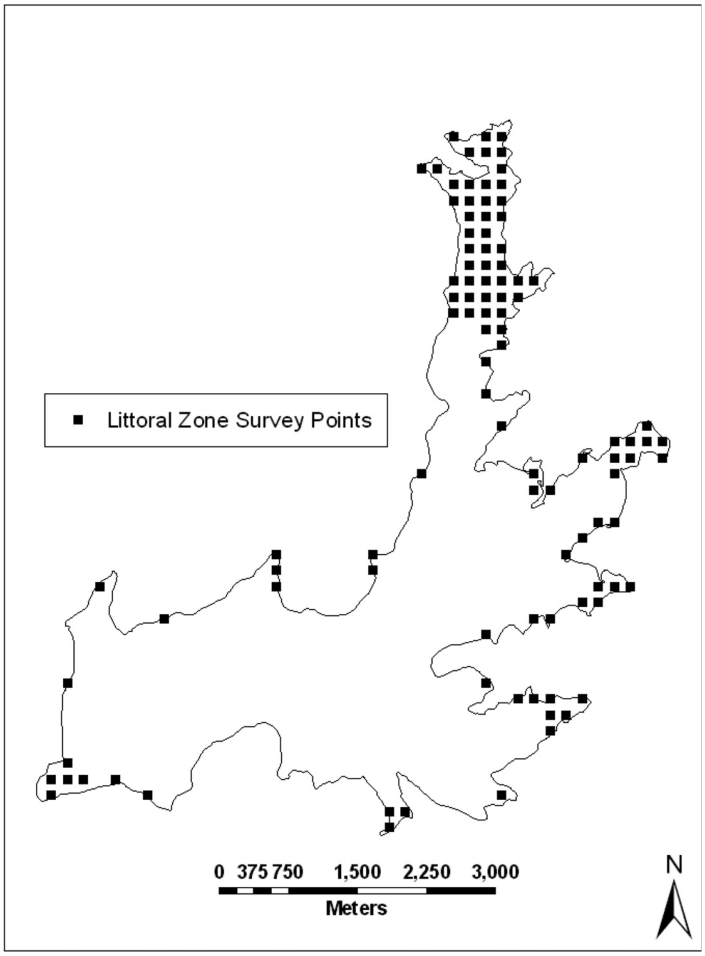

Figure 1. Survey points sampled during the littoral surveys of Hayden Lake, ID, June and September 2007.

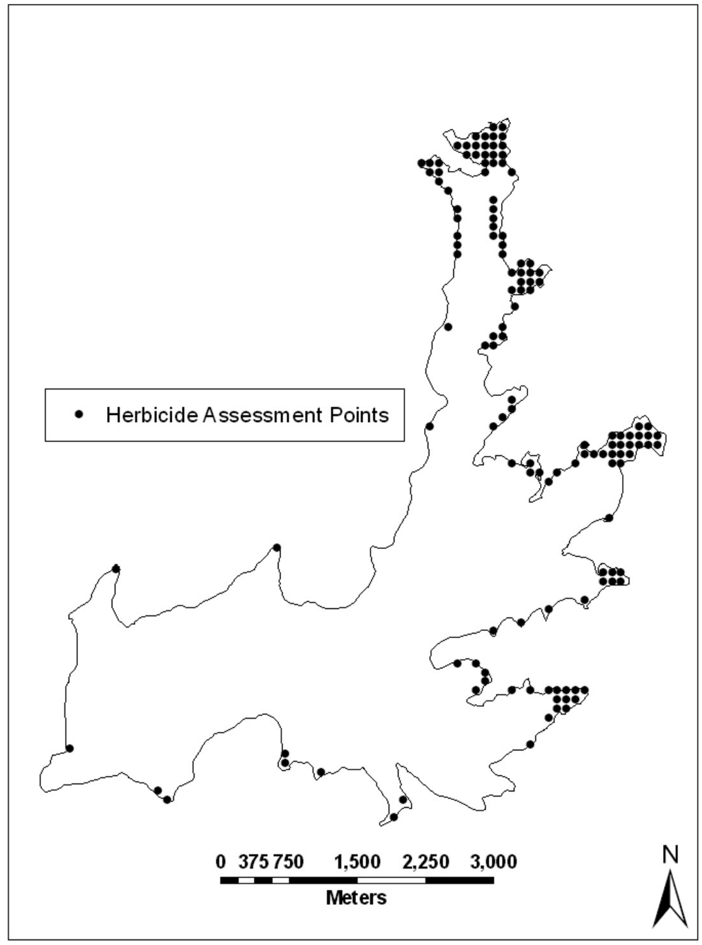

Figure 2. Survey points sampled during the pre and post treatment assessment of Hayden Lake, ID, June and September 2007.

culated as the mean number of species present at each point and presented as the mean (±1 SE) of all species observed at each point.

Herbicide Assessment

Herbicide assessment surveys were conducted similar to the littoral surveys; however, a 100-m grid was used to increase sampling intensity in the areas of Eurasian watermilfoil control (Figure 2). The pretreatment survey was conducted in June 2007 and consisted of 140 points. Herbicide treatments were made on 30 and 31 July 2007. The post-treatment survey was conducted in September 2007, 5 weeks after treatment (WAT) using the same points as the pretreatment survey.

The assessment surveys evaluated the effectiveness of triclopyr applied as liquid Renovate3® and 2,4-D applied as granular Navigate® for the control of Eurasian watermilfoil (Figure 3). Triclopyr was applied as a subsurface application to achieve a target concentration of 1.5 mg ae L^{-1} (mg acid equivalent per liter). The 2,4-D was applied using a granular spreader at rate of 112.3 to 168.0 kg ha^{-1} to achieve a target concentration of 1.5 mg ae L^{-1}. All applications were performed by a licensed commercial applicator. Because Hayden Lake is very deep, the water temperature does not warm sufficiently to allow plant growth until late June or early July. The applications in late July are an appropriate time to target actively growing plants. Water samples were collected by the Kootenai County Weed Board at 1 and 2 days after treatment (DAT) for triclopyr applications and 1, 2, 3, 14, and 42 DAT for most areas treated with 2,4-D. The samples were shipped to Anatek Labs (Moscow, ID) for herbicide residue analyses. Analytical methods followed those outlined in EPA 8321B, high performance liquid chromatography.

Statistical Analyses

Eurasian watermilfoil control was evaluated using McNemar's Test for dichotomous response variables using SAS to analyze differences in the presence of Eurasian watermilfoil between the pre- and post-treatment surveys. McNemar's Test assesses differences in the correlated proportions within a given data set between variables that are not independent (i.e., sampling the same points over time; Stokes et al. 2000, Wersal et al. 2006b, Madsen et al. 2008). The same analysis was conducted to compare the efficacy of triclopyr and 2,4-D

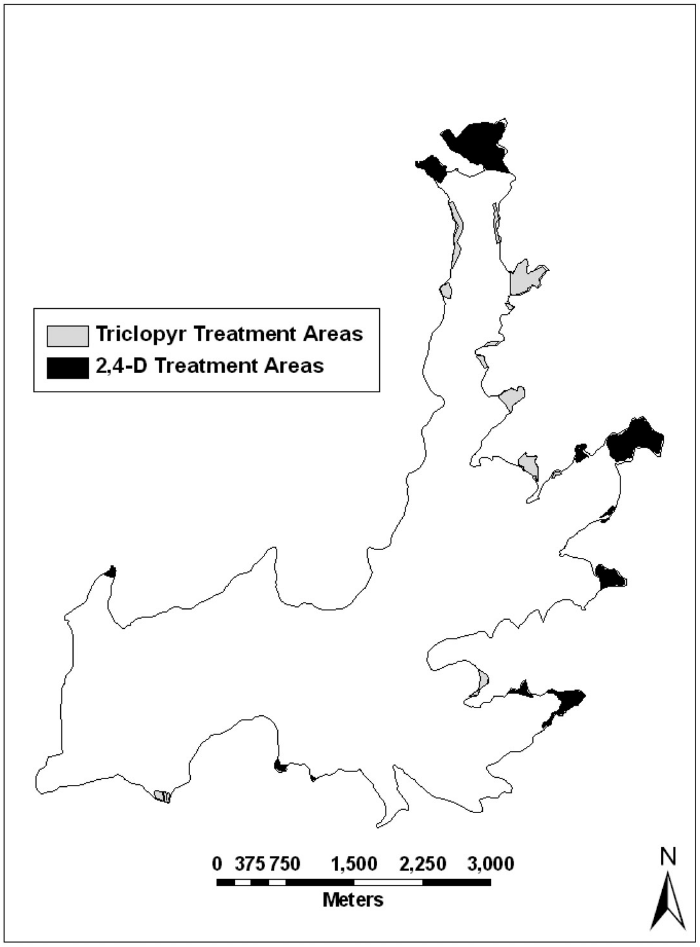

Figure 3. Eurasian watermilfoil herbicide treatment areas on Hayden Lake, ID, 2007.

for treating Eurasian watermilfoil. A paired-T test was used to assess differences in littoral native species richness and differences in native species richness for each herbicide between the pre- and post-treatment surveys (Statistix 8.0; Analytical Software 2003). All analyses were conducted at a $p = 0.05$ level of significance.

RESULTS AND DISCUSSION

Littoral Zone Surveys

During the initial survey of Hayden Lake we observed 18 different species of aquatic plants, with 17 species considered native (Table 1). Wild celery (*Vallisneria americana* Michx.) was considered a native species for the purposes of our analyses, although there is debate as to whether this species is native to the Northwestern United States. The United States Department of Agriculture (USDA 2009) reports wild celery to be native to the lower 48 States. Crow and Hellquist (2000) report wild celery to be introduced to Washington with no mention of other western states. The littoral zone was dominated by pondweed (*Potamogeton*) species, particularly Robbins' pondweed (*Potamogeton robbinsii* Oakes) and large-leaved pondweed (*Potamogeton amplifolius* Tuckerm.). Robbins' pondweed had a frequency of occurrence of 52% and 66% for the early and late season surveys, respectively. Large-leaved pondweed had a frequency of occurrence of 31% and 42% during this same time period.

Native plant species richness increased ($p < 0.01$) from 1.5 species per point during the early season survey to 2.1 species per point during the late season survey. We attribute some of the increase in species richness to the seasonality of native species, especially increases in the presence of some pondweeds. Pondweeds are adapted to grow in low light environments and likely expanded into deeper water habitats as the growing season progressed and temperatures increased, stimulating propagule germination and growth (Spence and Chrystal 1970a, 1970b, Madsen and Adams 1989, Wersal et al. 2006b). Alternatively, Eurasian watermilfoil had a frequency of occurrence of 15% during the early season survey and was observed at <1% of the points during the late season survey. The majority of Eurasian watermilfoil was located in areas of the lake targeted specifically for herbicide applications; therefore, a reduction in species presence is attributed to the use of herbicides and not natural senescence. Eurasian watermilfoil populations in northern areas such as Lake Washington, Washington (Perkins and Sytsma 1987) or Buckhorn Lake, Ontario (Painter 1988) typically are at or near their biomass peak during late summer (Aug and Sep).

Herbicide Assessment

A total of 83 ha (26 ha triclopyr, 57 ha 2,4-D) of Eurasian watermilfoil was treated with herbicides in Hayden Lake during the 2007 season. Water samples collected 1 and 2 d after herbicide applications indicated that measured concentrations of triclopyr were low in all treated areas, indicating rapid degradation or dissipation of the herbicide, considering the target rate was 1.5 mg ae L^{-1} (Table 2). These findings are consistent with other field trials using liquid triclopyr where highest concentrations in treated areas were observed between 4 and 8 h after application, followed by rapid (70 to 90%) degradation and dissipation within 24 h after application (Getsinger et al. 1997, 2000, Poovey et al. 2004). Triclopyr degradation in lakes and ponds is rapid, with half-lives ranging from 0.5 to 7.5 d, depending on degree of water exchange at the treated locations (Woodburn et al. 1993, Petty et al. 2001, 2003). However, overall control of Eurasian watermilfoil in triclopyr plots (26 ha) was 91%.

The presence of Eurasian watermilfoil was reduced in all treated areas by 88% ($p < 0.01$) from the pretreatment survey to the post-treatment survey (Table 3). There was no difference ($p = 0.81$) in the reduction of Eurasian watermilfoil between the triclopyr and 2,4-D treated areas. The use of triclopyr resulted in 91% control of Eurasian watermilfoil at 5 WAT. Similar results were achieved in the Pend Oreille River, Washington, where overall biomass of Eurasian watermilfoil was reduced by 99% within the year of treatment and maintained 99% and 72% control in the treated areas at 1 year after treatment (Getsinger et al. 1997). In Lake Minnetonka, Minnesota, Eurasian watermilfoil was significantly reduced within the year of treatment through the use of triclopyr (Getsinger et al. 2000, Poovey et al. 2004).

TABLE 1. FREQUENCY OF OCCURRENCE OF AQUATIC PLANT SPECIES OBSERVED DURING THE EARLY AND LATE SEASON LITTORAL SURVEYS OF HAYDEN LAKE, 2007. WATER DEPTH AND SPECIES RICHNESS ARE REPORTED AS THE MEAN ±1 SE. SIGNIFICANCE VALUES WERE DETERMINED USING THE MCNEMAR'S TEST AT P = 0.05; P-VALUES COULD NOT BE COMPUTED FOR THOSE SPECIES WITH A 0% OCCURRENCE REPORTED DURING EITHER SURVEY.

Species	Common Name	% Occurrence Early Season	% Occurrence Late Season	p-value
Ceratophyllum demersum L.	Coontail	10	16	0.15
Chara sp.	Muskgrass	3	5	0.41
Elodea canadensis Michx.	Elodea	20	21	0.99
Myriophyllum sibiricum Komarov	Northern watermilfoil	0	2	0.56
Myriophyllum spicatum L.	Eurasian watermilfoil	15	<1	<0.01
Najas flexilis (Willd.) Rostk. & Schmidt	Slender naiad, bushy pondweed	0	2	—
Nitella sp.	Nitella	6	3	0.10
Nuphar lutea L.	Yellow pond-lily	2	3	0.65
Potamogeton amplifolius Tuckerm	Large-leaved pondweed	31	42	0.07
Potamogeton foliosus Raf.	Leafy pondweed	2	0	—
Potamogeton gramineus L.	Variableleaf pondweed	1	0	—
Potamogeton natans L.	Floating-leaved pondweed	4	3	0.71
Potamogeton praelongus Wulf.	Whitestem pondweed	<1	24	<0.01
Potamogeton richardsonii (Ar. Benn.) Rydb.	Clasping-leaved pondweed	1	6	0.05
Potamogeton robbinsii Oakes	Robbins' pondweed	52	66	0.01
Potamogeton zosteriformis Fern.	Flat-stemmed pondweed	13	17	0.53
Ranunculus aquatilis L.	White water-buttercup	5	2	0.25
Vallisneria americana Michx.	Wild celery	2	5	0.25
Native Species Richness (per point)		1.5 ± 0.1	2.1 ± 0.1	<0.01
Non-native Species Richness (per point)		0.2 ± 0.0	0.0 ± 0.0	<0.01
Mean Water Depth (m)		3.1 ± 0.6	3.2 ± 0.6	

TABLE 2. HERBICIDE RESIDUE SAMPLES COLLECTED IN HAYDEN LAKE DURING JULY, AUGUST, AND SEPTEMBER 2007. APPLICATIONS WERE MADE ON JULY 30 AND 31 2007, CONCENTRATIONS REPORTED IN MG L^{-1}. RESIDUE DATA REPRINTED WITH PERMISSION FROM THE INLAND EMPIRE COOPERATIVE WEED MANAGEMENT AREA, ID.

Location[a]	Herbicide	1 DAT	2 DAT	3 DAT	4 DAT	14 DAT	42 DAT
Chicken Point	Triclopyr	—	0.00	—	—	—	—
Cooper Bay	Triclopyr	0.00	—	—	—	—	—
McLean's Bay	Triclopyr	0.58	0.33				—
Shenandoah	Triclopyr	0.07	—	—	—	—	—
Sunset Beach	Triclopyr	0.02	—	—	—	—	—
Welbourne	Triclopyr	0.00	0.02	—	—	—	—
Clark's Bay	2,4-D	0.28	0.15	0.10	-	-	0.00
Mokins Slough	2,4-D	—	0.35	0.47	0.33	0.26	0.002
O'Rourke Bay	2,4-D	0.35	0.47	0.31	0.29	0.01	0.002
Preston Beach	2,4-D	—	0.36	0.17	0.28	0.13	0.001
Schmidt's Bay	2,4-D	0.00	—	—	—	—	0.00
Sportsman's Bay	2,4-D	0.07	0.17	0.28	0.17		0.00
Victoria Bay	2,4-D	—	0.71	0.16	0.18	0.18	0.00

[a]Not all treated areas were sampled for herbicide residues.

Water samples collected in 2,4-D treated areas showed residues between 0 and 0.71 mg ae L^{-1} 1 to 2 DAT (Table 2). Based on concentration exposure time relationships, a 2,4-D concentration of 0.25 mg ae L^{-1} should yield >85% control if maintained for at least 72 hr (Netherland and Getsinger 1992). Herbicide residues of 0.10 to 0.47 mg ae L^{-1} were reported at 3 to 4 DAT in most 2,4-D treated areas. The slower rate of dissipation and degradation of 2,4-D compared to triclopyr is likely due to the slow release of 2,4-D from the granular formulation, as opposed to the use of the triclopyr in a liquid formulation. Observed control of Eurasian watermilfoil in Hayden Lake 2,4-D plots (57 ha) was 83%. Like triclopyr, 2,4-D offered excellent control of Eurasian watermilfoil 5 WAT. The use of granular 2,4-D resulted in significant reductions in the Eurasian watermilfoil population in Lake Quonnipaug, Connecticut (Bugbee and White 2004). Likewise, granular 2,4-D was efficacious in removing variable watermilfoil (*Myriophyllum heterophyllum*) in Bashan Lake, Connecticut (Bugbee et al. 2003). The use of 2,4-D is common in Eurasian watermilfoil control programs and has typically offered control during large scale treatments in lakes with little to no nontarget plant injury (Couch and Neslon

TABLE 3. FREQUENCY OF OCCURRENCE OF AQUATIC PLANT SPECIES OBSERVED DURING THE PRE-TREATMENT AND POST TREATMENT SURVEYS OF THE HERBICIDE APPLICATION AREAS IN HAYDEN LAKE, 2007. WATER DEPTH AND SPECIES RICHNESS ARE REPORTED AS THE MEAN ± 1 SE. SIGNIFICANCE VALUES WERE DETERMINED USING THE MCNEMAR'S TEST AT P = 0.05; P-VALUES COULD NOT BE COMPUTED FOR THOSE SPECIES WITH A 0 PERCENT OCCURRENCE REPORTED DURING EITHER SURVEY.

Species	Common Name	% Occurrence Pre Treatment	% Occurrence Post Treatment	% Change[a]	p-value
Callitriche sp.	Water-starwort	1	0		—
Ceratophyllum demersum L.	Coontail	19	16		0.66
Chara sp.	Muskgrass	0	4		—
Elodea canadensis Michx.	Elodea	39	39		0.99
Juncus pelocarpus Mey.	Rush	7	4		0.10
Myriophyllum sibiricum Komarov	Northern watermilfoil	0	2		—
Myriophyllum spicatum L.	Eurasian watermilfoil	34	4	- 88	<0.01
Najas flexilis (Willd.) Rostk. & Schmidt	Slender naiad, bushy pondweed	0	2		—
Nitella sp.	Nitella	5	0		—
Nuphar lutea L.	Yellow pond-lily	9	12		0.41
Potamogeton amplifolius Tuckerm	Large-leaved pondweed	13	42	+69	<0.01
Potamogeton crispus L.	Curlyleaf pondweed	1	2		0.65
Potamogeton epihydrus Raf.	Ribbonleaf pondweed	0	2		—
Potamogeton foliosus Raf.	Leafy pondweed	4	0		—
Potamogeton gramineus L.	Variableleaf pondweed	1	2		0.31
Potamogeton natans L.	Floating-leaved pondweed	6	5		0.73
Potamogeton praelongus Wulf.	Whitestem pondweed	16	10		0.06
Potamogeton richardsonii (Ar. Benn.) Rydb.	Clasping-leaved pondweed	3	2		0.70
Potamogeton robbinsii Oakes	Robbins' pondweed	50	70	+29	<0.01
Potamogeton zosteriformis Fern.	Flat-stemmed pondweed	19	14		0.14
Ranunculus aquatilis L.	White water-buttercup	6	2		0.06
Vallisneria americana Michx.	Wild celery	1	7	+90	0.01
Native Species Richness (per point)		1.9 ± 0.1	2.3 ± 0.1		<0.01
Non-native Species Richness (per point)		0.4 ± 0.1	0.1 ± 0.0		0.02
Mean Water Depth (m)		2.3 ± 0.3	2.1 ± 0.4		—

[a]Percent change is only reported for species showing a statistically significant change.

1982, Getsinger et al. 1982, Parsons et al. 2001). In Loon Lake and Lake Osoyoos, Washington, the use of 2,4-D resulted in >85% control of Eurasian watermilfoil 1 year after treatment (Killgore 1984, Parsons et al. 2001).

The use of herbicides to control Eurasian watermilfoil had no significant negative impact on the native plant community. In general, the occurrence of most species did not significantly change after herbicide application (Table 3); however, the occurrence of large-leaved pondweed, Robbins' pondweed, and wild celery increased by 69% ($p < 0.01$), 29% ($p < 0.01$), and 90% ($p = 0.01$), respectively. As a taxonomic group, the native pondweeds comprised the majority of plant species observed in Hayden Lake. The prevalence of monocot species is significant because these plant species are minimally affected by auxin herbicides (Sprecher and Stewart 1995, Sprecher et al. 1998), and in this study on Hayden Lake there were no significant adverse effects of herbicide applications on monocot or native dicotyledon species (dicot). In fact, it seems that the removal of Eurasian watermilfoil may have been a factor in increasing the presence of some plant species.

Other studies have documented that native species will recolonize those areas where Eurasian watermilfoil was removed. In the Pend Oreille River, Washington, Getsinger et al. (1997) reported that monocot species more than doubled in average diversity within treated areas, both 1 and 2 years after treatment. The increase in species diversity was attributed to the emergence of native pondweed species following the herbicide treatment. This same study reported that the dicot community was impacted initially by the application of triclopyr; however, once the Eurasian watermilfoil was removed native dicot species actually increased in abundance (Getsinger et al. 1997). In Loon Lake, Washington, the use of 2,4-D significantly reduced Eurasian watermilfoil presence and biomass while not significantly impacting the native plant community (Parsons et al. 2001). The removal of Eurasian watermilfoil and its canopy increases light penetration into the water column and increases available space for plant colonization, which results in increased growth of and competition from native species. Increases in native species may deter recolonization by Eurasian watermilfoil (Madsen 1994).

The presence of Eurasian watermilfoil in Hayden Lake was significantly reduced following the application of herbicides. The use of the point intercept survey facilitated the quantitative assessment of a lake-wide Eurasian watermilfoil control program for Hayden Lake, and also allowed quantitative documentation and tracking of native plant species over the growing season. The use of these herbicides resulted in the selective removal of Eurasian watermilfoil with no significant negative impact to native plant species. In fact, the removal of Eurasian watermilfoil may have resulted in increases in some native pondweeds and wild celery. Future applications of triclopyr and 2,4-D in Hayden Lake should have minimal to no detrimental/negative impact on the native plant community based on these findings. No single treatment of any herbicide is likely to eradicate all the invasive species in 1 year; long-term management will require persistent monitoring, management activity, and assessment of that activity. A long-term management plan should be developed and incorporate not only year-of-treatment management evaluations, but also long-term monitoring of the aquatic plant community. Intensive monitoring has been cited as the only effective way to determine a program's success and when to terminate a management program (Simberloff 2003).

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LITERATURE CITED

Analytical Software. 2003. Statistix 8. Analytical Software, Tallahassee, FL. 396 pp.

Bellatty, J. M. 1990. Hayden Lake, Kootenai County, Idaho 1987. Idaho Department of Health and Welfare, Division of Environmental Quality, Water Quality Bureau, Water Quality Status Report 92. 71 pp.

Bugbee, G. J. and J. C. White. 2004. Control of cabomba and Eurasian watermilfoil in Lake Quonnipag with fluridone and 2,4-D. The Connecticut Agricultural Experiment Station, New Haven, CT. 14 pp.

Bugbee, G. J., J. C. White and W. J. Krol. 2003. Control of variable watermilfoil in Bashan Lake, CT with 2,4-D: monitoring of lake and well water. J. Aquat. Plant Manage. 41:18-25.

Capers, R. S., R. S. Selsky, G. J. Bugbee and J. C. White. 2007. Aquatic plant community invasibility and scale-dependent patterns in native and invasive species richness. Ecology 88:3135-3143.

Couch, R. W. and E. N. Nelson. 1982. Effects of 2,4-D on non-target species in Kerr Reservoir. J. Aquat. Plant Manage. 20:8-20.

Crow, G. E. and C. B. Hellquist. 2000. Aquatic and wetland plants of northeastern North America. 2 Vol. University of Wisconsin Press, Madison, WI, USA.

Davies, K. F., P. Chesson, S. Harrison, B. D. Inouye, B. A. Melbourne and K. J. Rice. 2005. Spatial heterogeneity explains the scale dependence of the native-exotic diversity relationship. Ecology 86:1602-1610.

Getsinger, K. D., G. J. Davis and M. M. Brinson. 1982. Changes in a *Myriophyllum spicatum* L. community following 2,4-D treatment. J. Aquat. Plant Manage. 20:4-8.

Getsinger, K. D., D. G. Petty, J. D. Madsen, J. G. Skogerboe, B. A. Houtman, W. T. Haller and A. M. Fox. 2000. Aquatic dissipation of the herbicide triclopyr in Lake Minnetonka, Minnesota. Pest Manage. Sci. 56:388-400.

Getsinger, K. D., E. G. Turner, J. D. Madsen and M. D. Netherland. 1997. Restoring native vegetation in a Eurasian watermilfoil dominated plant community using the herbicide triclopyr. Regul. River. 13:357-375.

Hayden Lake Watershed Association. 2005. Water quality report for 2005. http://www.haydenlakewatershedassociation.com/id22.html. 6 pp. Accessed 3 April 2008.

Hayden Lake Watershed Association. 2006. Water Quality Report for 2006. http://www.haydenlakewatershedassociation.com/id41.html. 7 pp. Accessed 3 April 2008.

Hayden Lake Watershed Association. 2008. http://www.haydenlakewatershedassociation.com/id10.html. Accessed 3 April 2008.

ISDA (Idaho State Department of Agriculture). 2007. 2008 statewide strategic plan for Eurasian watermilfoil in Idaho. http://www.agri.idaho.gov/Categories/PlantsInsects/NoxiousWeeds/Documents/Eurasian watermilfoil/EWM%20Strategy%20Final.pdf. 84 pp. Accessed 2 April 2008.

Killgore, J. 1984. Use of herbicide/adjuvant formulations for the control of *Myriophyllum spicatum* L. Miscellaneous Paper A-84-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. 36 pp.

Lockwood, J. L., P. Cassey and T. Blackburn. 2005. The role of propagule pressure in explaining species invasions. Trends Ecol. Evol. 20:223-227.

Madsen, J. D. 1994. Invasions and declines of submersed macrophytes in Lake George and other Adirondack lakes. Lake Reserv. Manage. 10:19-23.

Madsen, J. D. 1999. Point and line intercept methods for aquatic plant management. APCRP Technical Notes Collection (TN APCRP-M1-02), U.S. Army Engineer Research and Development Center, Vicksburg, MS. 16 pp.

Madsen, J. D. and M. S. Adams. 1989. The light and temperature dependence of photosynthesis and respiration in *Potamogeton pectinatus* L. Aquat. Bot. 36:23-31.

Madsen, J. D., R. M. Stewart, K. D. Getsinger, R. L. Johnson and R. M. Wersal. 2008. Aquatic plant communities in Waneta Lake and Lamoka Lake, New York. Northeast. Nat. 15:97-110.

Netherland, M. D. and K. D. Getsinger. 1992. Efficacy of triclopyr on Eurasian watermilfoil: Concentration and exposure time effects. J. Aquat. Plant Manage. 30:1-5.

Painter, D. S. 1988. Long-term effects of mechanical harvesting on Eurasian watermilfoil. J. Aquat. Plant Manage. 26:25-29.

Parsons, J. K., K. S. Hamel, J. D. Madsen and K. D. Getsinger. 2001. The use of 2,4-D for selective control of an early infestation of Eurasian watermilfoil in Loon Lake, Washington. J. Aquat. Plant Manage. 39:117-125.

Perkins, M. A. and M. D. Sytsma. 1987. Harvesting and carbohydrate accumulation in Eurasian watermilfoil. J. Aquat. Plant Manage. 25:57-62.

Petty, D. G., K. D. Getsinger and K. B. Woodburn. 2003. A review of the aquatic environmental fate of triclopyr and its major metabolites. J. Aquat. Plant Manage. 41:69-75.

Petty, D. G., J. G. Skogerboe, K. D. Getsinger, D. R. Foster, B. A. Houtman, J. F. Fairchild and L. W. Anderson. 2001. The aquatic fate of triclopyr in whole-pond treatments. Pest Manage. Sci. 57:764-775.

Poovey, A. G., K. D. Getsinger, and J. G. Skogerboe, T. J. Koschnick, J. D. Madsen and R. M. Stewart. 2004. Small-plot, low-dose treatments of triclopyr for selective control of Eurasian watermilfoil. Lake Reserv. Manage. 20:322-332.

Simberloff, D. 2003. Eradication-preventing invasions at the outset. Weed Sci. 51:247-253.

Spence, D. H. N. and J. Chrystal. 1970a. Photosynthesis and zonation of freshwater macrophytes. I. Depth distribution and shade tolerance. New Phytol. 69:205-215.

Spence, D. H. N. and J. Chrystal. 1970b. Photosynthesis and zonation of freshwater macrophytes. II. Adaptability of species of deep and shallow water. New Phytol. 69:217-227.

Sprecher, S. L., K. D. Getsinger, and A. B. Stewart. 1998. Selective effects of aquatic herbicides on sago pondweed. J. Aquat. Plant Manage. 36:64-68.

Sprecher, S. L. and A. B. Stewart. 1995. Triclopyr effects on peroxidase activity in target and non-target aquatic plants. J. Aquat. Plant Manage. 33:43-48.

Stokes, M. E., C. S. Davis and G. G. Koch. 2000. Categorical Data Analysis Using the SAS® System, second edition. SAS Institute Inc., Cary, NC.

USDA (U.S. Department of Agriculture). 2009. Plants National Database. http://plants.usda.gov. Accessed 17 December 2009.

Wersal, R. M., J. D. Madsen and M. L. Tagert. 2006a. Aquatic Plant Survey of Ross Barnett Reservoir for 2005. GRI Report #5003, GeoResources Institute, Mississippi State University, Mississippi State, MS. 11 pp.

Wersal, R. M., J. D. Madsen, B. R. McMillan and P. D. Gerard. 2006b. Environmental factor affecting biomass and distribution of *Stuckenia pectinata* in the Heron Lake System, Minnesota, USA. Wetlands 26:313-321.

Wersal, R. M., J. D. Madsen and M. L. Tagert. 2007. Aquatic Plant Survey within the Littoral Zone of the Ross Barnett Reservoir for 2006. GRI Report #5011, GeoResources Institute, Mississippi State University, Mississippi State, MS. 19 pp.

Woodburn, K. B., W. R. Green and H. E. Westerdahl. 1993. Aquatic dissipation of triclopyr in Lake Seminole, Georgia. J. Agr. Food Chem. 41:2172-2177.