J. Aquat. Plant Manage. 53: 151–159

A comparison of two hydroacoustic methods for estimating submerged macrophyte distribution and abundance: A cautionary note

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ABSTRACT

Hydroacoustic systems have been used for > 30 yr to survey aquatic plant communities. The objective of this study was to collect and analyze data using two commonly available but different hydroacoustic systems to determine whether both sets of gear yielded similar estimates of aquatic plant abundance and height statistics. There were appreciable differences in the estimates of submerged macrophyte abundance, plant height, and variability in plant height estimated from data collected with a Lowrance HDS transducer and processed with BioBase compared with data collected with a BioSonics transducer and processed with Echoview. Both approaches produced estimates of plant abundance that deviated from plant community observations. Compared with the those plant community observations and the BioSonics/Echoview system, the Lowrance/BioBase system produced higher estimates of plant height by depth stratum with higher variability, likely because of lower occurrences of registered aquatic plants in each depth stratum, and may have overestimated plant heights in shallow waters. In contrast, BioSonics/Echoview produced a higher frequency of submerged macrophyte occurrences at all depths and may have overestimated occurrences in deep water. Differences appeared to be mostly due to the signal processing approaches. Investigators should tailor a system for their specific survey objectives, needed accuracy, and resources. The use of this technology for long-term monitoring will likely require standardization of data collection equipment and signal processing.

Key words: hydroacoustics, plant height, plant surveys, submerged macrophyte abundance.

INTRODUCTION

Submerged macrophyte communities constitute an important habitat component in many lakes (Valley et al. 2004). These communities are dynamic, reflecting the varied life histories and environmental preferences of the composed species, e.g., nutrient availability, wind exposure, bottom substrate, water level fluctuations, and water depth (Wetzel 2001). Consequently, quantification of submerged macrophyte abundance is important; however, abundance estimates are expensive to obtain and are highly variable across littoral areas (Downing and Anderson 1985).

There are several sampling approaches often used to quantify aquatic plant abundance (Johnson and Newman 2011). Many of these approaches consist of sampling plant biomass from plots that are randomly placed within littoral areas, often stratified by water depth. Plot-based sampling is considered the most accurate method of estimating plant biomass (Wetzel and Likens 2000). The sampling of plots can either be accomplished with divers or with mechanical devices deployed from a boat that dredge or core the lake bottom. These methods require considerable resources to obtain accurate and precise plant abundance estimates from large lakes or from many lakes over time (Madsen et al. 2007).

Researchers have used hydroacoustics—transmitted sound pulses to sample the water column—for aquatic plant surveys for > 30 yrs (Maceina and Shireman 1980). One of the main advantages of this remote-sensing technique is that sound travels quickly in fresh water (approximately 1,480 m s^{-1}), so that the entire water column can be sampled almost instantaneously using mobile survey techniques. The distance between the transducer and an acoustically reflective target can be calculated based on the time delay between an emitted signal and a return signal using the velocity of sound in water (Simmonds and MacLennan 2005). Sabol et al. (2002) noted that the acoustic reflectivity of submerged macrophytes was likely based on the presence of gases within the leaves and stems of plants so that more-buoyant plant species were more acoustically reflective. Thomas et al. (1990) published one of the first studies that determined hydroacoustic techniques yielded substantially greater precision of biovolume estimates and lower data collection costs than scuba-based estimates.

Consistent with the hydroacoustic theory that detection rates of small targets increase with the frequency of transmitted pulses, Sabol et al. (1994) found that return-echo intensity from vegetation increased with transducer frequency. Similarly, Hoffman et al. (2002) determined that a 420 kHz hydroacoustic system performed significantly better than that of a 70 kHz system for locating the boundary of aquatic plant stands. Based on these results, Winfield et al. (2007) recommended transducer frequencies of 200 to 430 kHz for aquatic plant surveys. Other transducer specifications that may influence hydroacoustic aquatic plant data collection include nearfield range and beam angle. The *nearfield* is the distance in front of the transducer at which the beam is not properly formed so that the return signal cannot be properly analyzed (Simmonds

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and MacLennan 2005). Nearfield range depends on its frequency and the beam angle. *Beam angle* is the angle between the half-power points on the main lobe, which determines the size of the beam and the water volume surveyed (Parker-Stetter et al. 2009).

Determining bottom depth is necessary when analyzing hydroacoustic data for aquatic plant height and aquatic plant presence. In areas with hard substrates, the strongest return echo is the true lake bottom and the top of the vegetation canopy signal is often weaker and more variable (Sabol and Johnston 2001, 2002). Conversely, in areas with soft substrates and dense vegetation, sound is often quickly attenuated so that the strongest return echo may be from the submerged vegetation itself. Signal-processing algorithms vary in how bottom depth is determined and could be a potential source of variability in data analysis. Although Sabol et al. (2002) noted close agreement in hydroacoustic and measured bottom depths, Valley and Drake (2005) noted that their hydroacoustic system and analysis algorithms slightly overestimated water depth and that this bias may have been due to signal penetration in soft bottom substrates.

Several studies have compared hydroacoustic estimates to directly measured attributes of aquatic plant communities. Maceina et al. (1984) developed several models to estimate aquatic plant biomass using hydroacoustic estimates of plant height and plant canopy depth. Sabol et al. (2002) and Valley and Drake (2005) found hydroacoustic estimated plant heights were not significantly different from physically measured maximum plant heights. Sabol et al. (2002) also noted that their hydroacoustic signal processor was conservative for false detections (false-positive error, Type I error), thereby, low-density vegetation was often missed or not detected (false-negative error, Type II error). Zhu et al. (2007) found high concordance in aquatic plant presence/absence with hydroacoustics and point samples using a double-headed rake tossed from a boat. Similarly, Winfield et al. (2007) concluded that there was high agreement in aquatic macrophytes coverage in two hard-bottom lakes when comparing hydroacoustic data with underwater video.

Given the value of hydroacoustics to estimate important aquatic plant community attributes, the objective of this investigation was to collect and analyze data using two commonly available but different hydroacoustic systems to determine whether both sets of gear yielded similar estimates of aquatic plant abundance and frequency. This study was initiated as a due-diligence investigation on the use of a relative new hydroacoustic system within a state agency, and as such, no detailed aquatic macrophyte measurements were made with scuba gear. It was expected that a system currently used by agency fisheries staff would produce similar results to that of the system in question. We speculate on the differences observed and encourage others to study further.

MATERIAL AND METHODS

Study site and survey procedures

Surveys were conducted in Elk Lake (Clearwater County, MN; 47°11′24″N; 95°13′12″W; 109 ha surface area) on August 19 and 20, 2013, near the peak of submerged plant abundance. Elk Lake is located within Itasca State Park. The lake has little development, and the aquatic plant community is not managed nor manipulated. Elk Lake is a deep, mesotrophic, dimictic lake, and it has a diverse aquatic macrophyte community, dominated by submerged plants. Detailed point-intercept aquatic plant surveys documenting submerged plant distribution and abundance were conducted in previous years, and no submerged vegetation was observed at depths exceeding 6 m, and in 2014, a plant survey detected vegetation at 7.6 m. More than 20 aquatic plant taxa have been recorded, primarily at depths < 5 m. The common plants present during the surveys included flatstem pondweed (*Potamogeton zosteriformis* Fern.), muskgrass (*Chara* L. spp.), coontail (*Ceratophyllum demersum* L.), pondweed (*Potamogeton* spp.), and slender naiad [*Najas flexilis* (Willd.) Rostk. & Schmidt], and the submerged plant community was of modest abundance with few occurrences of this vegetation reaching the water surface. Most of these species exhibit low signal strength hydroacoustically because of their fine structure, and it was expected that a higher transducer frequency might better detect some of these plants.

Each hydroacoustic system was deployed on a separate boat, and each boat conducted a daytime survey of Elk Lake using predetermined sampling methods (Figure 1). First, hydroacoustic sampling was conducted along 12 transects that were nonrandomly selected to provide a range of depth, substrate, and aquatic plant abundance. Second, hydroacoustic sampling was completed using a zigzag pattern. This zigzag pattern was designed to ensure representative sampling of the entire littoral area by applying a systematical random pattern using a geographic information system. First, evenly spaced shoreline points were created every 200 m around the lake. Second, points were created approximately equidistant between shoreline points and at water depths exceeding 9 m. The points were then connected to form the zigzag pattern.

Data collection equipment

We collected hydroacoustic data using two hydroacoustic systems (Table 1). The first system was a Lowrance High Definition System consumer echosounder.[1] A single-beam, 200-kHz transducer (20° by 20° half-power beam angle) was oriented vertically and mounted on the boat stern approximately 0.23 m below the surface. The global positioning system (GPS) signals were differentially corrected with a wide-area augmentation system. We used the Navico BioBase[2] settings recommended for the Lowrance unit (BioBase 2013). Ping rate varied between 15 to 20 pings s^{-1}. The GPS and acoustic signals were logged to data storage cards in sl2 format. Boat speed was not standardized, so that data collected with the Lowrance system averaged 1 m s^{-1} during transects and 2 m s^{-1} during zigzags.

The second system was a BioSonics DE-6000 scientific grade echosounder[3] with a 430-kHz split-beam transducer (6.9° by 6.9° half-power beam angle) that was connected to a GPS to collect positional data. The transducer was affixed to a stationary pole mount 0.13 m below the surface in a

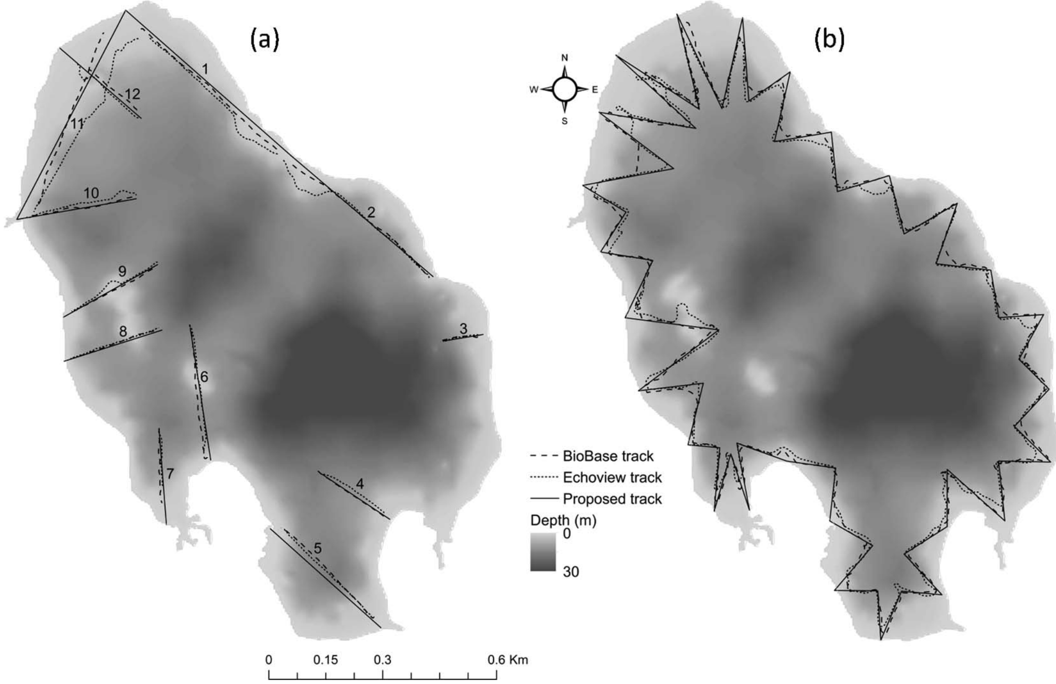

Figure 1. (a) Twelve transects and (b) a zigzag track were sampled on Elk Lake. The locations of completed transects and tracks are shown as dashed lines.

vertical orientation, and boat speed averaged 2 m s^{-1} during the entire data collection. Pulse duration was 0.4 ms and ping rate was 20 pings s^{-1}. Before data collection, the unit was calibrated using a standard-target method (Foote et al. 1987), where a tungsten-carbide sphere was used to measure on-axis acoustical energy related to a known strength, based on the diameter of the sphere, the frequency of the transducer, and the speed of sound in freshwater. The area-backscattering coefficient (s_a) measurements were within 0.3 dB of the standard, so that a calibration offset was not applied during data analysis.

Signal and data processing

Data collected with the Lowrance transducer were analyzed with a cloud-based, automated, signal-processing software retailed by BioBase (BioBase 2013). The software evaluated each ping to determine whether features could be extracted, and those failing that test were removed. For each valid ping, the algorithm calculated plant height as the difference between bottom depth determined by a propriety algorithm developed by Lowrance and the top of the plant signal determined by the BioBase. If the plant signal was located in the nearfield, the algorithm assigned the plant height as equal to the bottom depth (minus the vertical offset). GPS positions were typically recorded every second, and bottom and vegetation features from pings that elapsed between positions were averaged. Because the algorithm aggregated the signals by 1-s intervals, rather than a set distance, a record typically summarized 5 to 30 pings along a traveled track. An independent estimate of plant height was made for each 1-s record. To reduce false detections of vegetation (false-positives), two rules were used within the algorithm. First, the algorithm assigned a plant height of zero for records in which the average maximum plant height was $< 5\%$ of the average depth (only records that exceeded that 5% threshold were considered vegetated). Second, the algorithm discarded the 2% deepest records registering vegetation. Exported data included record number, latitude, longitude, bottom depth, depth to plant, and plant height. Bottom depths were corrected for transducer depth.

Table 1. The configuration of the two hydroacoustic transducers used in data collection for Lowrance data were analyzed with BioBase, and BioSonics data were analyzed with Echoview.

Attribute	Lowrance	BioSonics
Frequency (kHz)	200	430
Beam type	Single	Split
Transducer beam angle (°)	20	6.9
Beam diameter (m) at 5 m	1.68	0.59
Nearfield range (m)	0.06	0.25
Transducer offset from water surface (m)	0.23	0.13
Minimum water depth for vegetation detection (m)	0.73	0.96

Data collected with the BioSonics were analyzed with Echoview 5.4 software.[4] Our objective for analysis with Echoview was to interpret the echogram manually rather than developing an automated digital algorithm to reduce bottom-detection errors in areas with soft substrates and dense vegetation. Orientation was adjusted in the software to reflect the transducer depth below surface. Two range-dependent volume-backscattering strength (S_v) thresholds (–65 and –75 dB), which are commonly applied to plant hydroacoustic data (e.g., Salbol 2003, Valley and Drake 2005), were applied to echo-squared integration data to eliminate backscatter from small fish, zooplankton, and air bubbles, which might interfere with detecting the top of the plant canopy. Next, a line-pick algorithm was used to find

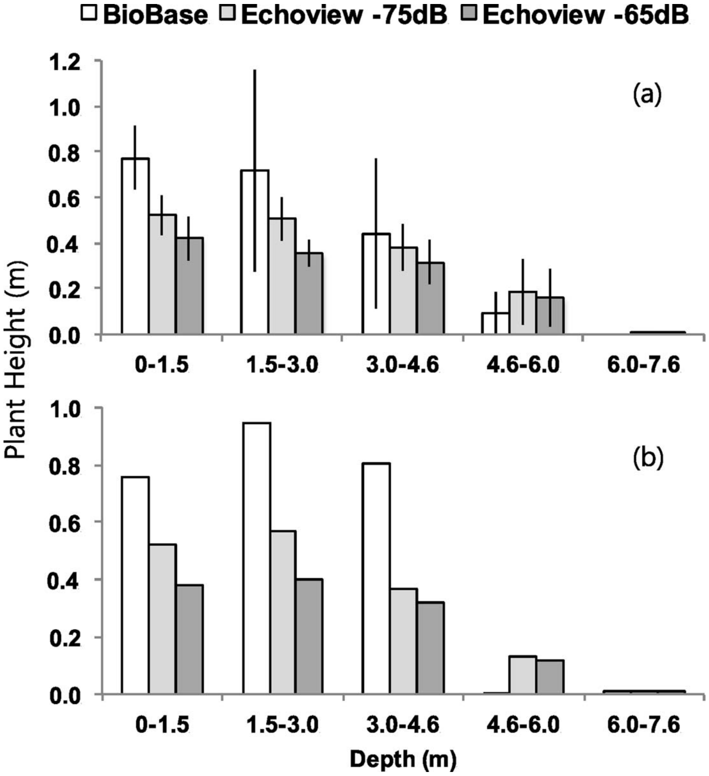

Figure 2. Mean plant height by depth strata for (a) transects and (b) zigzag tracks on Elk Lake using two hydroacoustic systems. Two target-strength thresholds (–65 and –75 dB) were used for the Echoview system. The vertical lines on the bars represent mean absolute deviation.

the shallowest depth of a return signal from submerged vegetation or substrate. The algorithm for this line pick included a minimum-volume back-scattering strength of –85 dB, a discrimination level of –53 dB, and a backstep of 0 m. The submerged vegetation line was then inspected visually to eliminate wayward pings so that there was continuity in the plant canopy (i.e., nonindependence). This line was copied and edited to draw in the bottom depth at locations with aquatic vegetation. Best professional judgment was used to determine the bottom depth at those locations, using the depth-of-sound penetration into the substrate and the maximum-backscatter values as guides. For comparison with BioBase's 1-s records, data associated with each line were aggregated in 1-s intervals. Exported variables included interval analyzed, latitude, longitude, and line depth. Data from both lines were combined, and plant height was calculated as the difference between the plant–substrate line depth and the edited bottom line depth. If the plant signal was located two times the nearfield (Simmonds and MacLennan 2005), the plant height was assigned as equal to the bottom depth minus the two times the nearfield (after incorporating the vertical offset of the transducer). A secondary plant height variable was also created by applying a 5% rule similar to what was done in BioBase, where records with an average maximum plant height < 5% of the average depth are assigned a plant height of 0 m. Transect and zigzag data were analyzed separately using the same visual analysis approach.

We evaluated estimates of mean plant height and presence–absence of plants. Comparisons of these variables were made using 1.5-m depth stratum. Finally, we compared hydroacoustic system costs and analysis time.

RESULTS AND DISCUSSION

We found appreciable differences between the Lowrance/BioBase (hereafter referred to as *BioBase*) and the BioSonics/Echoview (hereafter referred to as *Echoview*) hydroacoustic estimates of submerged macrophyte abundance. The mean plant height was greater for BioBase than it was for Echoview, whereas, for the deep-water strata > 4.6 m, BioBase produced lower estimates (Figure 2). Both approaches produced estimates of plant abundance that deviated from plant community observations. BioBase appeared to miss aquatic plants at mid depth strata and overestimated plant heights in shallow waters. In contrast, Echoview may have overestimated occurrences of submerged macrophytes in deep water.

To explore reasons for these differences, we compared processed data by transect. Figure 3 shows an example of one transect (other transects follow this pattern). Some minor differences in depth and plant height were expected given that the two systems were deployed on separate boats, and there was some variability in how each boat traversed the transect. We observed that estimates of bottom depth were fairly similar, and small differences were likely due to the aforementioned driver variability. However, plant heights were considerably different between the two systems. BioBase generally estimated higher plant heights at most depths than Echoview did, and the BioBase estimates of plant height were more variable across the transect (Figure 3). A similar pattern was observed in zigzag data where the plant-height coefficient of variation for the BioBase was higher than it was from Echoview for all depth strata, although differences were most pronounced in deeper > 4.6 m depth strata (Figure 4). BioBase plant height frequency distributions were also positively skewed, with a long tail, compared with Echoview distributions that were not (Figure 5). Finally, we found substantial differences between the two systems in the percentage of the 1-s aggregated records with vegetation. BioBase had lower probabilities of vegetation for all depth strata (Figure 6).

We examined differences in the hydroacoustic hardware used to collect the data and in the approaches used to analyze the data as potential explanations for these differences in results. Hydroacoustic principles dictate that submerged macrophyte detection is a function of the target strength of the plants within the sampling area, the detection threshold, and the background and system noise. Differences in hardware nearfield and beam angles could affect the amount of area sampled and the noise levels, whereas differences in hardware frequency and analysis approaches could affect detection limits.

The nearfield range of the Lowrance transducer used with BioBase was 0.19 m smaller than the nearfield range of the BioSonics transducer used with Echoview and would result in a reduced sampling area in shallower waters. BioBase detected higher mean plant heights than did

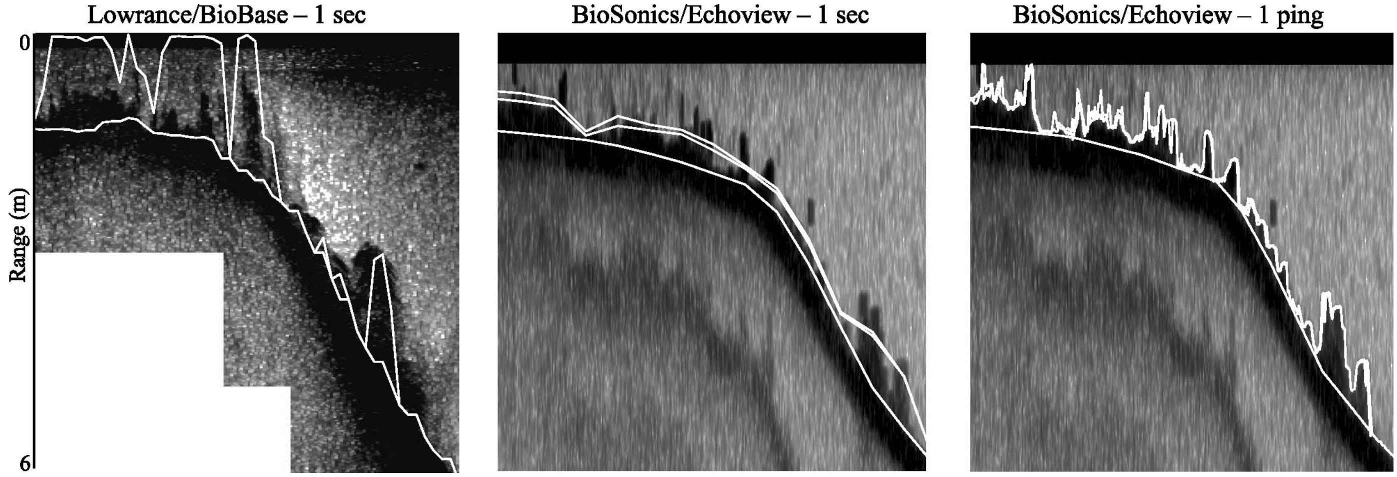

Figure 3. Raw echogram data from transect 6 (see Figure 1) overlaid with processed data from the two hydroacoustic systems. The upper white line denotes the top of the plant canopy, and the lower white line denotes the bottom depth. Two lines representing the top of the plant canopy are presented for the BioSonics/Echoview data that correspond with different thresholds. The shallower line represents plant canopy data processed using a –75-dB threshold, and the deeper line represents plant canopy data processed using a –65-dB threshold. The solid black bar near the surface represents the nearfield. Aggregated data (1 s) is shown for both Lowrance/BioBase and BioSonics/Echoview, and non-aggregated (1 ping) data are also presented for BioSonics/Echoview.

Echoview, which may be explained in the shallowest water stratum by the smaller nearfield of the BioBase system, because the BioBase equipment could detect plants higher in the water column, because the BioBase assigned a depth equivalent to the bottom depth (minus the transducer offset) for signals registered as plants in the nearfield, and because plants entering two times the nearfield were not analyzed by Echoview, according to standard fish hydroacoustic practices (Simmonds and MacLennan 2005). However, differences in transducer nearfields could not explain patterns in plant height observed at other depth strata, given that there were few observations of submerged vegetation reaching the water surface at those depths. The difference in plant height between the two systems may be due, in part, to differences in beam angle.

Beam angle has important implications for plant detection. The Lowrance transducer used with BioBase had a beam angle that was 20° wide, compared with the BioSonics transducer used with Echoview that had a narrow beam angle of 6.9°. The wide beam sampled a larger population than the narrow beam, so that the likelihood of detecting taller plants may increase. At a water depth of 5 m, and traveling at 2 m s^{-1} for a 1-s aggregate record, BioBase with a 20° beam angle sampled 4.5 times more of the bottom than did the Echoview system with a 6.9° beam angle. To minimize the undue influence of a few plants within a surveyed area, Sabol et al. (2009) calculated an effective canopy height metric (*ECH* = [*Mean of the maximum plant height* × *Proportion of pings with plants*]/100). We note that combining these two variables into a single metric may decrease the ability to interpret the condition of a plant community. The beam-angle difference does not explain why Echoview, the narrower beam angle system, had greater probabilities of vegetation for all depth strata (Figure 6). An additional consideration of wide-beam angles is that the equipment is more sensitive to background noise (Parker-Stetter et al. 2009). Background noise could reduce plant detections if the plant signal was unable to be detected over the noise or, alternatively, could be mistaken for plant detections depending on the threshold applied when the data are analyzed.

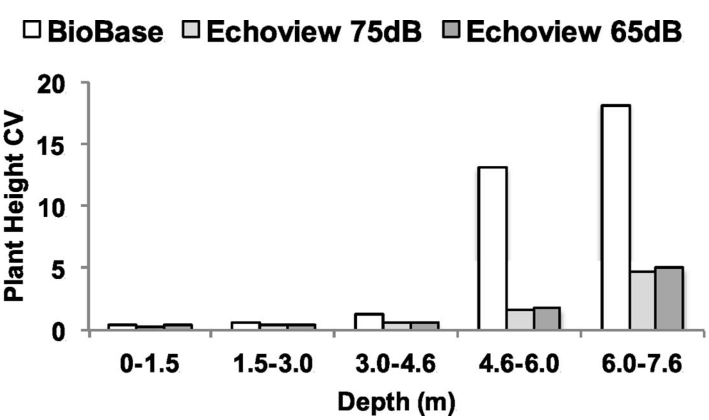

Figure 4. Plant height coefficient of variation (CV) by depth strata for the zigzag track on Elk Lake using two hydroacoustic systems. Two target-strength thresholds (–65 and –75 dB) were used for the Echoview system.

Transducer frequencies were also different between the two systems used in this study. Higher frequencies, such as the 430-kHz frequency used with the Echoview system, may be more effective at detecting the plant boundary (Hoffman et al. 2002) because the detectable object size decreases as the frequency increases. However, higher frequencies are also more susceptible to backscatter from invertebrates that could be misinterpreted as plant signals and the signal attenuates more quickly, so that it may be more difficult to detect the lake bottom in thick vegetation. All of these hardware factors are confounded, and this study cannot resolve the reasons for different results; however, we recommend that transducer specifications should be carefully evaluated in any system-selection process.

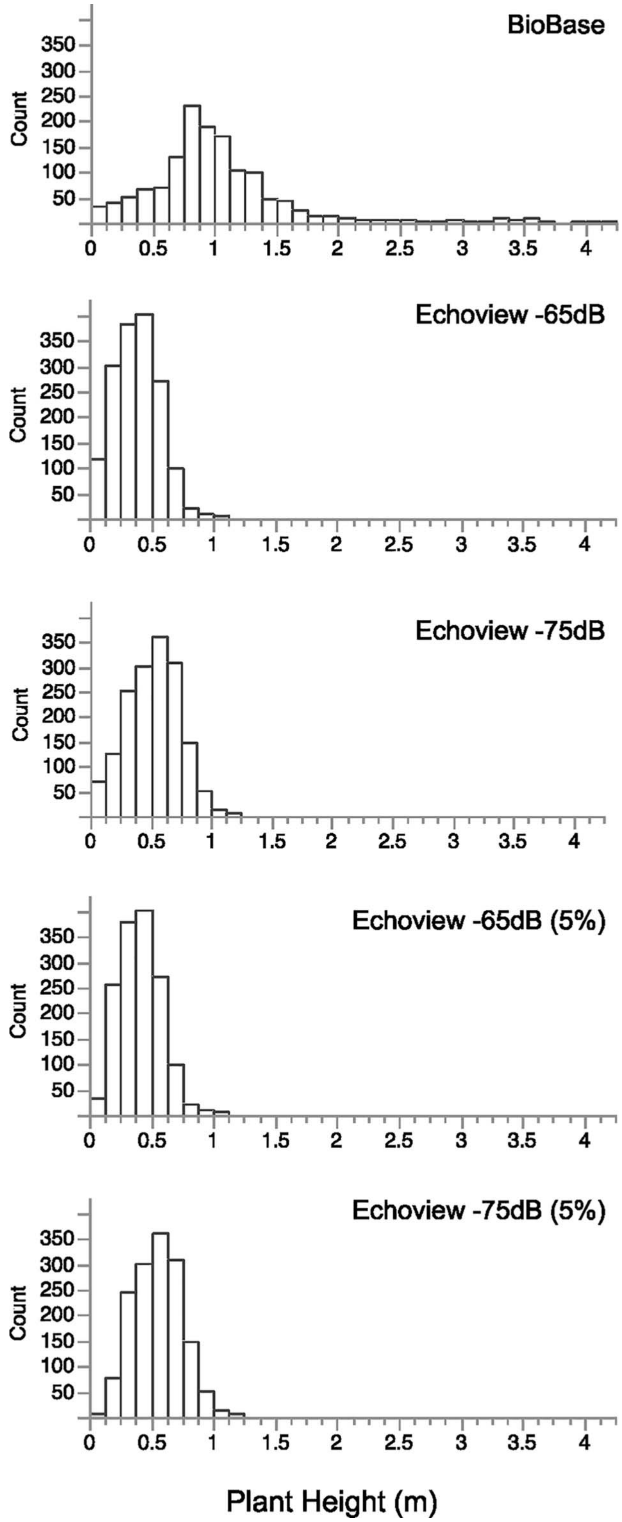

Figure 5. Plant height frequency distributions for the zigzag track on Elk Lake using two hydroacoustic systems. Two target-strength thresholds (–65 and –75 dB) were used for the Echoview system. The 5% rule within Echoview represents the application of the BioBase 5% threshold rule for the vegetation height to water depth ratio within the Echoview system.

Despite hardware differences in the two hydroacoustic systems, echograms of the raw data appeared similar (Figure 3), suggesting that differences in the signal-processing approaches may have contributed most to the observed differences in hydroacoustic estimates of submerged macrophyte abundance. There were three potential differences in signal processing that could have influenced results: 1) the threshold applied to the raw data, 2) the method used to reduce false detections, and 3) the approach used to detect the top of the plant canopy.

Signal processing is often standardized to produce comparable results. Setting minimum target-strength thresholds is one such standardization. We applied two target-strength thresholds in the Echoview system (–65 and –75 dB), and the resulting estimates of submerged macrophyte height and occurrence varied (Figures 2, 5, and 6), although the plant height coefficient of variation did not (Figure 4). Similarly, BioBase also applied a "sensitivity" threshold to the raw data but because the data were collected with a commercial transducer, the equivalent threshold in decibels was unknown. Higher target-strength thresholds may more effectively eliminate backscatter from small fish, zooplankton, and air bubbles that could be interpreted as the top of the plant canopy, but at a tradeoff of potentially failing to detect sparse vegetation or individual plants extending above a submerged macrophyte canopy. A range of thresholds from –65 to –75 dB have been applied in submerged macrophyte hydroacoustic studies (Sabol 2003, Valley and Drake 2005, Spears et al. 2009), and a single optimal target-strength threshold may not exist given that gas-bubble conditions likely vary from lake to lake or within a lake across time due to changes in physical disturbances and biological processes.

Another potential source of differences in signal processing is the method used to reduce false detections. BioBase applied a 5% threshold rule for the vegetation height to water depth ratio (see signal and data processing above) and discarded the 2% deepest records registering vegetation. In contrast, Echoview data were analyzed without applying a rule to reduce false detections. As a result, the Echoview system may have overestimated plant occurrences compared with BioBase. Applying a 5% threshold within the Echoview system reduced the number of records with low-growing plants (Figure 5) and lowered the probability of occurrence by depth so that estimates were intermediate between the two systems (Figure 6). Such threshold rules, like minimum target-strength thresholds, may need to be set based on study objectives and lake conditions.

Lastly, differences in how the top of the plant canopy was detected could also lead to differences in plant height and variability in plant height. The Echoview analysis emphasized continuity of the aquatic macrophyte canopy so that each record considered the location of the previous ping and was, therefore, not independent. In contrast, the BioBase generated an independent estimate of plant height for each 1-s record. Although the BioBase system may have been more conservative in estimating plant occurrence because of its methods of reducing false detections, in areas where plants were detected, it appeared that BioBase's

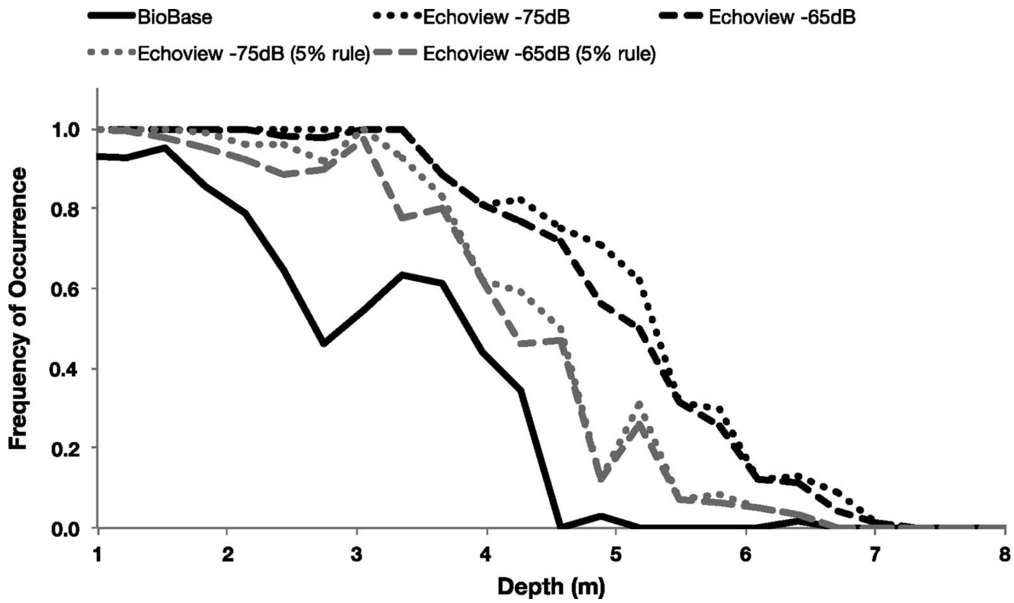

Figure 6. Frequency of submerged macrophyte occurrence for the zigzag tracks on Elk Lake using two hydroacoustic systems. Two target strength thresholds (–65 and –75 dB) were used for the Echoview system. The 5% rule within Echoview represents the application of a 5% threshold rule for vegetation presence similar to the algorithm applied to BioBase data.

algorithm more frequently assigned a shallower depth to the top of the plant canopy than was assigned in Echoview (Figure 3).

One aspect of the signal processing that was not addressed in this study was the manner in which data were aggregated during analysis and the consequences of boat speed when aggregating by time. The signals from both systems were aggregated in 1-s intervals for consistency. However, that aggregation of data greatly influenced the resulting pattern of the submerged plant community (Figure 3) and could also lead to differences in plant measurements if data are collected at different boat speeds. The effect of boat speed on the aggregation of data can be observed in Figure 3, where the speed of the Lowrance/BioBase boat for transects was half the speed of the BioSonics/Echoview boat. For these transects, the Lowrance/BioBase produced more-aggregated data for the same distance as BioSonics/Echoview, and that resulted in a greater smoothing effect for the BioSonics/Echoview data. If aggregating by time, it is critical to maintain constant boat speed; otherwise, biases in abundance will be introduced.

Basic principles of hydroacoustic theory dictate that during surveys of submerged plant communities, only the highest detected plant or plants are recorded for a single ping. As ping data are often aggregated by time or distance, the mean plant height is actually a measure of the means of maximum plant heights. If the submerged macrophyte community has a consistent canopy without a scattering of taller plants, the average of the maximum plant height will be similar to mean plant height. However, submerged plant communities with variable plant heights are common (Wetzel 2001). Signal processing for plant abundance becomes a mathematical analysis of aggregates and, depending on the amount of data aggregated, may reduce variability in plant height (Figure 3). Using a time aggregate may be computationally efficient, but a distance aggregate may account for differences in boat speed and be more intuitive for the ecologist who thinks of plots and areas sampled.

Although many investigators have compared estimates of plant abundance using hydroacoustic surveys with traditional submerged plant sampling techniques (Duarte 1987, Fitzgerald et al. 2006, Zhu et al. 2007, Spears et al. 2009), the results from our study indicate that differences in estimates of plant abundance from hydroacoustic systems may be underappreciated. Similarities in the raw data (Figure 3) suggest that differences in the signal-processing approaches may have been more important than hardware differences for assessing aquatic macrophytes. BioBase's algorithms were designed to reduce false detections of vegetation, and it is likely that low-density or low-growing vegetation was often missed (false-negative error). The Echoview system, which was dependent on human interpretation, allowed greater flexibility in assessing echo intensity and the likelihood of plant presence. BioBase's algorithm was also designed for a range of lakes, and plant heights may be overestimated in acoustically noisier environments. Such an algorithm may produce results that incorrectly characterize plant canopy heights or vegetation presence in some lakes or under hydroacoustically noisy conditions. A system that incorporates a heuristic process may outperform a general-purpose algorithm in these conditions.

There are also considerations related to the cost of data collection and analysis. The BioBase system had substantially lower hardware and analysis costs, compared with the Echoview system. In addition to the advantage of lower total cost, the BioBase system used a Lowrance transducer that had a smaller nearfield, which provided more information in shallow water. Data processing time was also quicker with BioBase's cloud-based algorithm compared with an individual user analyzing the data in Echoview. The advantage of the Echoview system was that the analyst had greater control over data processing compared with the BioBase system in which only a few algorithm rules or settings could be altered by request (e.g., changes in the threshold rule for vegetation height or altering the sensitivity by changing the threshold for plant detection). Valley (2012) reported on a cost analysis of several systems and concluded that BioBase was the most affordable.

Based on our observations with two commonly used hydroacoustic systems, we suggest that investigators tailor a system for their specific survey objectives and resources. The investigator should assess cost and the needed accuracy. For example, if the objective is to identify areas of dense or matted, submerged macrophytes for the purposes of aquatic plant management, the use of the BioBase system is reasonable because it is rapid, efficient, and cost effective. This system quickly creates maps of dense vegetation when surveyors adequately cover an area of interest. However, if the objective is to detect changes in the submerged plant community over time, additional considerations may be necessary. First, investigators will need to standardize the system for transducer frequency, beam angle, and signal processing (in addition to managing hydroacoustic raw data for long periods). Second, given the dynamic nature of the submerged macrophyte community that includes within-year variability, the study design needs to address sampling frequency and timing. Third, investigators need to consider whether the objective includes the creation of vegetation-density maps or whether collecting data from a representative sample of the littoral area is sufficient. The former requires considerably more field survey time and resources. Hydroacoustics survey techniques are unique for submerged plant assessment because it allows large-scale assessment of submerged plants. As noted > 30 yr ago by Maceina and Shireman (1980), hydroacoustics remains faster and less expensive than other means of monitoring submerged macrophytes; however, the results of this study indicate that standardization of data-collection equipment and the signal processing approach is necessary before using this technology as an assessment tool.

SOURCES OF MATERIALS

[1]Lowrance high-definition system consumer echosounder, Lowrance, 12000 E. Skelly Dr., Tulsa, OK 74128.

[2]Navico BioBase, Navico Inc., 2800 Hamline Ave. N #223, Roseville, MN 55113.

[3]BioSonics DE-6000 scientific grade echosounder, BioSonics, Inc., 4027 Leary Way NW, Seattle, WA 98107.

[4]Echoview 5.4 software, Myriax Software Pty., GPO Box 1387, Hobart Tasmania 7001, Australia.

ACKNOWLEDGEMENTS

We thank the following people for their review and helpful comments on an earlier draft of this report: Ray Valley, Donna Perleberg, and Donna Dustin. We appreciated the help from Donna Dustin and Tyler Ahrenstoff in the hydroacoustic data collection and Andy Carlson in study design. Formal reviewers improved the manuscript.

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