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In 1993, Eurasian watermilfoil (*Myriophyllum spicatum* L.) was discovered in Crystal Lake, Hancock County, Iowa. During the next three years, new infestations were discovered by the Iowa Department of Natural Resources (IDNR) fisheries personnel in four Iowa lakes. In July 1996, a program was established by the IDNR to address the threat posed by Eurasian watermilfoil to Iowa's aquatic ecosystems. As part of the Eurasian Watermilfoil Program, statewide aquatic vegetation monitoring was begun to identify those lakes currently infested with Eurasian watermilfoil. Monitoring activities were conducted by IDNR field technicians during the summers of 1996 through 2000. During this time period, 366 surveys of 290 waterbodies were conducted. These surveys resulted in the identification of 11 infested lakes located in eight counties. Following identification of an Eurasian watermilfoil infestation, management plans were prepared for each identified waterbody and prescribed management activities were implemented. These activities included posting Eurasian watermilfoil signs, mapping existing Eurasian watermilfoil beds, surveying the waterbody to determine the abundance and diversity of native aquatic macrophytes, determining lake water volume, and surveying the waterbody for threatened and endangered aquatic plant species. Boating restrictions were also implemented if warranted. As a result of the management plan review process, chemical treatment was determined to be the most suitable management practice for all waterbodies identified as infested with Eurasian watermilfoil. Chemical treatment was accomplished primarily through the use of the aquatic herbicide fluridone (*Sonar*). Complete eradication appears to have been achieved for seven of the 16 identified infestations.

INDEX DESCRIPTORS: Eurasian watermilfoil, aquatic nuisance species, aquatic macrophytes, *Myriophyllum spicatum.*

In the 1980's, reports began to appear in the upper Midwest concerning an aquatic plant that was beginning to infest lakes and cause serious problems (Couch and Nelson 1985). The initial response to these reports was one of guarded optimism. Sometimes with a new exotic species, original fears never fully materialize. However, this was not to be the case with Eurasian watermilfoil (*Myriophyllum spicatum* L.). Within several years, the plant had rapidly sptead to numerous lakes across the area. As the number of new infestations continued to increase, concern began to grow in Iowa (Phillips 1997a).

Eurasian watermilfoil (*Myriophyllum spicatum* L.), an exotic aquatic weed which is native to Europe and Asia, was first documented over fifty years ago in waters of the Chesapeake Bay area (Reed 1977). Since its arrival in the United States, the plant has moved steadily westward and is now found in forty-five states and rhree Canadian provinces (Florida Caribbean Science Center 2000). In the United States, only Alaska, Hawaii, Maine, Montana, and Wyoming have not reported infestations of Eurasian watermilfoil (Fig. 1). Eurasian watermilfoil is presently known to exist in the waters of all states bordering Iowa and is also common in the Mississippi River, including that portion of the river bordering Iowa (Aulwes 1999).

Eurasian watermilfoil was first discovered within the state of Iowa in 1993 in Crystal Lake, Handcock County. Following the discovery of Eurasian watermilfoil in Crystal Lake by the Iowa Department of Natural Resources (IDNR) fisheries personnel, similar finds were made at St. Benedict Pond, Kossuth County and Walnut Creek Marsh, Ringgold County in 1994; Koutny Pond, Buchanan County in 1995; and Wilson Grove Pond, Bremer County in 1996 (Phillips 1997a).

Eurasian watermilfoil is a member of the Watermilfoil Family (Haloragaceae) of plants. Members of this large and widespread family of plants exhibit long, slender, submerged stems and leaves arranged in whorls of three or four. Leaves are divided into leaflet pairs, the number of which are commonly used for species identification. Eurasian watermilfoil (Fig. 2) typically exhibits 10 to 21 leaflet pairs per leaf, the leaflets are closely spaced, and the leaves are oval shaped. The plant has a fragile appearance, the leaves collapse against the stem when removed from the water, the plants branch profusely at the surface, and there is no production of winterbuds known as turions (Fassett 1966).

Eurasian watermilfoil is a highly prolific perennial submergent aquatic plant that spreads primarily by means of vegetative propagation. When the plant is broken into small pieces, these fragments can take root and grow a new plant. Fragmentation can occur as a result of boating activities or naturally through a process called autofragmentation, which occurs at the end of the normal growing season. Once the plant has been fragmented, these fragments can be carried to new locations in a waterbody by wind or water currents (Smith and Barko 1990). These fragments may also be transported between bodies of water after they become attached to boats and/or trailers (Engel 1993).

Eurasian watermilfoil is capable of growing under a wide range of environmental conditions and on a variety of bottom substrates. Although this plant typically grows in shallow water, under clear water conditions it can exist in water up to 10 meters or more in depth. The surface mat-forming growth and prolific nature of the plant also allows it to outcompete and replace native aquatic vegetation (Smith and Barko 1990). For these reasons, Eurasian watermilfoil is extremely difficult to manage and control.

After introduction into waterbodies, Eurasian watermilfoil establishes dense stands which by mid-summer reach the surface of the water and create heavy mats of vegetation. These mats of vegetation severely restrict boating, water-skiing, sailing, fishing, and other forms of aquatic recreation (Engel 1993). Eurasian watermilfoil also

Fig. 1. Distribution of Eurasian watermilfoil in the United States.

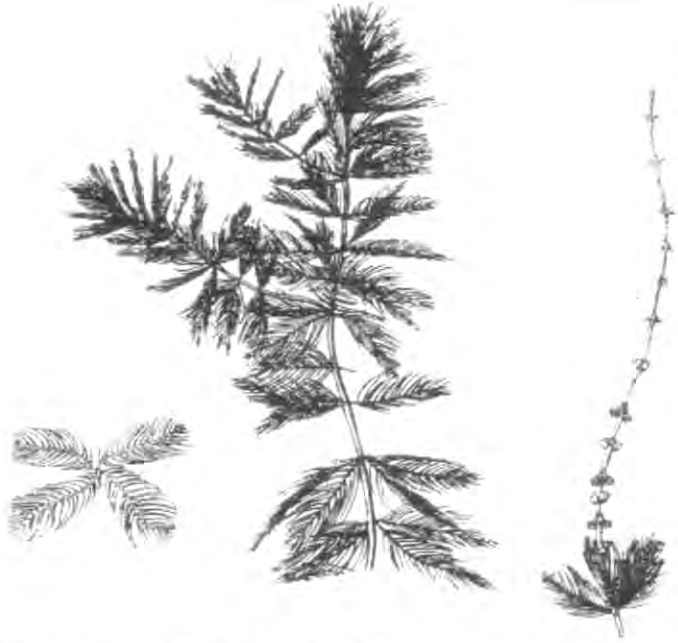

Fig. 2. Eurasian watermilfoil (*Myriophyllum spicatum* L.).

displaces native aquatic vegetation, thereby reducing the species diversity and ecological stability of a waterbody (Smith and Barko 1990). While Eurasian watermilfoil may provide good fish habitat in certain instances, severe infestations generally have a negative impact on fish and wildlife populations (Engel 1995). Infestations in a waterbody also impact local economies by lowering the value of lakefront property and reducing tourism (Engel 1993). Control and/or eradication of Eurasian watermilfoil can become extremely costly. In Iowa, over $200,000 have been spent since 1993 on the management of Eurasian watermilfoil infestations (Phillips 2000).

Management of Eurasian watermilfoil is generally directed towards two goals; (1) limiting the spread of Eurasian watermilfoil from infested waterbodies to uninfested waterbodies and (2) reducing or eradicating Eurasian watermilfoil in infested waterbodies (Bratager et al. 1996). Currently, the options available for eradicating or controlling Eurasian watermilfoil in infested waterbodies are extremely limited and often provide only temporary reduction in the amount of Eurasian watermilfoil present in a waterbody. Furthermore, many states have formal policies which emphasize the use of non-chemical control methods over chemical control methods (Vermont Department of Environmental Conservation 1996).

METHODS

Aquatic vegetation monitoring activities were conducted as part of the Iowa Eurasian Watermilfoil Program between 09 July 1996 and 25 October 1996, 16 June 1997 and 28 August 1997, 27 May 1998 and 05 September 1998, 02 June 1999 and 13 August 1999, and 31 May 2000 and 11 August 2000. Field surveys conducted during these sampling periods were made by IDNR summer field technicians and supervised by the Eurasian Watermilfoil Program coordinator.

Lakes were surveyed by establishing transects perpendicular to the shoreline. Transects were begun at the high water mark and were extended outward into open water to the outer edge of the submerged vegetation zone. Samples were collected by hand in shallow water and using a grapple in deep water. The distance between transects was determined by the abundance of aquatic vegetation present and the size of the lake being surveyed. Distances between transects varied from less than 100 meters for small, heavily vegetated lakes to 300 meters for large, sparsely vegetated lakes (Phillips 1998). Species identification was made in the field whenever possible. If a positive identification could not be made in the field, specimens were collected and returned to the Environmental Studies Laboratory at Iowa Lakes Community College for examination. While the primary goal of aquatic monitoring activities was to identify lakes infested with Eurasian watermilfoil, aquatic vegetation inventories were also prepared for all of the lakes surveyed.

Following identification of waterbodies infested with Eurasian watermilfoil, management plans were prepared prior to implementation of management practices. These plans were prepared in accordance with the criteria established in the *Comprehensive Plan for the Management of Eurasian Watermilfoil in Iowa* (Phillips 1997b).

RESULTS

With the activation of the Iowa Eurasian Watermilfoil Program on 1 July 1996, an organized effort to survey all lakes in the state managed by the IDNR was begun. During these aquatic vegetation monitoring activities, a total of 366 surveys of 290 lakes were conducted. Lakes selected for aquatic vegetation monitoring included 228 of the 242 lakes 8 hectares or more in size that are managed by IDNR fisheries personnel (Iowa Department of Natural Resources 1999). Excluded lakes included four federal flood control reservoirs, three Mississippi River lakes, one lake drained for renovation (Backbone Lake, Delware County), and six low-head dam impoundments located on rivers in northeast Iowa. Seven county lakes less than 8 hectares in size, 10 Missouri River oxbow lakes, and 41 lakes and marshes managed by IDNR wildlife personnel were also surveyed. Lakes identified as having a high risk of infestation were surveyed annually. These included Blue Lake, East Okoboji Lake, Upper Gar Lake, Spirit Lake, and West Okoboji Lake in northwest Iowa, Volga Lake in northeast Iowa, and Lake Wapello and Pleasant Creek Lake in southeast Iowa (Phillips 1997b). Follow-up surveys of infested lakes were also conducted annually by Eurasian Watermilfoil Program personnel following herbicide treatment.

As a result of these survey activities, infestations were identified at Snyder Bend, Woodbury County in 1996; Sweet Marsh, Bremer County in 1997; Mitchell Lake and South Prairie Lake, Blackhawk County and Sportsman Lake, Palo Alto County, in 1998; Mile Hill Lake and Keg Creek Lake, Mills County, Scott "A" Lake, Fremont County, and Horseshoe Pond, Jackson County in 1999; and Beeds Lake, Franklin County and a private pond owned by Jerry Mortensen,

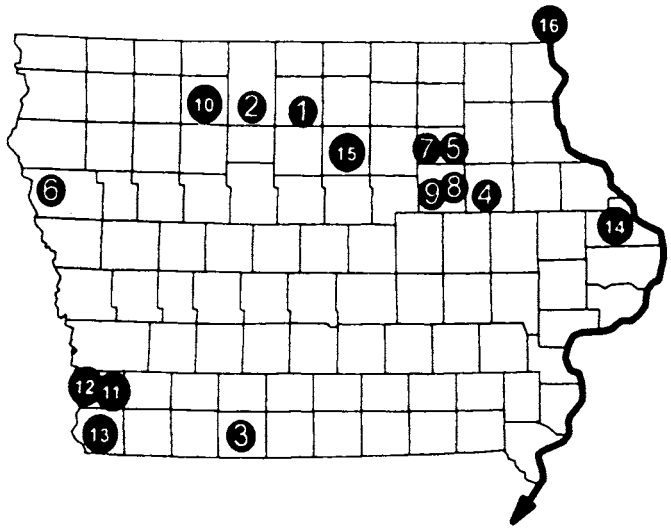

Fig. 3. Locations of Eurasian watermilfoil infestations in Iowa. Site numbers are as follows: 1—Crystal Lake, 2—St. Benedict Pond, 3—Walnut Creek Marsh, 4—Koutny Pond, 5—Wilson Grove Pond, 6—Snyder Bend, 7—Sweet Marsh, 8—Mitchell Avenue Pit, 9—South Prairie Lake, 10—Sportsman Lake, 11—Mile Hill Lake, 12—Keg Creek Lake, 13—Scott "A" Lake, 14—Horseshoe Pond, 15—Beeds Lake, 16—private pond owned by Jerry Mortensen, and 17—Mississippi River.

Blackhawk County in 2000. While no effort was undertaken to survey the Mississippi River, numerous reports by IDNR personnel of Eurasian watermilfoil infestations at various locations on the river were reported to the Eurasian Watermilfoil Program coordinator. Figure 3 shows the location of all waterbodies identified as infested with Eurasian watermilfoil in Iowa.

Following the preparation of management plans for each identified infestation, prescribed management activities were implemented for each infested waterbody. Actions included posting Eurasian watermilfoil infestation signs at all boat ramps, mapping the area of the waterbody where Eurasian watermilfoil beds existed, surveying the waterbody to determine the species and abundance of native macrophytes, determining the water volume of the lake, and surveying the waterbody for the presence of threatened and endangered aquatic plant species. Boating restrictions were also implemented if such actions were warranted. As a result of the review process associated with management plan preparation, chemical treatment was determined to be the most suitable management practice for all waterbodies identified as infested with Eurasian watermilfoil. Chemical treatment was accomplished primarily by the use of the aquatic herbicide fluridone (*Sonar*).

DISCUSSION

Prior to establishment of the Eurasian Watermilfoil Program, five lakes were identified as infested with Eurasian watermilfoil. Identification of these infestations was made by IDNR fisheries personnel while conducting routine fisheries surveys. Following identification of the presence of Eurasian watermilfoil, these lakes were all treated with the aquatic herbicide fluridone (*Sonar*) by IDNR fisheries personnel. Successful eradication was achieved in Crystal Lake, Walnut Creek Marsh, and Wilson Grove Pond. Follow-up inspections of St. Benedict Pond and Koutny Pond revealed that Eurasian watermilfoil was still present. Subsequent treatment of St. Benedict Pond with diquat failed to achieve eradication. However, additional treatments of Koutny Pond with fluridone (*Sonar*) appears to have eradicated the Eurasian watermilfoil infestation.

Since the establishment of the Eurasian Watermilfoil Program, 11 additional infested waterbodies have been identified in eight counties. While the distribution of these infestations are scattered across the state of Iowa, three infestation clusters were documented. These clusters occurred in northeast Iowa in Blackhawk, Bremer, and Buchanan Counties, in southwest Iowa in Fremont and Mills County, and northwest Iowa in Franklin, Hancock, Kossuth, and Palo Alto Counties. These clusters account for 13 of the 16 identified infestations and suggest the role which boating activities play in the spread of Eurasian watermilfoil.

While the number of lakes identified as infested with Eurasian watermilfoil was not large enough to allow for statistical analysis of characteristics to determine the potential for infestation, several common features appear to impact the successful introduction of Eurasian watermilfoil into a waterbody. Of the lakes identified as infested, only three lakes were over 25 hectares (100 acres) in size. Of the remaining 13 lakes, nine were less than 8 hectares (20 acres) in size. Man-made lakes accounted for 14 of the 16 infested waterbodies. Six of the man-made lakes were gravel and highway borrow pits with very limited aquatic macrophyte populations prior to infestation. Recently renovated lakes (Crystal Lake and Horseshoe Pond) accounted for two of the infested waterbodies. While this information is inconclusive, it appears that a lack of existing populations of native aquatic macrophytes plays a significant role in the development of Eurasian watermilfoil in Iowa waterbodies. According to Smith and Barko (1990), habitat disturbance favors colonization by Eurasian watermilfoil when competitor plants are removed and lake beds are open to milfoil rooting.

Because it was impossible to inspect all of Iowa's state managed lakes during a single field season, different areas of the state were targeted for aquatic vegetation monitoring activities during the summer field seasons. During the 1996 and 1997 field seasons, monitoring efforts were concentrated in northwest Iowa. Aquatic vegetation monitoring activities for the rest of the state were targeted as follows; northeast Iowa during the 1998 field season, southwest Iowa during the 1999 field season, and southeast Iowa during the 2000 field season. Because of this approach, the dates for identification of infestations appears to represent a regional trend when in reality they actually reflect the scheduling of monitoring activities.

Due to the advanced stage of infestation at the time waterbodies were identified as infested by IDNR field technicians, it appears reasonable to assume that these lakes had been infested with Eurasian watermilfoil several years prior to their identification. This fact suggests that Eurasian watermilfoil was more widespread than was originally believed. Because most infested lakes exist in clusters further suggests that the plant is being spread and that other infested lakes can be expected to be identified during the next several years throughout Iowa.

Once infested waterbodies are discovered, there are three basic approaches to control or eradicate Eurasian watermilfoil. These include physical removal, biological control, and use of herbicides. Physical control techniques include the removal of fragments by raking, removal of plants by hand-pulling, removal by hand-pulling by SCUBA divers, placement of bottom barriers, and removal by mechanical harvesters (Phillips 1997b). Because none of these methods provide the potential for complete eradication, they were not considered suitable for identified infestations in Iowa.

While biological control provides a method which minimizes disruption to aquatic ecosystems, this technique is still in the early developmental stages. Furthermore, biological control does not offer the potential for complete eradication (Sheldon 1994, Sheldon and Creed 1995, Bratager et al. 1996) For this reason, biological control was also rejected as not being suitable for Iowa infestations where complete eradication was desired.

Chemical treatment of infestations with aquatic herbicides was considered the only method which offered the opportunity to completely eliminate Eurasian watermilfoil from infested waterbodies. Because Iowa is in the early stages of invasion by Eurasian watermilfoil, total eradication was considered the desired goal of management activities (Phillips 1997b). Of the 16 infested waterbodies, only two were natural lakes. This fact played an important role in the decision to select chemical control techniques.

Many factors must be considered before deciding which method, if any, to apply to individual infestations. When developing a management plan for an infested waterbody, a large number of factors were considered. These included the size of the waterbody, the water quality of the waterbody, the recreational usage of the waterbody, the quality of the fisheries present, the diversity and abundance of native aquatic plant species present, and the potential for the infestation spreading to other waterbodies.

When these facts were considered, it was determined that the most desirable management approach for all identified infestations was to attempt to completely eradicate the existing populations of Eurasian watermilfoil. To facilitate this management philosophy, all infestations were treated with the aquatic herbicide fluridone (*Sonar*), except Beeds Lake which was treated with 2,4-D (*Navigate*) and St. Benedict Pond which was treated with diquat following the discovery of Eurasian watermilfoil in small ponds located adjacent to the main waterbody which had been initially treated successfully with fluridone (*Sonar*).

Selection of the herbicide fluridone (*Sonar*) was based on the desire to utilize an aquatic herbicide which was allowable for use in drinking waters and waters used for domestic purposes; has water use restrictions which can be realistically implemented; provides control which lasts for two or more years; is relatively non-toxic to the nontarget environment; and can be used on a whole-lake basis (Vermont Department of Environmental Conservation 1996). Furthermore, by carefully selecting the time of application and the concentration of fluridone (*Sonar*) used, the herbicide has been shown to be relatively selective for Eurasian watermilfoil (SePRO 2000).

While it is to early to fully evaluate the impact of the use of fluridone (*Sonar*) on all treated waterbodies, some preliminary observations have been made. In the case of Crystal Lake, follow-up surveys have failed to detect the presence of Eurasian watermilfoil. However, following chemical treatment in 1994, Crystal Lake experienced severe problems with curly-leaf pondweed (*Potamogeton crispus* L.) during the summers of 1995 through 1997. These problems may have been related to the removal of Eurasian watermilfoil. Crystal Lake was the only lake which responded in this fashion.

Of the lakes treated with herbicide, only Snyder Bend and Sweet Marsh had diverse aquatic macrophyte populations prior to treatment. Follow-up surveys of these two lakes have indicated a resurgence of native macrophytes following the removal of Eurasian watermilfoil. The continued existence of native macrophytes in these waterbodies is consistent with the timing of the treatment and the concentration of fluridone (*Sonar*) used. In both cases, treatment was carried out based on the recommendations of SePRO representatives in an effort to achieve the highest degree of selectivity possible. All other treated waterbodies had limited native macrophyte populations prior to treatment, thereby reducing the need for selectivity.

Over the course of the next several years, additional observations of treated waterbodies should provide the IDNR with the data necessary to adequately evaluate the impact of chemical treatment as a management tool for controlling Eurasian watermilfoil. Until that point is reached, the Eurasian Watermilfoil Program will be required to continue to implement the criteria specified in the Iowa Eurasian Watermilfoil Law which requires the IDNR to identify, contain, and eradicate Eurasian watermilfoil infestations in Iowa.

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