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MANAGEMENT BRIEF

Reproducibility of Emergent Plant Mapping on Lakes

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Abstract
Bulrushes *Schoenoplectus* spp. are widely distributed emergent plants that provide important fish habitat. Despite their importance, the precision of aquatic plant surveys conducted within lakes is rarely studied. Reproducibility of field-based bulrush stand coverage was assessed by using three different surveyors to conduct repeated delineations of bulrush stands in five north-central Minnesota lakes. Lakes were mapped by means of Global Positioning System delineation. The reproducibility trial of this study demonstrated that coverage mapping of bulrush stands could be completed in a timely manner and with reasonable precision. No significant differences were found among surveyor estimates of whole-lake bulrush stand coverage. The ability to detect a change in bulrush coverage over time appears to depend on the extent of mixed stands of bulrushes and perhaps on stand size. For lakes with monospecific bulrush stands, it may be reasonable to detect a whole-lake change of 10% or greater by using the techniques described here.

Littoral zone vegetation is critical for numerous fish and wildlife species. Amphibians, ducks, loons, herons, and other wildlife depend on emergent vegetation stands for feeding, breeding, nesting, and shelter (Meyer et al. 1997; Lindsay et al. 2002; Woodford and Meyer 2003). Emergent vegetation provides fish with foraging areas and refuge from predators (Killgore et al. 1993; Casselman and Lewis 1996; Valley et al. 2004), and many fish depend on this habitat for at least part of their life cycle (Becker 1983). For numerous fish species, the use of emergent vegetative cover is disproportionate to its availability (Wei et al. 2004). Of particular importance for many fish species are hardstem bulrush *Schoenoplectus acutus*, softstem bulrush *S. tabernaemontani*, and their hybrids. These widely distributed emergent plants provide spawning habitat, juvenile fish cover, colonization sites for aquatic invertebrates, and protection from shore erosion by dampening wave energy (Langeland 1981; Nichols and Vennie 1991).

These important emergent vegetation communities require effective monitoring to identify and determine ecological consequences of change. Lakeshore development may be a driving factor in changing aquatic plant communities (Meyer et al. 1997; Radomski and Goeman 2001). Quantifying changes in aquatic macrophyte communities is important in the assessment of ecological consequences of human activities (Jennings et al. 2003; Hatzenbeler et al. 2004; Radomski 2006). Despite the need for effective lake monitoring, surveys of lake habitat often neglect to address the important issue of reproducibility (Paukert et al. 2002). Reproducibility of a lake habitat survey is the similarity in measurements of the same lake when determined by different observers or with different methods. Reproducibility is also defined as the strength of agreement between replicate measures. Replicate measures will vary from the "true" measurement, which is unknown, and the measurement error is the variation between measurements of the same quantity on the same lake (or experimental unit). Whereas reproducibility studies for stream habitat and terrestrial, riparian, or wetland vegetation are common (e.g., Wang et al. 1996; Helm and Mead 2004; Herlihy et al. 2009), studies of precision in lake habitat and aquatic plant surveys are rare (e.g., Paukert et al. 2002).

Before the use of geographical information systems (GIS), high spatial accuracy was not achievable for survey maps (Bolstad and Smith 1992). The increased use of GIS has generated the interest in and ability to use spatial analysis tools to document change, and thus there is an increased need to measure and report spatial data accuracy (Smith et al. 1991). Global Positioning System (GPS) field measurements may be appropriate when accuracy is required but alternative methods are unavailable. This is the case for delineation of bulrush *Schoenoplectus* spp. stands that are difficult to delineate with aerial photography or other remote sensing techniques (Marshall and Lee 1994). Dauwalter et al. (2006) noted that GPS methods also allow for the collection of data that describe perimeter, a variable that is not often measurable with traditional methods (e.g., tape measure). Traditionally, field mapping has been an iterative exercise during which surveyors interpret their observations and

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measurements as they map and modify these interpretations as more information is acquired (Jones et al. 2004). In our bulrush mapping work, we have found that these interpretations include the following questions: (1) "Which individual bulrush plants are included within a bulrush bed?"; (2) "Where does the bulrush bed end and another plant bed type begin (e.g., water lily)?"; (3) "Where is the shoreward edge of the bed?"; and (4) "How do we deal with patchiness or openings within a bed?"

The objective of this study was to determine the reproducibility of field-based mapping efforts carried out by different surveyors. It is likely that surveyor differences are the major source of measurement variability because of the need for the surveyor to make repeated subjective decisions about the areas to be included as part of a bulrush stand. This can be particularly challenging with the occurrence of many bulrush stands with low stem density. This subjectivity and the inherent variability among surveyors in mapping aquatic vegetation stands support the need for testing. The goal was to repeatedly map bulrush stands in several lakes by using existing survey protocols to (1) compare results between surveyors and (2) determine whole-lake and site-scale precision in order to give guidance on the applicability of these surveys to detect change over time.

METHODS

Study lakes.—We selected five study lakes in north-central Minnesota. All lakes are deepwater, mesotrophic, glacial lakes. Lake surface area ranges from 91 to 587 ha (Table 1). Development on the lakes is moderate to heavy (6–14 dwellings/km). These lakes are representative of important Minnesota fishery lakes and exhibit a gradient of emergent and floating-leaf vegetation abundance. Common emergent and floating-leaf vegetation for these lakes includes bulrushes (most notably hardstem bulrush), yellow water lily *Nuphar variegata*, American white water lily *Nymphaea odorata*, cattails *Typha* spp., arrowheads *Sagittaria* spp., sedges *Carex* spp., spike-rushes *Eleocharis* spp., water horsetail *Equisetum fluviatile*, common reed *Phragmites australis*, bur-reeds *Sparganium* spp., northern wild rice *Zizania palustris*, floating-leaf pondweed *Potamogeton natans*, three-way sedge *Dulichium arundinaceum*, and watershield *Brasenia schreberi*. Submerged aquatic plants in shallow areas occasionally impeded our mapping of bulrush stands. These plants included muskgrasses *Chara* spp., coontail *Ceratophyllum demersum*, and numerous species of broad-leaf pondweed *Potamogeton* spp. Of the five lakes that were mapped, two had extensive mixed aquatic vegetation stands. Lawrence Lake had numerous mixed stands of bulrushes and water lilies; the bulrushes were generally nearer to shore and in shallower water than were the water lilies. Ada Lake had a large stand of spike-rushes with bulrushes present.

TABLE 1. Attributes of the five north-central Minnesota lakes used in the study of reproducibility of bulrush stand coverage estimates.

Lake	Surface area (ha)	Littoral area (ha)	Shoreline length (km)
Ada	387	220	12
Lawrence	91	38	7.7
Little Boy	587	265	16
Thunder	545	163	26
Wabedo	496	176	18

Bulrush stand mapping.—By means of GPS delineation, three surveyors (A–C) mapped bulrush stands from boats or by walking around the edge of any monospecific bulrush stand or mixed emergent vegetation stand that included bulrushes. Surveys were generally conducted during midday under low to moderate wind conditions (<20 km/h); console-steering boats of 5.8-m length were used. Where bulrush stands were mixed with water lilies and where practical, the surveyors were instructed to only map the boundary of the bulrush stand and to exclude areas that only consisted of water lilies. Surveyors were directed to map all bulrush stands greater than 10 m^2. Three individuals mapped each of the five lakes in the late summer of 2009. Handheld Garmin GPSmap 76CSx units were used for all surveys, and units were set to automatically collect location data at a fixed 5-s interval. In addition, one surveyor (surveyor C) concurrently used the Garmin unit and a Trimble Geo XT handheld GPS unit set to automatically collect location data every second. Position accuracy of the Garmin unit is typically less than 10 m (Garmin International 2006), and the Trimble unit achieves submeter accuracy with data processing (Trimble 2007). Estimated position error for the Garmin units averaged about 3 m during surveys (high errors did not stop the planned surveys).

The GPS data were imported into a GIS for processing (ArcMap version 9.3). Each surveyor edited their GPS track lines to create bulrush stand polygons. This was accomplished by extending nearshore bulrush stand track lines to the land–lake boundary layer and by connecting track lines of offshore stands. This meant that the surveyor made a small data processing decision for nearly every stand. Processing of data in the GIS also included aerial photography interpretation that was aided in some cases with field notes. After bulrush polygons for each mapped vegetation stand were created, whole-lake estimates of bulrush stand coverage (m^2) were determined, and bulrush stand coverage was compared between surveyors. In addition, a grid consisting of 30- × 30-m grid cells, each totaling 900 m^2, was transposed over the littoral areas of each lake. To determine a smaller-scale precision than the whole-lake estimate, bulrush coverage (m^2) was estimated for each grid cell for all surveyors.

Bulrush stand maps existed for each of the five lakes before this study. In August and September 2007–2008, survey crews had mapped these lakes by using handheld Garmin GPSmap units. The GPS units were set to automatically collect location data at either a fixed distance or rapid time interval, and these surveys used the same GIS processing as was used in the reproducibility surveys. However, field and process protocols for handling mixed beds of aquatic plant species differed between survey crews and years. For some of the existing surveys, all stands with bulrushes present were incorporated into the analysis; these stands included large mixed stands of bulrushes and water lilies. These existing emergent plant and floating-leaf plant survey data were compared with the data collected by the three surveyors in 2009 to assess the consequences of differing field and process protocols.

Statistical analysis.—Descriptive statistics, including the mean, standard deviation (SD), and coefficient of variation (CV $= 100 \times$ SD/mean) of bulrush stand coverage, were computed for each surveyor and each lake based on the whole-lake mapping and the 30- × 30-m grid cells. To measure the degree of congruence between surveyors for whole-lake bulrush mapping, the Jaccard similarity coefficient (J; Pielou 1984) was used:

$$J(A,\ B) = |A \cap B|/|A \cup B|,$$

where $A \cap B$ is the bulrush stand area covered by both surveyors A and B (i.e., size of the intersection) and $A \cup B$ is the bulrush stand area covered by the union of the two areas covered by surveyors A and B (i.e., size of the union). The index approaches a value of 1 as two surveyors match their bulrush stand polygons; thus, J is the proportion of overlap in the areas mapped by the two independent surveyors. If surveyors had high spatial congruency within lakes, then the mean surveyor differences in bulrush coverage for the 30- × 30-m grid cells were calculated. In addition, Pearson's product-moment correlations for bulrush stand coverage were calculated for each surveyor pair. Only grid cells in which at least one surveyor mapped bulrushes were used in these analyses; this was done to minimize biases created by using grid cells where no bulrushes were likely to be present.

Surveyor precision was evaluated with the CV. To test whether there were differences in surveyor estimates of whole-lake bulrush stand coverage and the number of bulrush stands mapped, an F-test was applied (lake was the experimental unit, and surveyors were the treatments). In addition, significant differences between surveyors were tested with the Tukey–Kramer honestly significantly difference test. A statistical power analysis was used to determine how precision might influence detection of bulrush stand coverage. The power to detect a 10% change in coverage was estimated for each lake (Gerow 2007). This analysis used the mean and SD from the estimates of bulrush stand coverage, a two-tailed test, and an experimental design consisting of two independent samples with a sample size n of 3. For all tests, significance was assessed at an α value of 0.05.

RESULTS AND DISCUSSION

Many of the whole-lake estimates of bulrush stand coverage were similar (Table 2). The largest discrepancies occurred on Lawrence Lake, where the existing survey included extensive areas of water lilies. The three surveyors in 2009 did not include those areas; instead, they traversed through the floating-leaf vegetation as instructed to delineate only the nearshore bulrush areas. On Ada Lake, two surveyors (A and B) included large areas of spike-rushes in their estimates because occasional bulrushes were present, whereas the other two estimates (surveyor C and the existing survey) did not. The total bulrush stand coverage determined for the five lakes was about 2% more when estimated by using the Garmin GPS unit compared with the more accurate Trimble GPS unit, and stand coverage differences were higher on lakes with more bulrush stands.

The spatial precision was found to be high. The degree of congruence (i.e., Jaccard similarity coefficient) for whole-lake bulrush mapping across all lakes was greater than 75%, demonstrating a substantial overlap in the areas mapped by the three independent surveyors (Table 3). Smaller-scale estimates of precision were comparable with the whole-lake results. In the 30- × 30-m grid cells, many of the differences in bulrush coverage between surveyors had SE values of 4 or less, and surveyor estimates of bulrush coverage were highly correlated (Table 4).

No significant difference was found among the surveyor estimates of whole-lake bulrush stand coverage ($F = 0.01$; df = 3, 16; $P = 0.9987$) and number of mapped bulrush stands ($F = 2.90$; df = 3, 16; $P = 0.0673$). The CVs were low (<7%) for three of the five lakes (Little Boy, Thunder, and Wabedo lakes). Excluding the existing survey estimate, the CVs were less than 4% for all lakes except Ada Lake, indicating that survey precision was relatively good (Table 2). The bulrush stand mapping technique required two to three 8-h days per lake. Bulrush stands as mapped were often less than 500 m^2 (Figure 1; Table 5), in part because of the fragmentation of large stands by docks, piers, boatlifts, and other human activities. The median bulrush stand coverage determined by the three surveyors was 375 m^2; the first quartile was 110 m^2 and the third quartile was 1,466 m^2.

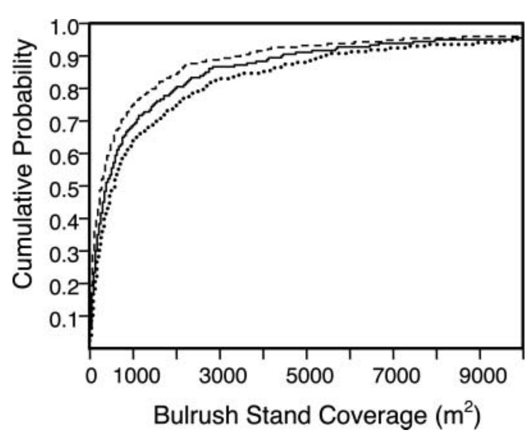

FIGURE 1. Cumulative distribution function grid cell for bulrush stand coverage (m^2) mapped by three surveyors on five lakes in north-central Minnesota.

TABLE 2. Estimate of bulrush stand coverage (m^2) in each by lake. The number of bulrush stands mapped is in parentheses. Mean, SD, coefficient of variation (CV), 95% confidence interval (CI), and minimum and maximum bulrush stand coverage are presented. Minimum and maximum bulrush stand coverages were determined by the intersection and union of all estimates, respectively. Data collected by the three surveyors (A–C) in 2009 and data from existing emergent and floating-leaf plant surveys conducted in 2007–2008 are shown. Power is the statistical power to detect a 10% change in whole-lake bulrush stand coverage.

	Lake				
Estimate	Ada	Lawrence	Little Boy	Thunder	Wabedo
Surveyor A	52,766	33,286	687,533	153,793	188,310
	(72)	(73)	(105)	(148)	(96)
Surveyor B	57,708	33,996	660,941	149,238	198,935
	(47)	(59)	(84)	(134)	(80)
Surveyor C	39,607	33,966	649,148	144,639	182,450
	(92)	(74)	(131)	(170)	(126)
Existing surveys	39,758	145,017	666,932	145,547	170,863
	(29)	(38)	(65)	(85)	(79)
Mean	47,460	61,566	666,139	148,304	185,140
SD	9,204	55,635	16,063	4,165	11,711
CV (%)	19.39	90.37	2.41	2.81	6.33
± 95% CI	14,644	88,515	25,556	6,626	18,631
Minimum coverage	24,541	22,611	527,766	112,611	124,072
Maximum coverage	72,097	148,236	798,641	181,777	244,116
Power (%)	70	10	100	100	100
Excluding the existing survey estimate:					
CV (%)	18.70	1.19	2.95	3.07	4.40
Minimum coverage	30,719	23,547	576,598	129,392	154,368
Maximum coverage	68,781	45,092	751,636	167,681	227,090

The reproducibility trial of this study demonstrated that the mapping of bulrush stand coverage with consumer-grade equipment could be completed in a timely manner with reasonable precision. When mixed emergent and floating-leaf aquatic vegetation stands are present, mapping precision may be lower. Mapping bulrushes in association with other emergent plants or water lilies may result in an overestimate of bulrush stand coverage. We offer several suggestions on how to best map mixed stands based on the protocol used by the three independent surveyors in this study. For bulrush stand coverage determination, mapping should be conducted in fall to minimize difficulties in traversing nearshore areas with extensive water lily coverage. As water lilies senesce in the fall, boating through these areas is easier and less damaging to the water lily stand. In some mixed stands that contain bulrushes, it may not be feasible to delineate only bulrushes because the bulrush plants could be interspersed with other emergent plants (e.g., northern wild rice). In this case, surveyors may wish to clearly describe the plant beds as “mixed bulrush stands” to distinguish them from monotypic beds. For emergent and floating-leaf plant beds that do not

TABLE 3. Degree of congruence (as determined by the Jaccard similarity coefficient) between estimates of whole-lake bulrush stand coverage obtained by three surveyors (A–C). Data from existing emergent and floating-leaf plant surveys are also compared with the data collected by the three surveyors.

	Lake					
Estimate pair	Ada	Lawrence	Little Boy	Thunder	Wabedo	All lakes
A and B	0.80	0.97	0.95	0.96	0.90	0.94
A and C	0.86	0.96	0.94	0.94	0.92	0.94
B and C	0.75	0.96	0.94	0.94	0.88	0.92
Existing and A	0.83	0.23	0.90	0.88	0.86	0.81
Existing and B	0.75	0.24	0.90	0.88	0.83	0.80
Existing and C	0.82	0.24	0.89	0.86	0.84	0.80

TABLE 4. Mean (SE in parentheses) difference (m^2) in estimated bulrush coverage for 30- × 30-m grid cells between pairs of surveyors (A–C), and Pearson's product-moment correlation coefficients (*r*) calculated for estimates from surveyor pairs.

	Lake					
Surveyor pair	Ada	Lawrence	Little Boy	Thunder	Wabedo	All Lakes
Mean difference						
A versus B	−16 (5.9)	−3 (3.1)	17 (3.5)	7 (1.5)	−14 (3.7)	4 (1.9)
A versus C	42 (6.7)	−3 (4.4)	25 (3.3)	14 (2.7)	8 (4.0)	19 (1.9)
B versus C	58 (9.1)	0 (6.3)	8 (3.9)	7 (2.7)	22 (4.9)	15 (2.3)
All pairs	28 (4.4)	−2 (3.1)	17 (2.1)	9 (1.4)	5 (2.5)	13 (1.2)
r-value						
A versus B	0.91	0.91	0.92	0.99	0.93	0.94
A versus C	0.85	0.93	0.93	0.97	0.91	0.94
B versus C	0.77	0.87	0.90	0.97	0.87	0.91
Pair sample (*N*)	314	231	1,509	651	736	3,441

contain bulrushes, surveyors may find aerial photography to be a more useful delineation tool.

Additional factors that may influence mapping precision include patch size and fragmentation, water depth, weather conditions, and lakeshore development. Surveyor agreement was often highest for the mapping of large, contiguous patches of offshore bulrushes (Figure 2). Webster and Cardina (1997) and Dauwalter et al. (2006) found that as patch size increased, the errors decreased. Dauwalter and Rahel (2011) demonstrated that mapping precision was highest for large (>100 m^2), elongated habitat patches. In the present study, small patches of bulrushes were occasionally mapped by one surveyor but not by others; surveyors may not have detected these patches or may have deemed them too small to qualify as a stand. Decisions by surveyors to treat a fragmented stand as one large stand or as discrete small stands were also clearly a factor in precision. Surveyor interpretation of what constitutes a stand or the surveyor's ability to navigate (e.g., among docks, plant stands, and shore) may account for these differences. For shallow-water bulrush stands, surveyors differed in whether they mapped from boats or walked the perimeter of the stand. In mapping submerged aquatic plants, Valley and Drake (2005) found that precision increased with water depth. Surveyors in our study mapped on some windy days (>20 km/h), which probably decreased accuracy. Boat and motor size or type (i.e., outboard or trolling motor) may also influence precision. Smaller boats may provide greater maneuverability around small bulrush stands; slower driving speeds will result in the collection of more data points, thus yielding finer resolution of stand polygons.

TABLE 5. Mean, SD (in parentheses), and range of bulrush stand coverage (m^2) mapped by each surveyor (A–C) in each lake.

Lake and statistic	Surveyor A	Surveyor B	Surveyor C
Ada			
Mean (SD)	733 (1,900)	1,228 (2,627)	431 (1,087)
Range	3–14,707	12–16,438	1–8,610
Lawrence			
Mean (SD)	456 (637)	576 (820)	459 (702)
Range	2–3,588	39–4,985	7–3,487
Little Boy			
Mean (SD)	6,548 (16,466)	7,868 (18,553)	4,955 (14,353)
Range	14–147,009	94–148,986	10–141,528
Thunder			
Mean (SD)	1,039 (3,787)	1,114 (3,932)	851 (3,305)
Range	5–33,077	2–32,993	5–31,404
Wabedo			
Mean (SD)	1,962 (2,726)	2,487 (3,130)	1,448 (2,363)
Range	8–16,126	13–17,158	14–14,996

The type of GPS unit, GPS settings, and GIS data processing may influence mapping precision. Wing et al. (2005) found that consumer-grade GPS units under open-sky conditions—likely the standard conditions for emergent plant mapping in lakes—varied in their accuracy but that most units had positional accuracies within 5 m of true position. In devising mapping protocols, researchers should consider the use of GPS offset options and whether to set GPS units to automatically collect location data at either a fixed distance or a rapid time interval. The 5-s interval used in this study is probably the maximum desirable interval for use in similar applications, and we recommend a finer-scale interval (e.g., 3 s or even 1 s) for mapping small stands or when high precision is required. Finally, some variability in stand size was the result of the GIS data processing step. For example, small differences were noted in how surveyors treated GPS track lines and the potential errors associated with shoreline delineation. We recommend

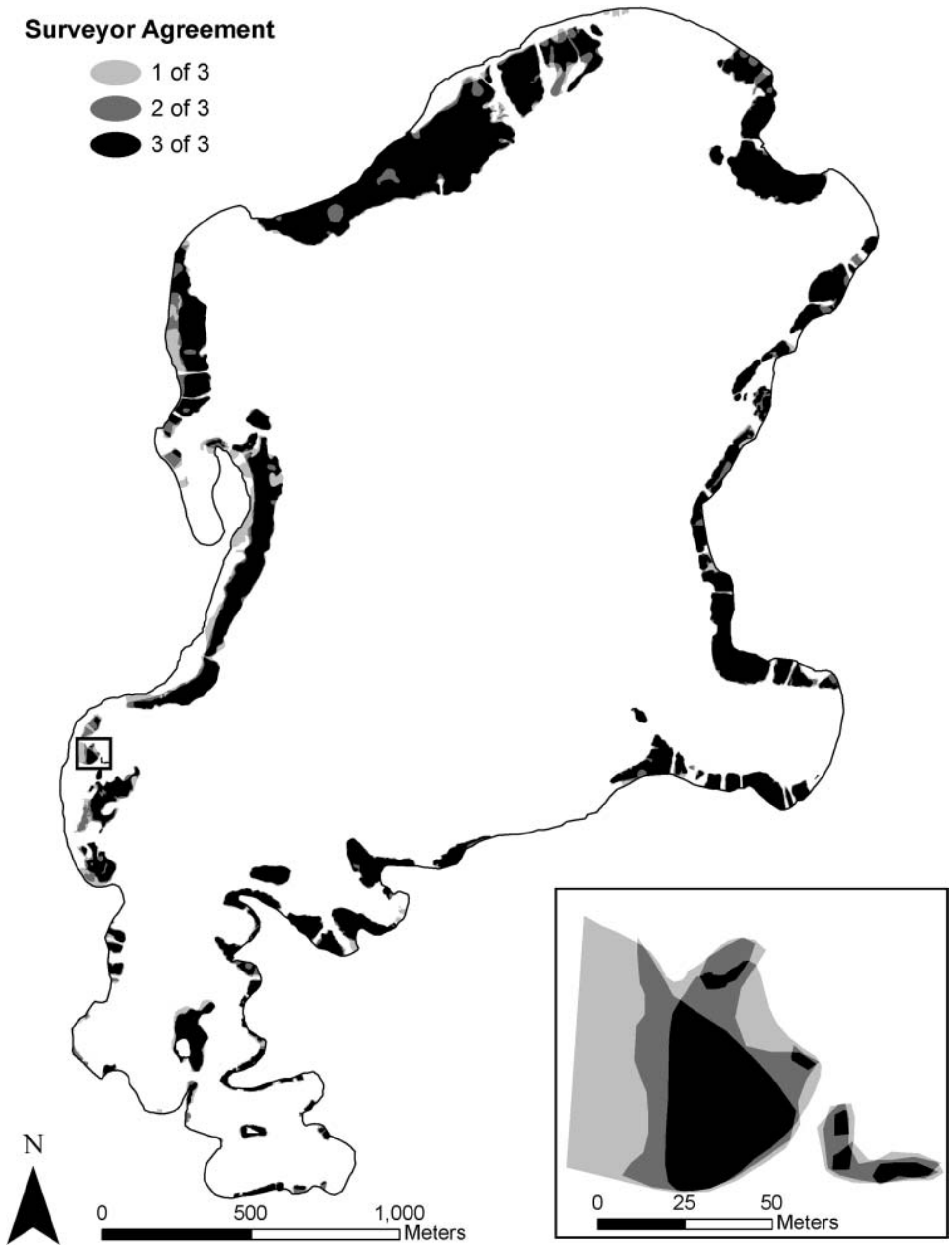

FIGURE 2. Bulrush stands in Little Boy Lake, north-central Minnesota, as mapped by three surveyors; areas of agreement among surveyors are depicted. Inset shows a detailed view of one nearshore area.

that a specific protocol be developed to reduce the influence of these factors in mapping studies of emergent plants when high precision is needed. Protocols should also specify consistent methods of aerial photograph interpretation and data processing steps.

The ability to detect change in bulrush coverage appears to depend on the extent of mixed stands of bulrushes and perhaps on stand size. For relatively small plant stands (2–200 m^2), Dauwalter and Rahel (2011) concluded that the ability to detect change increases with stand size. Based on the whole-lake survey estimates, it may be reasonable to detect a change of 10% or greater for a whole lake with monospecific bulrush stands by using the techniques detailed here (Table 2). The estimated ability to detect change was low for Lawrence Lake because of the differences in techniques and purpose between the existing protocol, which was designed to include large mixed stands of bulrushes and water lilies, and the protocol we used in 2009, which was designed to exclude water lily stands that were devoid of bulrushes. However, the statistical power was high for Lawrence Lake, like the other lakes, when analysis was based on the mean and SD of bulrush stand coverage from 2009 (i.e., the estimates from the three surveyors only). Based on the distribution of stand coverage differences between surveyors from randomly placed 30- × 30-m grid cells, one may also expect to reasonably detect coverage changes exceeding 10%. We therefore recommend that for lakes with numerous mixed stands, efforts should be focused on detecting change in the floating-leaf and emergent plant communities rather than on single-plant species coverage. Lastly, we recommend that field and processing protocols be clearly defined and reviewed so that future efforts to detect change are not hampered by inconsistent mapping of mixed stands of aquatic plant species.

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