Sample Size Requirements for Estimating Species Richness of Aquatic Vegetation in Iowa Lakes

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ABSTRACT

We described the distribution of aquatic macrophytes sampled from 130 lakes (1997-2005) across Iowa and estimated the number of samples required to determine species richness at various detection levels. Sago pondweed (*Stuckenia pectinatus*), cattails (*Typha* spp.), reed canarygrass (*Phalaris arundinacea*), longleaf pondweed (*Potamogeton nodosus*), and coontail (*Ceratophyllum demersum*) were generally the most common species sampled, but several exceptions were observed. For instance, bulrushes (*Schnoenoplectus* spp.) were among the most common taxa in natural lakes, and American water lotus (*Nelumbo lutea*) was one of the most common species in oxbow lakes. Sample size estimates were closely related to lake size, with larger systems requiring more samples. Our analysis suggests that lakes smaller than 10 ha require about 12 vegetated transects to have a 95% probability of detecting all of the species present in the lake. Lakes between 10.1 and 40 ha require 13 transects, those between 40.1 and 101 ha require 19 transects, lakes between 101.1 and 202 ha require 25 transects, lakes between 202.1 and 404 ha require 29 transects, and lakes greater than 404.1 ha require 35 transects.

INTRODUCTION

Aquatic vegetation plays an important functional role in aquatic ecosystems. For instance, extensive macrophyte growth in lentic systems can reduce algal biomass through competitive uptake of nutrients and by reducing nutrient recycling through a reduction in mixing and nutrient resuspension (Dennison et al. 1993, Kufel and Ozimek 1994, Van den Berg et al. 1997, Barko and James 1998). Aquatic macrophytes are beneficial to fish and wildlife populations by serving as a direct food resource or indirectly through increased diversity and production of aquatic invertebrates (Low 1945, Driver et al. 1974, Chilton 1990). Aquatic vegetation increases habitat complexity (Crowder and Cooper 1982, Weaver et al. 1996, 1997) and provides important refuge habitat for larval and juvenile fishes (Wiley et al. 1984, Dewey et al. 1997, Pothoven et al. 1999). Tate et al. (2003) found that abundance of age-0 largemouth bass (*Micropterus salmoides*) increased with increasing coverage of aquatic vegetation in Florida lakes. Similar results have been reported across a variety of systems for a variety of fish species (e.g., Durocher et al. 1984, Colle et al. 1987, Killgore et al. 1989). Although macrophytes provide a number of benefits, extremely high densities or extensive surface coverage of vegetation may have negative effects, including reduced growth and survival of fishes (Crowder and Cooper 1982, Bettoli et al. 1992), and may be a hindrance to recreational activities (e.g., swimming, boating; Colle et al. 1987, Henderson 1996). Consequently, management of aquatic vegetation is a complex issue that requires careful consideration of both positive and negative effects, particularly in systems managed for multiple uses. Regardless, determining the occurrence and distribution of species is critical for guiding vegetation management activities.

A number of studies have been conducted to provide managers and researchers with tools for assessing aquatic macrophytes. Most of these studies have focused on

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sampling technologies (e.g., Marshall and Lee 1994), while others have focused on collection methods (e.g., transects versus quadrats, boat versus in-water techniques; Capers 2000, Rodusky et al. 2005). Fewer studies have focused on sampling designs, and those that have been conducted typically used some form of power analysis to estimate the amount of sampling necessary to detect a change in abundance or biomass (e.g., Heidelbaugh and Nelson 1996). While these studies provide important guidance for monitoring changes in vegetation abundance, little information is available on sampling designs for assessing the distribution and occurrence of plant species. Distribution studies (i.e., presence-absence, species richness) are becoming increasingly important because they can provide insight on the status of threatened, endangered, and sensitive species (e.g., Phillips 1998) and which species may or may not be suitable for restoration activities (e.g., Smart et al. 1996). Distributional studies are also important because they are used to monitor the presence and distribution of nonnative aquatic plant species (Skinner et al. 1994, Phillips 2001). The objective of this study was to determine the number of samples required to estimate species richness and determine the effects of geographic location (e.g., latitude), lake type (e.g., natural lake, impoundment, oxbow lakes), and lake size on sample size requirements for Iowa lakes. We also hoped to provide descriptive information on the spatial distribution of native and nonnative aquatic macrophyte species in Iowa.

MATERIALS AND METHODS

One hundred and thirty lakes sampled from 1997 to 2005 were used in this study. Lakes were distributed across Iowa and varied from 0.8 to 2,174.4 ha. Lakes were surveyed by establishing transects perpendicular to the shoreline. Transects began at the high-water mark and terminated at the outer edge of the submersed vegetation zone. In shallow water, samples were collected by hand. A grapnel or vegetation rake was used to sample aquatic vegetation in deep water. Distance between transects varied from less than 100 m in small, highly-vegetated lakes to over 300 m for large, sparsely-vegetated lakes (Phillips 1998). Whenever possible, vegetation was identified in the field;

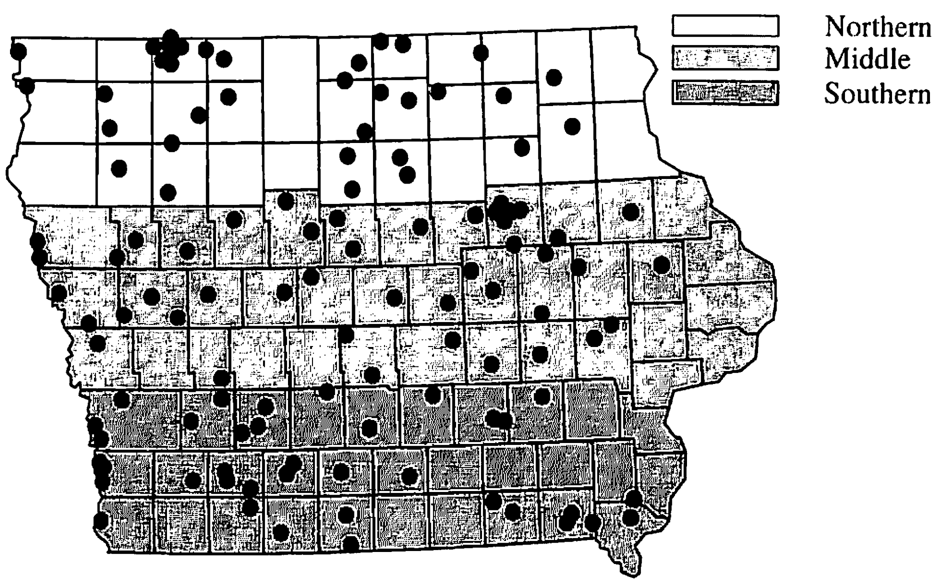

Figure 1. Location of 130 Iowa lakes sampled during 1997-2003. Geographic locations were defined as the northern, middle, and southern thirds of the state.

otherwise, samples were identified to species in the laboratory using Prescott (1980), Eilers and Roosa (1994), and Runkel and Roosa (1999). Although most vegetation was identified to species, cattails (*Typha* spp.) were only identified to genus. Because cattails were an important component of most vegetation communities, we treated unidentified *Typha* spp. as a "species" in our analysis.

The spatial distribution of vegetation species was evaluated by examining the presence and frequency of occurrence (i.e., percentage of lakes present) of each species by geographic region, lake type, and lake size. Geographic regions were defined as the northern ($N = 41$ lakes), middle ($N = 49$), or southern third ($N = 40$) of Iowa (Fig. 1). Lake type categories included impoundments ($N = 82$ lakes), natural lakes ($N = 19$), oxbow lakes ($N = 5$), surface mines ($N = 15$), and wetlands ($N = 9$). Lake size categories were based on the distribution of lakes present in the study and to conform to protocols established for fishery surveys. Lake size categories included those lakes <10 ha ($N = 35$ lakes), 10.1-20 ha ($N = 22$), 20.1-40 ha ($N = 21$), 40.1-101 ha ($N = 17$), 101.1-202 ha ($N = 16$), 202.1-404 ha ($N = 13$), and ≥404.1 ha ($N = 6$). In addition to patterns of occurrence, patterns of species richness and rank abundance were examined. Species richness was estimated as the total number of species sampled in a lake. Rank abundance curves were developed by plotting the natural logarithm of the relative frequency (i.e., percentage of transects sampled in a lake) against the rank of each species in the sample (the most frequent species had a rank of one) and were used to provide insight on how "evenly" species were distributed among transects. A simple linear regression was fit to each lake, and slope estimates were compared among lakes. A high slope indicated that the vegetation community was dominated (i.e., based on frequency of occurrence) by a few species; whereas, a low slope indicated a more even distribution of occurrence (Whittaker 1998). Differences in species richness and slope estimates among geographic location, lake-type, and lake-size categories were compared using a factorial analysis of variance (Milliken and Johnson 1992). When differences were significant, pairwise comparisons among categories were accomplished using contrast statements (Milliken and Johnson 1992, Kuehl 1994).

Sample size requirements were estimated using resampling techniques. The first step in the analysis was to randomly-select transects (without replacement) from each lake with the number of transects varying from one to the maximum number of transects sampled during the field survey. Each sample size (i.e., number of transects) was replicated 1,000 times, and the total number of species was recorded for each replicate. For each sample size, we had 1,000 replications with some observed number of successes defined as the number of times a minimum number of species was observed. In other words, replicates provided raw estimates of the probability (number of times out of 1,000) of observing various numbers of species. We estimated the probability of sampling 25, 50, 90, 95, and 100% of the species observed in a lake. Probabilities were then modeled using nonlinear regression methods (i.e., logistic or Gompertz models depending on the data structure; Seber and Wild 2006). Resulting models allowed for the estimation of the number of transects necessary to sample a defined percentage of the species present at some probability of detection (Fig. 2). For instance, 50 transects were sampled from Spirit Lake and yielded 22 different species of aquatic macrophytes. For a sample size of one transect, one transect was randomly-selected 1,000 times. For a sample size of two transects, two transects were randomly-selected 1,000 times, and so forth up to 50 transects. Species richness was estimated for each replication as the total number of species occurring across transects included in the simulated sample. This portion of the simulation resulted in 1,000 estimates of species richness for sampling one transect, 1,000 estimates of species richness for sampling two transects, and so forth. The probability of sampling 25% (e.g., 25% of 22 species in Spirit Lake or six species), 50%

(11 species), 90% (20 species), 95% (21 species), or 100% of the species (22 species) was estimated by dividing the number of replications with the defined number of species by 1,000. A nonlinear regression model was then fit to the estimated probabilities and associated number of transects. The regression model was then used to estimate the number of transects necessary to have a 90 or 95% probability of detecting 25, 50, 90, 95, or 100% of the species present in the lake. A similar technique is provided in Bailey and Gerow (2005). The mean number of transects required to meet desired levels of detection were compared among geographic location, lake type, and lake size categories using a factorial analysis of variance (Milliken and Johnson 1992). When differences were significant, pairwise comparisons among categories were accomplished using contrast statements (Milliken and Johnson 1992, Kuehl 1994). All statistical analyses and resampling procedures were conducted using the Statistical Analysis System (SAS 1996). An alpha level of 0.05 was used to determine statistical significance for all statistical tests.

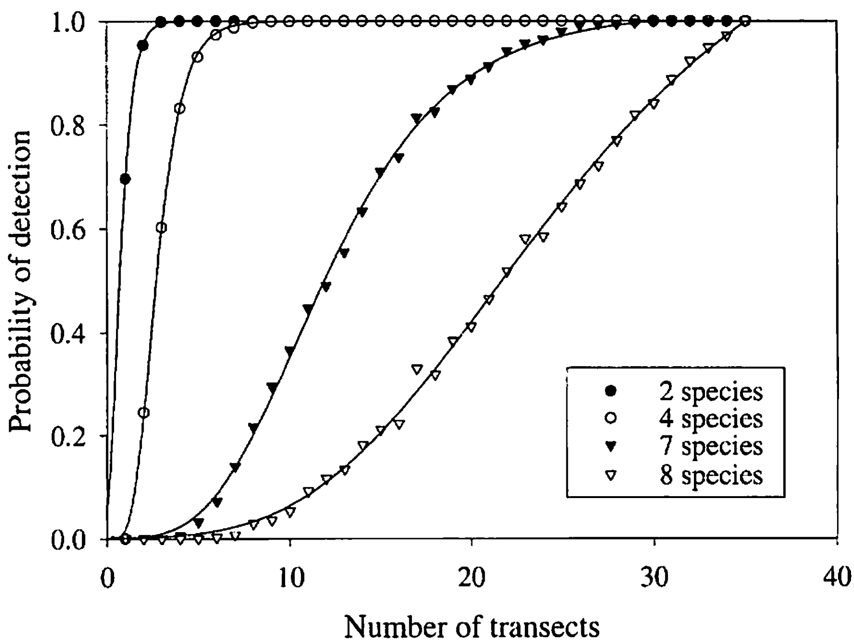

Figure 2. Example of the resampling technique used to calculate sample size requirements for aquatic plant species richness in Iowa lakes. Data are from Sweet's Marsh where eight plant species were sampled from 35 transects in 2003. Each point on the figure represents the number of times out of 1,000 random replications that a defined number of species was sampled (i.e., probability of sampling a defined number of species). The defined numbers of plant species were 25, 50, 90, 95, and 100% (i.e., 2, 4, 7, 8, and 8 species, respectively) of the species present in a water body. Nonlinear regression models were fit to the probabilities and used to estimate the number of transects required to attain either a 90 or 95% probability of detecting a given percentage of the plant species.

RESULTS

A total of 43 species (not including unidentified *Typha* spp.) representing 22 families was sampled (Table 1). Sago pondweed, cattails, reed canarygrass, longleaf pondweed, and coontail were the most common species across all lakes. These same

Table 1. Scientific name, common name, and relative frequency (i.e., percentage of lakes containing the species) of aquatic vegetation sampled from 130 Iowa lakes, 1997-2005. Species with an asterisk are identified as invasive species by the Iowa Department of Natural Resources.

Scientific name	Common name	Relative frequency	Scientific name	Common name	Relative frequency
Potamogeton pectinatus	Sago pondweed	73.8	*Nelumbo lutea.*	American water lotus	6.9
Typha spp.	Unidentified cattail	70.0	*Nymphaea odorata tuberosa*	White water lily	6.9
*Phalaris arundinacea**	Reed canarygrass	60.0	*Heteranthera dubia*	Water stargrass	6.2
Potamogeton nodosus	Longleaf pondweed	43.1	*Potamogeton pusillus*	Small pondweed	5.4
Ceratophyllum demersum	Coontail	41.5	*Potamogeton richardsonii*	Claspingleaf pondweed	5.4
Lemna minor	Little duckweed	29.2	*Iris versicolor*	Blue flag iris	4.6
Potamogeton zosteriformis	Flatstem pondweed	28.5	*Sagittaria cuneata*	Narrowleaf arrowhead	4.6
Schoenoplectus fluviatilis	River bulrush	26.9	*Potamogeton natans*	Floatingleaf pondweed	3.8
Schoenoplectus tabernaemontani	Softstem bulrush	26.9	*Polygonum amphibium*	Water smartweed	3.8
*Potamogeton crispus**	Curlyleaf pondweed	23.8	*Lythrum salicaria**	Purple loosestrife	3.1
Chara vulgaris	Muskgrass	19.2	*Myriophyllum spicatum**	Eurasian watermilfoil	3.1
Najas flexilis	Bushy pondweed	19.2	*Nuphar lutea variegate*	Yellow water lily	3.1
Spirodela polyrrhiza	Big pondweed	15.4	*Potamogeton friesii*	Frie's pondweed	3.1
Zannichellia palustris	Horned pondweed	15.4	*Spartina pectinata*	Prairie cordgrass	3.1
Vallisneria americana	Wild celery	13.8	*Asclepias incarnate*	Marsh milkweed	1.5
Elodea canadensis.	Canada waterweed	13.1	*Eleocharis palustris*	Small's spikerush	0.8
Myriophyllum sibiricum	Northern watermilfoil	11.5	*Lemna trisulca*	Star duckweed	0.8
Potamogeton amplifolius	Largeleaf pondweed	10.8	*Marsilea vestita*	Water clover	0.8
Potamogeton illinoensis	Illinois pondweed	10.8	*Ranunculus aquatilis*	White water crowfoot	0.8
Sagittaria latifolia	Broadleaf arrowhead	10.8	*Ruppia maritima*	Widgeon grass	0.8
Potamogeton foliosus	Leafy pondweed	9.2	*Sagittaria graminea*	Grassleaf arrowhead	0.8
*Najas minor**	Brittle naiad	7.7	*Schoenoplectus acutus*	Hardstem bulrush	0.8

Table 2. The five most frequently sampled aquatic vegetation species by geographic location, lake type, and lake size categories for 130 Iowa lakes, 1997-2005. Number in parentheses represents the percentage of lakes within each category that contained the species.

Category	Taxa
Geographic location	
Northern ($N = 41$)	Sago pondweed (75.5), cattail (73.2), coontail (56.1), reed canarygrass (46.3), flatstem pondweed (46.3)
Middle ($N = 49$)	Sago pondweed (79.6), cattail (75.5), reed canarygrass (63.2), longleaf pondweed (46.9), coontail (36.8)
Southern ($N = 40$)	Sago pondweed (75.0), reed canarygrass (72.5), cattail (70.0), longleaf pondweed (65.0), coontail (35.0)
Lake type	
Impoundments ($N = 82$)	Sago pondweed (73.2), reed canarygrass (70.7), cattail (70.7), longleaf pondweed (48.7), coontail (43.9)
Natural lakes ($N = 19$)	Sago pondweed (84.2), cattail (78.9), river bulrush (68.4), reed canarygrass (63.2), softstem bulrush (52.6)
Oxbow ($N = 5$)	Cattail (100), reed canarygrass (80.0), sago pondweed (80.0), American water lotus (60.0), coontail (40.0)
Surface mine ($N = 15$)	Sago pondweed (80.0), cattail (73.3), longleaf pondweed (46.7), softstem bulrush (40.0), river bulrush (33.3)
Wetland ($N = 9$)	Sago pondweed (100), coontail (77.8), cattail (66.7), little duckweed (55.6), longleaf pondweed (55.6)
Lake size	
<10 ha ($N = 35$)	Sago pondweed (74.3), cattail (68.6), reed canarygrass (45.7), coontail (37.1), flatstem pondweed (34.3)
10.1-20 ($N = 22$)	Sago pondweed (72.7), reed canarygrass (72.7), cattail (68.2), little duckweed (40.9), softstem bulrush (36.4)
20.1-40 ha ($N = 21$)	Cattail (61.9), sago pondweed (57.1), coontail (52.3), reed canarygrass (47.6), longleaf pondweed (42.9)
40.1-101 ha ($N = 17$)	Cattail (76.5), sago pondweed (70.6), reed canarygrass (70.6), coontail (52.9), longleaf pondweed (47.1)
101.1-202 ha ($N = 16$)	Cattail (61.9), sago pondweed (57.1), reed canarygrass (62.5), curlyleaf pondweed (43.8), longleaf pondweed (37.5)
202.1-404 ha ($N = 13$)	Sago pondweed (84.6), reed canarygrass (76.9), cattail (76.9), river bulrush (53.8), curlyleaf pondweed (46.2)
>404.1 ha ($N = 6$)	Sago pondweed (83.3), bushy pondweed (66.7), largeleaf pondweed (66.7), reed canarygrass (66.7), river bulrush (66.7)

species were generally the most common species when lakes were examined based on geographic location, but a few exceptions were observed (Table 2). For instance, flatstem pondweed was more common in the northern third of Iowa compared to the middle and southern thirds of the state. Frie's pondweed, white water crowfoot, and widgeon grass were only sampled in the northern third of Iowa, star duckweed was only found in the middle third, and water clover and grassleaf arrowhead were only sampled from the southern portion of Iowa. No species were unique to both the northern and middle portions of the state. Five species were unique to southern and middle Iowa, including marsh milkweed, Small's spikerush, brittle naiad, prairie cordgrass, and narrowleaf arrowhead. Aside from brittle naiad, which was not sampled in the northern third of Iowa, all other invasive species (e.g., Eurasian watermilfoil, purple loosestrife) were found throughout the state. Similar to the geographic distribution of plant species, sago pondweed, reed canarygrass, cattails, longleaf pondweed, and coontail were generally the most common species in all lake types. River bulrush and softstem bulrush were common in natural lakes and surface mines, American water lotus was common in oxbows, and little duckweed was one of the most common species in wetland habitats. Star duckweed, brittle naiad, narrowleaf arrowhead, and grassleaf arrowhead were only sampled in impoundments, while white water crowfoot and widgeon grass were only found in natural lakes. Impoundments and natural lakes were the only habitats where claspingleaf pondweed and prairie cordgrass were sampled. Although unique species were not found in oxbows, surface mines, or wetlands, marsh milkweed was only sampled in impoundments and oxbows, Eurasian watermilfoil was only found in impoundments and surface mines, and Small's spikerush was unique to surface mines and wetland habitats. Similar patterns were observed when examining the most common species by lake size. Curlyleaf pondweed was one of the most common species in lakes that were 101.1-404 ha, and river bulrush was one of the most frequently encountered species in lakes greater than 202.1 ha. Star duckweed was only sampled in the smallest lakes (i.e., <10 ha), and white water crowfoot and widgeon grass were only found in the largest lakes (i.e., >404.1 ha). Water clover, hardstem bulrush, and Small's spikerush were only sampled in 20.1-40 ha lakes, and grassleaf arrowhead was only found in lakes between 202.1-404 ha.

Species richness was highly variable among lakes and was not significantly different among location, lake-type, or lake-size categories ($F_{40,89} = 1.30$, $P = 0.15$; Fig. 3). Although the mean number of species was not statistically different among lake categories, the smallest lakes tended to have fewer species than the largest lakes. Similar to species richness, slopes of the rank abundance curves were not statistically different among categories ($F_{40,89} = 1.00$, $P = 0.48$; Fig. 4).

The number of transects required to estimate species richness in the study lakes varied by geographic location, lake type, and lake size. For all combinations of detection probability (i.e., 90 or 95% probability) and percentage of species sampled (i.e., 25, 50, 90, 95, 100% of the species present), none of the interactions were statistically significant ($P = 0.38$-0.99). Lake size was the only main effect that was significant ($P = 0.004$-0.01). Consequently, sample size requirements were summarized by lake size categories (Table 3). Among lake size categories, only those combinations requiring that a sample contain 90% or more of the species were significant ($P < 0.05$). For example, the number of transects required to have a 90% probability of sampling 50% of the vegetation species was not statistically different among categories ($F_{40,89} = 1.47$, $P = 0.07$); whereas, the number of transects required for a 90% probability of detecting 90% of the species was significantly different among lake size categories ($F_{40,89} = 1.90$, $P = 0.005$). Lakes greater than 404.1 ha required the most transects, regardless of the percentage of species sampled.

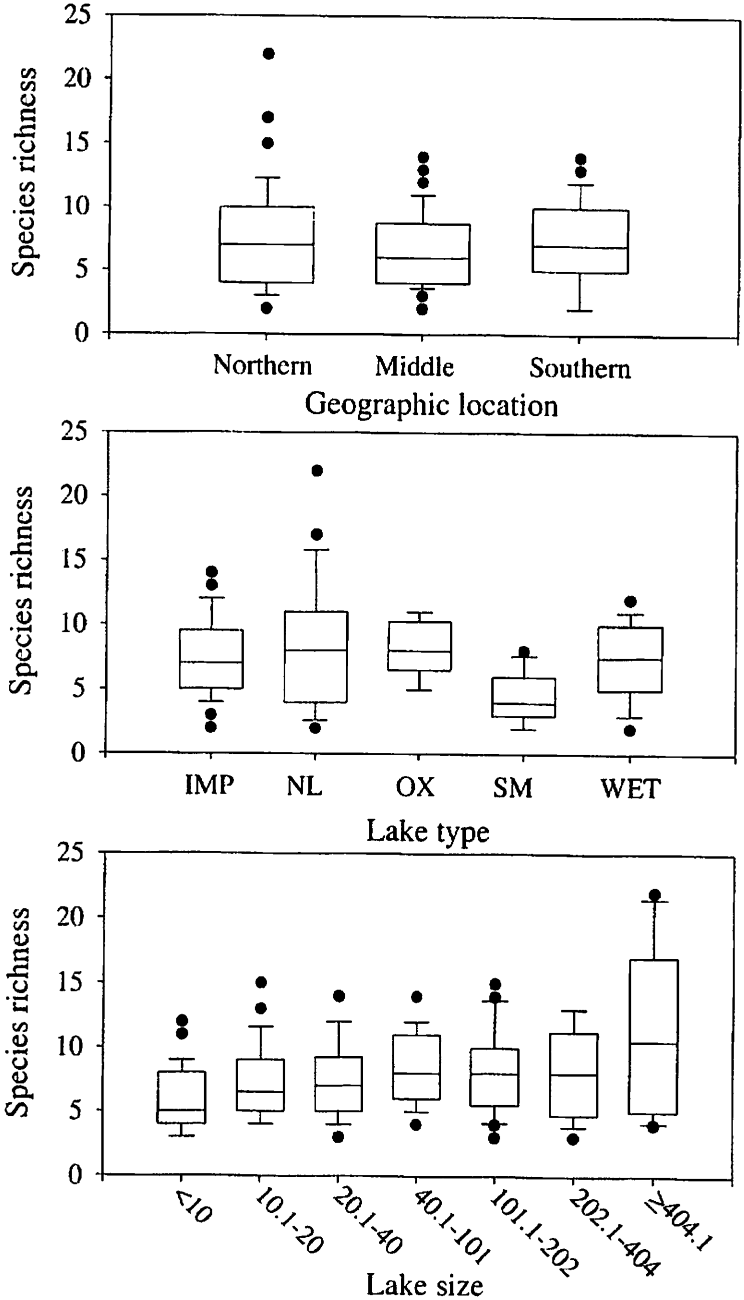

Figure 3. Box plots of aquatic vegetation species richness by geographic location (i.e., northern, middle, or southern third of Iowa), lake type, and lake size categories in 130 Iowa lakes, 1997-2005. Lake types include impoundment (IMP), natural lake (NL), oxbow lake (OX), surface mine (SM), and wetland (WET). Error bars represent the 90th and 10th percentiles, the upper and lower portions of the box represent the 75th and 25th percentiles, and the line inside the box represents the median.

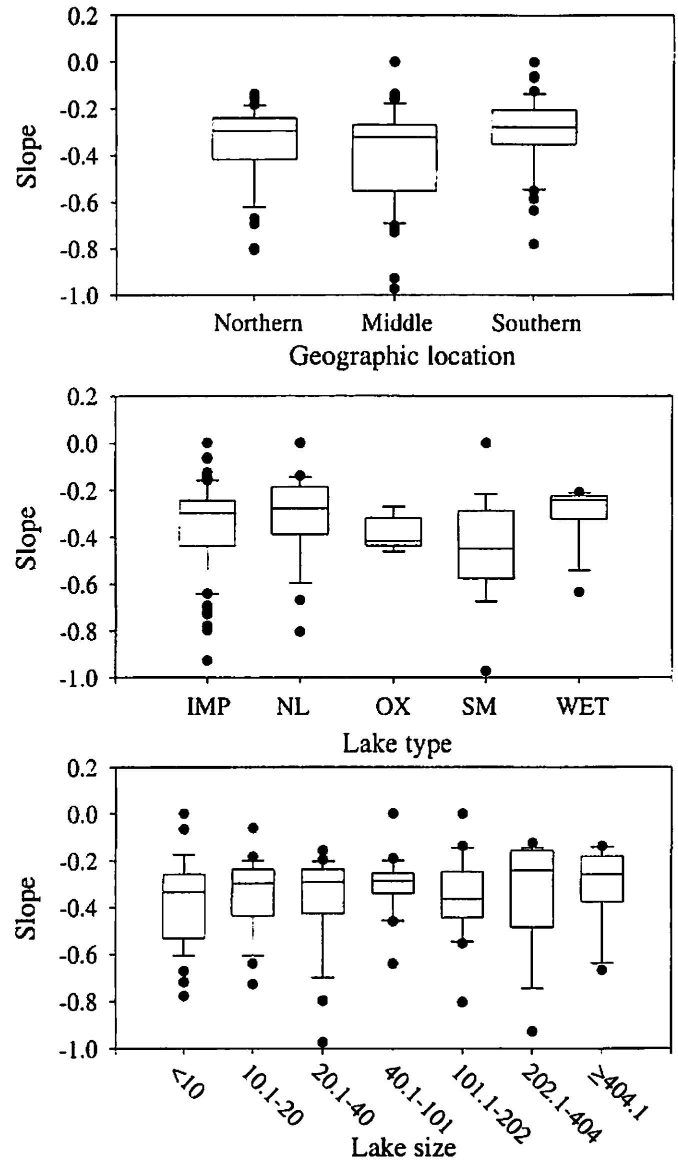

Figure 4. Box plots of rank abundance slope estimates by geographic location (i.e., northern, middle, or southern third of Iowa), lake type, and lake size categories in 130 Iowa lakes, 1997-2005. Slopes were estimated for each lake using a linear regression of the natural logarithm of the frequency of each aquatic vegetation species (i.e., percentage of transects in which a species was present) on the ranked abundance of each species (i.e., most common species was given a rank equal to one). Steep slopes indicate that the occurrence of vegetation was dominated by one species, while slopes near zero indicate that vegetation species were more evenly distributed in a lake. Lake types include impoundment (IMP), natural lake (NL), oxbow lake (OX), surface mine (SM), and wetland (WET). Error bars represent the 90th and 10th percentiles, the upper and lower portions of the box represent the 75th and 25th percentiles, and the line inside the box represents the median.

Table 3. Sample size requirements by lake size category for estimating species richness of aquatic vegetation in Iowa lakes. Sample size requirements were estimated for 90 and 95% probabilities of sampling 25, 50, 90, 95, and 100% of the species present in a lake. Number outside of parentheses represents the mean number of required transects (N = 130 lakes) and the number in parentheses represents the maximum number of required transects observed across lakes within each size category. Mean sample sizes with the same letter are not significantly different ($P > 0.05$). Comparisons were made across lake size categories, within different levels of probability and percentage of species sampled.

Lake size	Percentage of species sampled				
	25[a]	50[a]	90[a]	95	100
			90% probability		
<10 ha	1 (2)	2 (5)	5 (9)[w]	5 (9)[w]	6 (10)[w]
10.1-20	1 (3)	3 (5)	6 (11)[w]	7 (11)[w]	8 (12)[w]
20.1-40 ha	1 (3)	3 (7)	7 (12)[w]	7 (12)[w]	8 (13)[w]
40.1-101 ha	2 (4)	3 (9)	9 (15)[x]	9 (17)[x]	11 (18)[x]
101.1-202 ha	2 (3)	3 (5)	10 (20)[xy]	10 (20)[xy]	13 (21)[y]
202.1-404 ha	2 (4)	4 (8)	11 (20)[y]	11 (23)[y]	14 (26)[y]
>404.1 ha	3 (8)	8 (17)	20 (42)[z]	23 (45)[z]	23 (49)[z]
>404.1 ha[b]	3 (9)	6 (17)	13 (22)	15 (32)	16 (33)
			95% probability		
<10 ha	1 (3)	2 (6)	5 (10)[w]	5 (10)[w]	7 (12)[w]
10.1-20	1 (3)	3 (6)	7 (12)[w]	7 (12)[w]	8 (13)[w]
20.1-40 ha	1 (4)	4 (9)	8 (12)[w]	8 (12)[w]	9 (13)[w]
40.1-101 ha	2 (5)	4 (10)	10 (16)[x]	10 (18)[x]	12 (19)[x]
101.1-202 ha	2 (4)	4 (6)	11 (23)[xy]	11 (23)[xy]	14 (25)[y]
202.1-404 ha	2 (5)	5 (10)	12 (22)[y]	12 (25)[y]	15 (29)[y]
>404.1 ha	4 (10)	9 (18)	22 (44)[z]	25 (48)[z]	27 (50)[z]
>404.1 ha[b]	4 (10)	8 (18)	14 (25)	16 (34)	20 (35)

[a]Differences among categories were not significantly different ($P > 0.05$).
[b]Excluding East Okoboji and Spirit lakes.

DISCUSSION

Sago pondweed, longleaf pondweed, and coontail were three of the most common vegetation species sampled in our study, all of which have important ecological values. Sago pondweed is generally considered one of the more cosmopolitan species of submersed aquatic vascular plants and occurs across a variety of habitats in North America (e.g., Anderson 1978). Sago pondweed and other pondweeds (*Potamogeton* spp.), including longleaf pondweed, provide important food resources for waterfowl (Driver et al. 1974, Godfrey and Wooten 1979) and habitat for fishes (Weaver et al. 1997). Coontail is also an important plant species in aquatic systems that serves as a food resource for waterfowl (Low 1945, Driver et al. 1974) and provides important habitat for invertebrates (Chilton 1990) and fishes (Bart 1989). Consequently, these species (i.e., pondweeds, coontail) are frequently recommended for inclusion in plantings to enhance wildlife habitat or restore aquatic vegetation communities and ecological function in lakes and reservoirs (Spencer 1987, Smart et al. 1996).

Although several interesting patterns were observed with regard to the occurrence of aquatic vegetation in Iowa lakes, our data were limited to a subset of Iowa lakes and may not reflect distributional limits (e.g., geographic or lake type). For example, narrowleaf arrowhead and Small's spikerush were only found in the southern two-thirds of Iowa, but both species are commonly found at much higher latitudes (e.g., Moyle 1945, Gleason et al. 2003). Similarly, star duckweed and narrowleaf arrowhead were only observed in impoundments, and Eurasian watermilfoil was only found in impoundments and surface mines. These same species are common in natural lakes in other portions of their distribution (Moyle 1945, Beal and Thieret 1986, Nichols and Shaw 1986, Gleason et al. 2003) and Eurasian watermilfoil is present in at least one natural lake and one oxbow lake in Iowa (Phillips 2001). Many of the distributional patterns associated with one of the categories may also be confounded with one or both of the other categories. Widgeon grass and white water crowfoot were only sampled from the northern third of Iowa, only sampled in natural lakes, and only in lakes with a surface area greater than 404.1 ha. Because large natural lakes are generally limited to northern Iowa, associations with lake types, lake size, or geographic location may be difficult to discern. Despite these potential limitations, these data still provide important insight on vegetation communities in Iowa lakes.

The number of native aquatic plant species in Iowa has declined and although several species were relatively rare, no threatened or endangered plant species were observed in our study. Phillips (1998) used data from historic (1915) and recent (1996) surveys in 15 Iowa lakes. The author found that species richness varied from seven to 50 species (mean = 22.2 species) in 1915, but samples from 1996 indicated that species richness of aquatic plants had declined substantially with only one to 25 species (mean = 9.8 species) present in the same lakes. Not only were declines in species richness noted in 12 of the 15 lakes, but two-thirds of the lakes lost 50% or more (up to 91%) of the aquatic plant species between 1915 and 1996. A number of environmental changes were hypothesized to be responsible for the observed changes, including stabilization of water levels, increased sediment and nutrient loading, and shoreline development. Similar mechanisms have been implicated for the decline of aquatic plants throughout North America (e.g., Gleick 1998, Gleason et al. 2003). In addition to these changes, invasive species are thought to be an important cause for the decline of native species in Iowa lakes (Phillips 1998). In our study, five species of invasive plant species were sampled in the study lakes, including two emergent (reed canarygrass, purple loosestrife) and three submersed species (Eurasian watermilfoil, curlyleaf pondweed, brittle naiad). All of these species are considered detrimental because they replace native species, thereby disrupting the ecology of natural systems (e.g., Nichols and Shaw 1986, Mills et al. 1996, Mal et al. 1997, Barnes 1999). As an example, reed canarygrass was one of the most common species in our study lakes. Although reed canarygrass has a circumtemporal native distribution, introduction of European strains have resulted in a significant expansion of this species in the western and midwestern United States (Barnes 1999). Borman et al. (1997) indicated that at one time both native and introduced strains of reed canarygrass were present in Wisconsin, but the native strain is now thought to have been completely replaced by the European strain. Volker and Smith (1965) reported that eleven plant species disappeared from wetland habitats of the East Okoboji system, Iowa, following establishment of reed canarygrass. Another species commonly observed in our study was curlyleaf pondweed, which occurred in nearly a quarter of the lakes surveyed. Similar to reed canarygrass, curlyleaf pondweed often dominates plant communities once it becomes established, resulting in a significant loss of native plant species (Nichols and Shaw 1986, Bolduan et al. 1994, Phillips 1998, Netherland et al. 2000). Eurasian watermilfoil, purple loosestrife, and brittle naiad were less frequent than reed canarygrass and curlyleaf pondweed in Iowa lakes, but when present often dominated plant communities, particularly Eurasian watermilfoil and brittle naiad.

Lake type and geographic location had little influence on sample size requirements. Rather, lake size was the most important factor influencing sample size requirements. Sampling five vegetated transects was sufficient to sample 25-50% of the species present for all but the largest lakes. However, sampling 90% or more of the species required considerably more effort. Although we modeled a number of different scenarios, most scientists would likely want a high probability of detecting (i.e., 95% probability) all of the species present in a system, particularly when surveys are conducted to monitor the occurrence of sensitive or invasive species. In our analysis, we provided the mean number of transects required to estimate species richness at some probability of detection. While the mean may provide some guidance, the maximum number of required transects observed across lakes within a category is a more conservative and better estimate of required sample size. Also, the required number of samples was extremely high for lakes greater than 404 ha and was highly influenced by East Okoboji and Spirit lakes. These two lakes had the highest number of vegetation species (East Okoboji = 17 species, Spirit = 22 species) and required an extremely high number of samples. Although our sample size estimates were derived from Iowa lakes, our methodology and results may provide guidance for other efforts on similar systems in the Midwest.

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