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Identification of Eurasian watermilfoil using hydroacoustics

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ABSTRACT

Successful Eurasian watermilfoil (*Myriophyllum spicatum* L.) management requires the ability to rapidly establish the presence and relative abundance of the plant. Using hydroacoustics (BioSonics DT-X equipped with a 430-kHz transducer), we have developed a method to quickly survey the littoral zone for the presence of Eurasian watermilfoil. The algorithm developed to interpret hydroacoustics data makes it possible to distinguish Eurasian watermilfoil from native species. Physical growth parameters, including depth, lateral extent, percentage of water column occupied by the plant, and other parameters are used to locate or identify the plant based upon hydroacoustics data. After establishing the ability to accurately identify milfoil quickly and effectively, the method was utilized in 5 bays in the southern end of Lake George, New York. Survey results identified 6 previously unknown Eurasian watermilfoil sites and confirmed the existence of an additional 10 known locations.

Key words: *Myriophyllum spicatum*, remote sensing, Lake George, mapping.

INTRODUCTION

Lake George is an 11,375-ha (43.9 mi^2) oligotrophic lake located in northern New York with more than 50 native submerged aquatic plant species reported in the littoral zone (Ogden et al. 1976). Eurasian watermilfoil (*Myriophyllum spicatum* L.) was first recorded in Lake George in 1985 (Madsen et al. 1988, 1989) and has been found to grow to depths as great as 20 m (65.6 feet) (Madsen et al. 1988). Subsequently, the plant has spread to at least 186 sites throughout the water body as reported by the Lake George Park Commission (King and Laginhas 2010). The Lake George Park Commission oversees an extensive milfoil management program based on physical techniques, including hand and suction harvesting and benthic barrier installation (Eichler et al. 1993, Boylen et al. 1997). The program relies on public discovery and reporting of milfoil locations and periodic scuba surveys of tributaries and delta areas.

Management of Eurasian watermilfoil (hereafter milfoil) requires an ongoing yearly reconnaissance program due to its ability to rapidly spread and proliferate. Remote sensing via hydroacoustics is relatively new and has been used with moderate success to detect submersed aquatic vegetation in other water bodies (Winfield et al. 2007, Zhu et al. 2007). In the present study we evaluated hydroacoustics as a developing technology to rapidly detect milfoil in Lake George. We focused initially on 1 site, Sunset Bay, as a proof of concept and then extended the study to 5 additional bays in the southern basin of Lake George to detect unknown milfoil locations.

The study was designed to improve the spatial resolution of current maps of the milfoil infestation in Lake George. Traditionally, ascertaining the presence of milfoil was limited primarily by the time and funding constraints of conducting point intercept surveys and scuba line intercept transects. The success of the work described here makes it possible to effectively and accurately detail the presence of milfoil throughout the littoral zone of Lake George via hydroacoustic technology with significantly less time and effort than required by traditional survey methods.

With the advent of modern signal processing technology, hydroacoustics has been used to identify presence/absence and abundance of submerged aquatic vegetation. Sabol et al. (2002) developed SAVEWS, a precursor to EcoSAV (Sabol 2003), the software currently used to process the hydroacoustic information to identify milfoil. EcoSAV has been used to identify plant communities in other locations (Valley et al. 2005, Spears et al. 2009).

One previous study went as far as developing a method of reporting the collective biovolume of plants in a given location but stopped short of identifying individual species (Winfield et al. 2007). This research demonstrated the ability to identify an individual plant species through hydroacoustic data processing; whereas, others have focused more broadly on entire plant communities. The algorithms we have developed advance the application of hydroacoustics to identify a specific plant species (milfoil) in shallow depths using its hydroacoustic signature.

METHODS

Hydroacoustic surveys were performed during the field seasons of 2006 to 2011. For the purposes of this paper, we present data primarily from the 2006 and 2007 surveys. The

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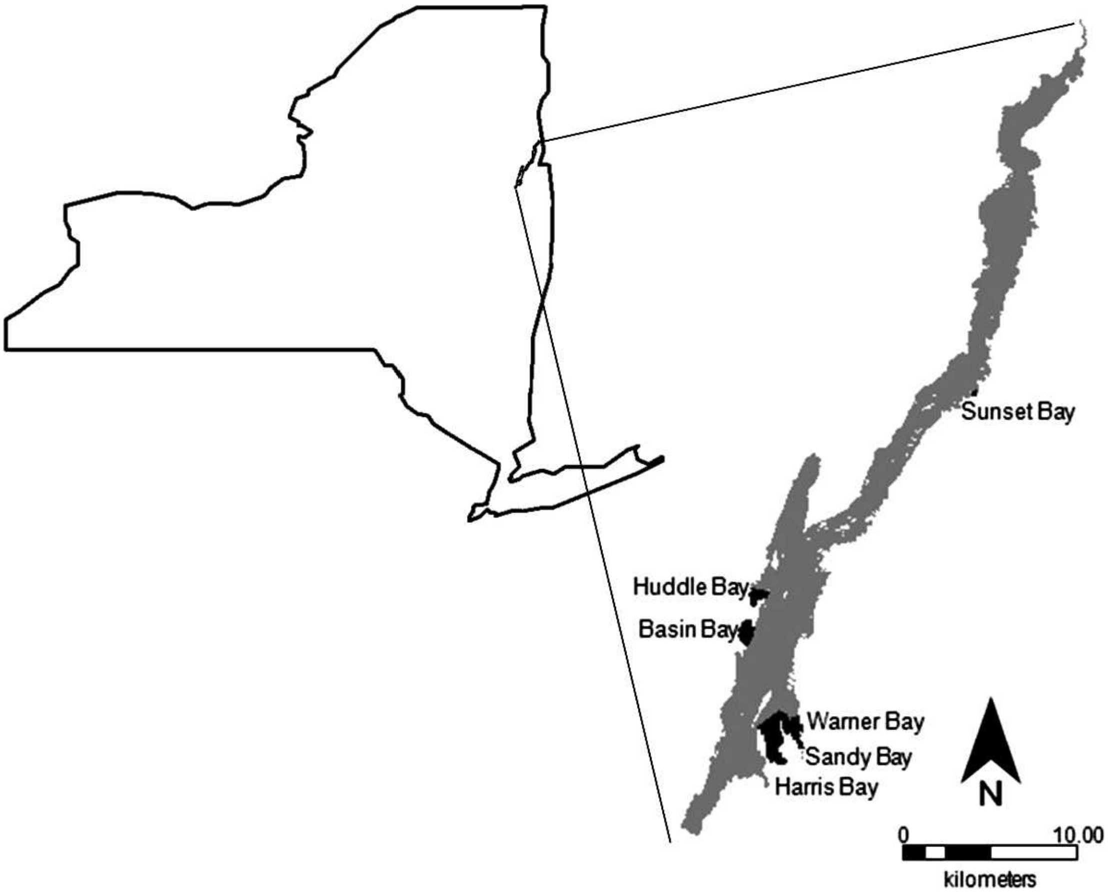


Figure 1. Lake George, New York, with 6 surveyed bays shaded.

BioSonics DT-X[1] is equipped with a 430-kHz transducer, employing a 9.5° beam angle, pulse width of 0.1 ms, and pinging 5 times s^{-1}. A narrower beam angle may increase the effectiveness of the identification but that was not studied in this paper. Surveys were performed to maximize coverage of the littoral zone and were arranged perpendicular, parallel, and zigzag to the shore. Boat speed averaged approximately 3.5 km h^{-1} (2.2 mi h^{-1}) for all surveys. One small bay (Sunset) was surveyed in conjunction with a point intercept/scuba survey to verify the method and compare results between methods. After proving its effectiveness, approximately 550 ha in 5 other bays (Huddle, Basin, Harris, Sandy, and Warner) were surveyed (Figure 1). Presence, absence, and relative abundance of milfoil were verified using snorkel surveys for each location identified using hydroacoustic transects.

All hydroacoustics data were analyzed using BioSonics EcoSAV[2] software with default settings modified to generate bundles of 12 ping packets and analyze plant presence at deeper depths characteristic of deep oligotrophic lakes. Data were imported into Microsoft Excel[3] for postsurvey processing. Bottom depths were corrected for transducer depth during deployment and matched to actual depth measurements. Data were further processed via Geographic Information System software[4] in order to map survey points. Using identified points as the center, a circle was drawn to create a buffer for identifying areas to revisit with a snorkel survey and for further analysis of spatial data.

Distinguishing between plant categories and species is challenging given the fact that many plant communities have overlapping habitats and growth forms. Milfoil tends to grow through the water column in dense, nearly monospecific stands, whereas native species produce a more open architecture even though they might reach the same height. While plant height is one variable that is important in identifying milfoil, it is not the only variable to be included in the current algorithm. Figure 2 shows that milfoil tends to be one of the taller submerged plants in Lake George, but it is not the only tall plant in the lake. Plants identified in the echograms in Sunset Bay that were not milfoil grew as tall as 1.13 m, whereas the plants identified as milfoil overlapped this height growing between 0.55 and 1.33 m. In order to distinguish between milfoil and other plants, additional variables from the hydroacoustics data stream were employed, including volume of the plant present, both vertically and horizontally within the water column.

An algorithm based on milfoil life history was developed and used to facilitate analysis of the hydroacoustics data. This provided a graded index or score of potential milfoil occurrence to be verified via snorkel or SCUBA inspection. The algorithm for identifying milfoil was composed of 3 distinct components including:

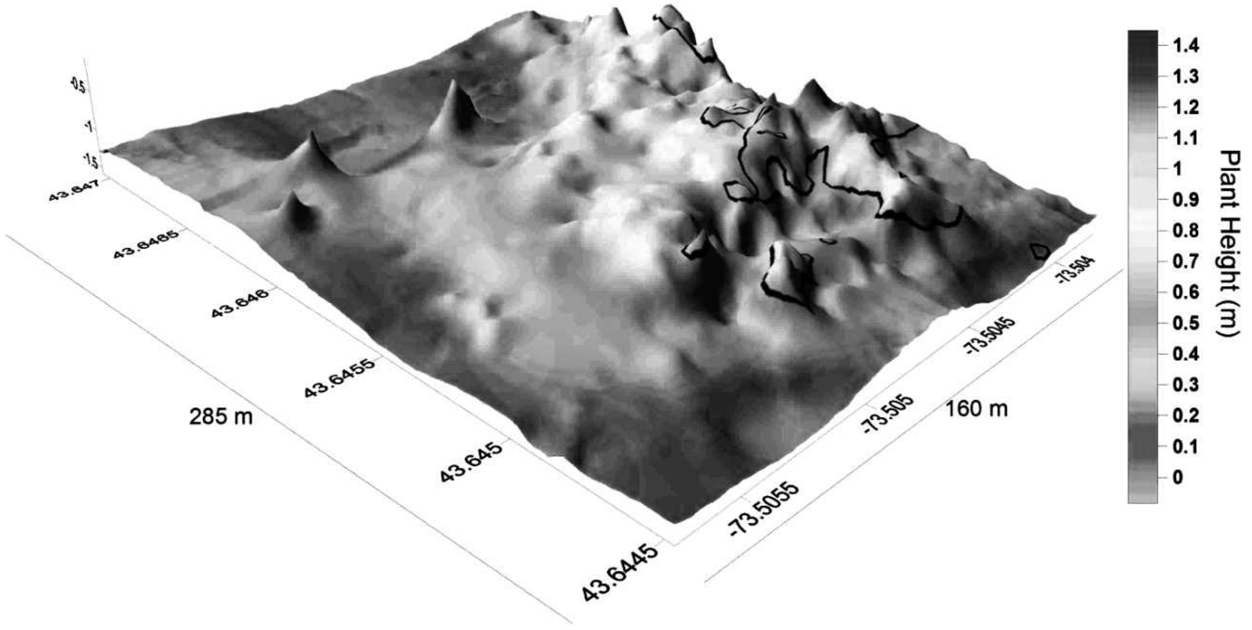


Figure 2. Three-dimensional rendering of height of plants in Sunset Bay produced with hydroacoustic data interpreted with kriging to extrapolate between data points. Verified Eurasian watermilfoil locations are outlined in black.

Feature C1 Description: percentage of water column occupied by contiguous plant growth

Compute C1: ((ABS(HP/D))*PC)
Where ABS = absolute value and HP = height of plant, D = depth, PC = percent plant cover

This component yields a milfoil index equal to the ratio of height in the water column multiplied by the percent cover of the area isonified (examined by the hydroacoustic beam).

Feature C2 Description: measure of suppressed output

Compute C2: If reporting output gap $>$ 25 pings, Then C2 = 45 Else C2 = 0

Feature C2 yields a score of 45 if $>$ 25 pings have passed between 2 midping numbers and a 0 if $<$ 25 pings have passed (see Table 1). This part of the algorithm was created because in very dense beds EcoSAV is unable to process these data, thereby missing the presence of milfoil. Other possibilities for report output gaps other than milfoil exist, including loss of differential Global Positioning System (GPS) signal or out of water ping, but including this component increases our ability to exactly identify milfoil locations in areas where plants grow to the surface and only marginally increases the possibility of false positives. A score of 45 is given to these dense areas to automatically delineate the site as a probable location of milfoil.

Table 1. Score given by output of algorithm and Eurasian watermilfoil classification for that score.

Score	Milfoil likelihood
0–35	No milfoil present
35–45	Possible milfoil present
45–160	Probable milfoil present

Feature C3 Description: sum of C1 and C2 within feasible depth limits

Compute C3: if depth between 0.75 m and 20 m, Then C3 = C1 + C2 Else C3 = 0

This component yields the sum of: (1) percentage of water column occupied by contiguous plant growth, and (2) measure of suppressed output component with the limitations of depth between 0.75 and 20 m. The data generated in $<$ 0.75 m of water were unreliable for milfoil identification and often dangerous to obtain because the transducer is deployed 0.25 m below the surface and an irregular bottom could damage the transducer. The deeper limit ($>$ 20 m) set represents the maximum depth of the hydroacoustic detection for milfoil, which has been reported to grow as deep as 20 m in Lake George (Madsen et al. 1988).

Based upon ground-truthing, the index created by this algorithm indicates that a score of 45 or higher is categorized as "probable" milfoil. A score of 35 to 45 was considered to be possible milfoil and a score of 0 to 35 is considered to not represent milfoil. Within 1 wk of hydroacoustic surveys, divers or snorkelers trained in aquatic plant identification verified the presence of milfoil at sites meeting the "probable" and "possible" milfoil categories. Divers surveyed a perimeter of 15 m around all sites identified using the algorithm. The diver assigned a GPS waypoint each time a milfoil plant, "clump of plants," or edge of an area of dense milfoil growth (bed) was observed. A 10-m buffer was placed around all "milfoil" GPS points. If any point was inside the buffer, it was considered a positive identification of milfoil. The buffered

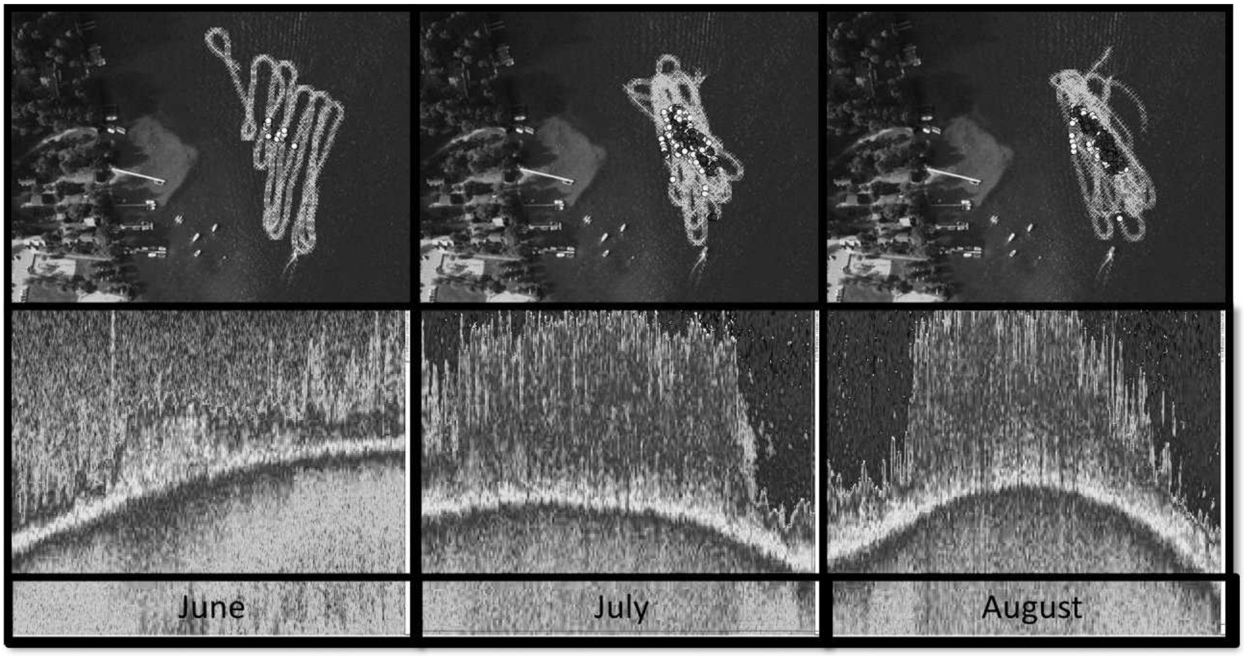


Figure 3. Maps and echograms of Eurasian watermilfoil through the growing season. Maps show where milfoil was accurately identified with hydroacoustic data. Yellow stars represent possible presence, and red stars represent likely milfoil categories. The echogram series shows the growth pattern of milfoil through the growing season, with June data indicating a plant that is very thick lying on its side (boxed) and the July and August echograms showing the plant growing throughout the water column (circled).

points provided an outline of the milfoil bed. Where milfoil was scattered or in small clumps interspersed with dense native plants, GPS waypoints were condensed into an outline to encompass a larger than 10-m buffer for ground-truthing purposes. This type of buffer was applied only to 1 bay (Harris) where milfoil was equally distributed and sparsely scattered within dense native plant growth. This type of plant growth was more consistent with a shallow, more eutrophic system, and consequently made it more difficult to identify.

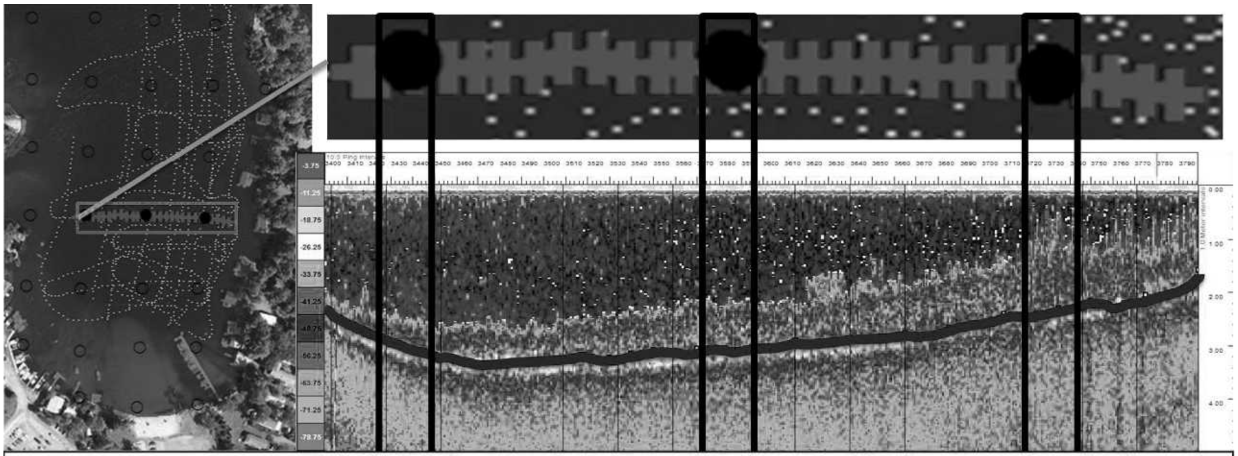
RESULTS AND DISCUSSION

Hydroacoustic surveys provided accurate assessment of milfoil presence in all of the bays surveyed (Figure 1). Six previously undetected milfoil sites were identified and confirmation was made of all 10 previously known locations in the study areas. Information was generated on an additional 1.3 ha for the current Lake George milfoil inventory. In total, the survey included 49,985 packets of pings having an average of 12.7 pings. The algorithm selected 970 ping packets as probable milfoil or possible milfoil. Of these 970 ping packets, 62% were within 10 m of a milfoil bed, cluster, or milfoil interspersed in a native bed. Fifteen of the 16 sites that were identified were found with the probable milfoil threshold (only 1 location needed the $> 35 < 45$ designation—where the milfoil atypically grew sparsely and not very tall within a dense native community).

False positives are the primary limitation to hydroacoustic detection. False positives were caused by large native species (e.g., *Potamogeton amplifolius* Tuckerman) in shallow areas (typically < 2.5 m). The "possible milfoil" category was more susceptible to identification of false positives: 41% of the points in this category were not within 15 m of any milfoil as determined by ground-truth snorkel surveys. Only 20% of the points in the "probable milfoil" designation were later proven to be false positives.

The impact of seasonality of milfoil growth on hydroacoustic assessment was evaluated by revisiting a site having a known presence of milfoil in June, July, and August. Echograms from each of these sample months were compared to determine the best time of year for identifying milfoil with hydroacoustics (Figure 3). Hydroacoustics was successful in identifying milfoil throughout the growing season; however, a number of factors were considered in determining when the protocol was most effective. Milfoil was unidentifiable in June with the current algorithm due to the lack of height of individual milfoil plants. However, by the middle of July, milfoil was detectable and the method continued to work successfully through the month of August. It is desirable both to detect milfoil early in the season in order to start early treatment and to monitor its spread throughout the growing season. However, at this point in our study this method cannot detect milfoil presence until July at the earliest.

To compare the results of hydroacoustics and point intercept surveys, Sunset Bay was surveyed using both methods (Figure 4). The hydroacoustic field effort lasted approximately 1 h and encompassed 3.6 ha. The point intercept survey of 30 points on a 100-m grid required approximately 3 h in the same area as the hydroacoustic survey. Scuba surveys were then conducted to provide perimeter maps of positive identification of milfoil. A series of line intercept transects surveyed by scuba divers



Point Intercept	A	B	C
Elodea canadensis	3	4	1
Megalodonta beckii	1		
Myriohyllum spicatum			5
Potamogeton gramineus			2
Potamogeton perfoliatus			2
Potamogeton pusillus			
Potamogeton robbinisii	4	4	
Potamogeton zosteriformis		2	1
Vallisneria americana	2	2	1
Hydroacoustics			
Milfoil Score	17.5	24.0	41.8

Figure 4. A side-by-side comparison between a hydroacoustic transect and 3 point intercept locations from Sunset Bay. Stars indicate all point packets along the hydroacoustic survey and circles indicate point intercept rake toss survey points with relative abundance (1–5 scale) of each plant found at that location reported.

encompassing the same 3.6 ha took approximately 8 h to complete. Scuba outlines of identified beds took an additional 3 h. This effort verified that milfoil was identifiable within the hydroacoustic echograms and that other categories of plants could also be identified with further refinements and correlations.

In Sunset Bay, 1,226 packets of pings were analyzed. From these, 51 packets were identified as probable milfoil and 87 packets were identified as possible milfoil. The probable and possible milfoil locations clustered together in 3 locations (Figures 5A–C). Diver surveys revealed that all 3 clusters had positively identified milfoil (Figure 5). Point intercept data revealed 1 location where milfoil was growing in water deep enough to be identified using hydroacoustics for identification. Scuba transects around the point intercept data identified areas that revealed outlines of 2 beds of milfoil (A, B). The point intercept/scuba survey failed to reveal the 3rd bed (C) because it was small and did not overlap with any of the point intercept locations; whereas, the hydroacoustic method did not miss any of the milfoil locations.

The hydroacoustic method has proven to be an effective way to identify infestations of milfoil in a large oligotrophic lake. One limitation is an overestimation of the presence of milfoil, or false positives. This overestimation was purposefully introduced to the study with the "probable milfoil" designation in order to assure that all growth was found. It may be possible to reduce overestimation through more extensive ground-truth exercises within different plant bed sizes and types. A 2nd limitation of this method is an inability to detect milfoil in < 1 m of water. This is inherent to the system as the transducer is deployed below the surface and the boat cannot safely access areas with very shallow depth. However, other groups have safely deployed the DT-X transducer face 3 inches (7.6 cm) below the surface at a much reduced boat speed and were able to detect submerged aquatic vegetation into a depth of 18 inches (45.7 cm) if the vegetation was not topped out.

Hydroacoustic surveys provided an efficient and accurate means of identification of milfoil across large spatial scales. Through identification of previously unknown sites and confirmation of established sites, it was conclusively determined that hydroacoustics is a viable alternative for the initial identification of milfoil with follow-up ground-truthing. An algorithm for identifying and indexing potential milfoil sites was developed than can be employed in deep oligotrophic lakes. Based on repeated hydroacoustic efforts the best time of year for hydroacoustic analyses for milfoil was determined to be in July or August, which could

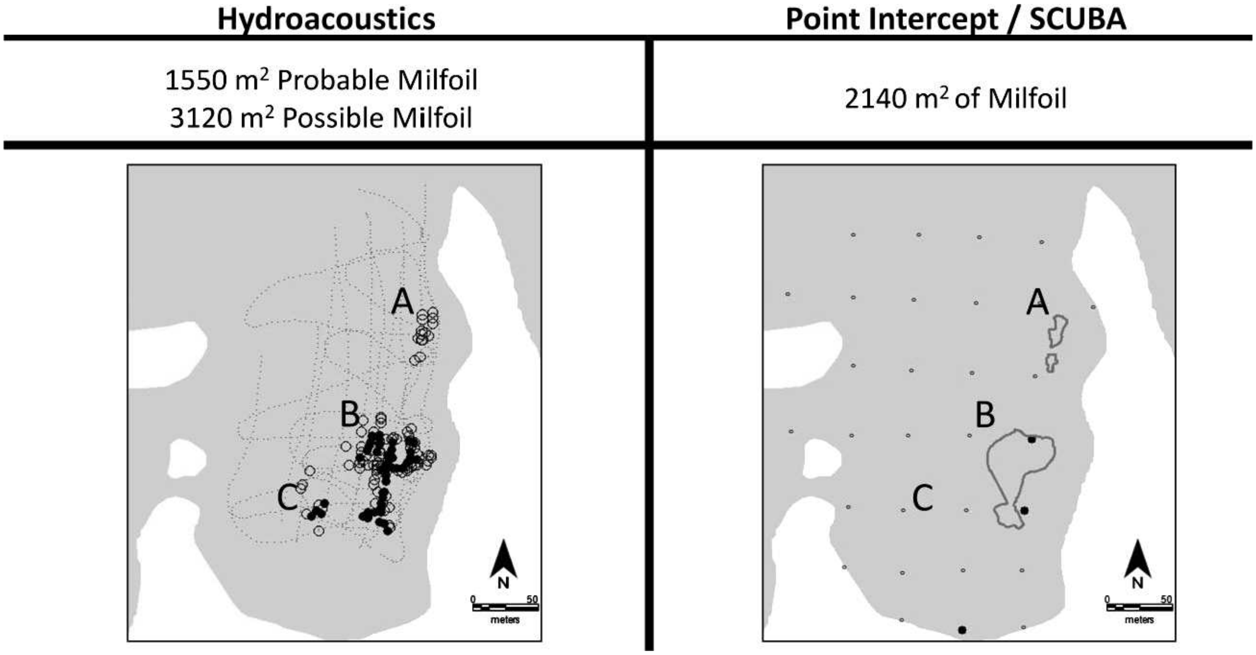


Figure 5. Map depicting Eurasian watermilfoil sites as identified by hydroacoustics surveys (left) and point intercept analysis (right). The track of the hydroacoustic survey is plotted with sites identified as potential milfoil (open circles) and sites with likely milfoil (closed circles) and the transect track (small black dots). All points of the point intercept survey are plotted with locations that contain milfoil plotted as large closed circles and the outline of milfoil beds is also plotted.

potentially provide enough time for a control effort within the same year after the survey. Hydroacoustics provided improved efficiency and accuracy for milfoil identification in comparison to more traditional survey methods. Hydroacoustics has improved aquatic invasive plant management efforts by adding a labor-saving technology useful in the inventory of known milfoil beds.

Another advantage of using hydroacoustics for plant survey studies is the expanded spatial understanding of submerged plant communities. Point intercept data provide only a snapshot of a single point of data with no way to interpret data between the points, so the precision of the survey is dictated by the density of the points. Scuba surveys provide a better understanding of the plant community, but are limited by time, effort, and cost. Hydroacoustic surveys provide a continuous stream of plant data across a greater area so that distinct changes between plant types can be identified; however, the method still requires some follow-up with these traditional methods for verifying the information it generates.

This study has furthered the use of hydroacoustics for assessment of submerged aquatic vegetation by successfully identifying milfoil through processing of the signals. While the method used is quite similar to others proposed by Sabol et al. (2009) and Winfield et al. (2007), both addressed only biomass quantities; whereas, this method builds on that work to go one step further and identifies beds of milfoil directly. This study verified the usefulness of the quick and accurate detection of milfoil through processing hydroacoustic signals in the midsummer in an oligotrophic lake. Future work should focus on identifying milfoil earlier in the season and attempting to modify this method for use in more densely macrophyte growth characteristic of eutrophic lakes. One likely method of such an analysis would be to examine plant-specific sound reflectance for identification.

SOURCES OF MATERIALS

[1]BioSonics DT-X system, 4027 Leary Way NW, Seattle, WA 98107.

[2]BioSonics EcoSAV, 4027 Leary Way NW, Seattle, WA 98107.

[3]Microsoft Excel, 1 Microsoft Way, Redmond, WA 98052.

[4]MapInfo Corp., Pitney Bowes, Inc., One Global View, Troy, NY 12180.

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