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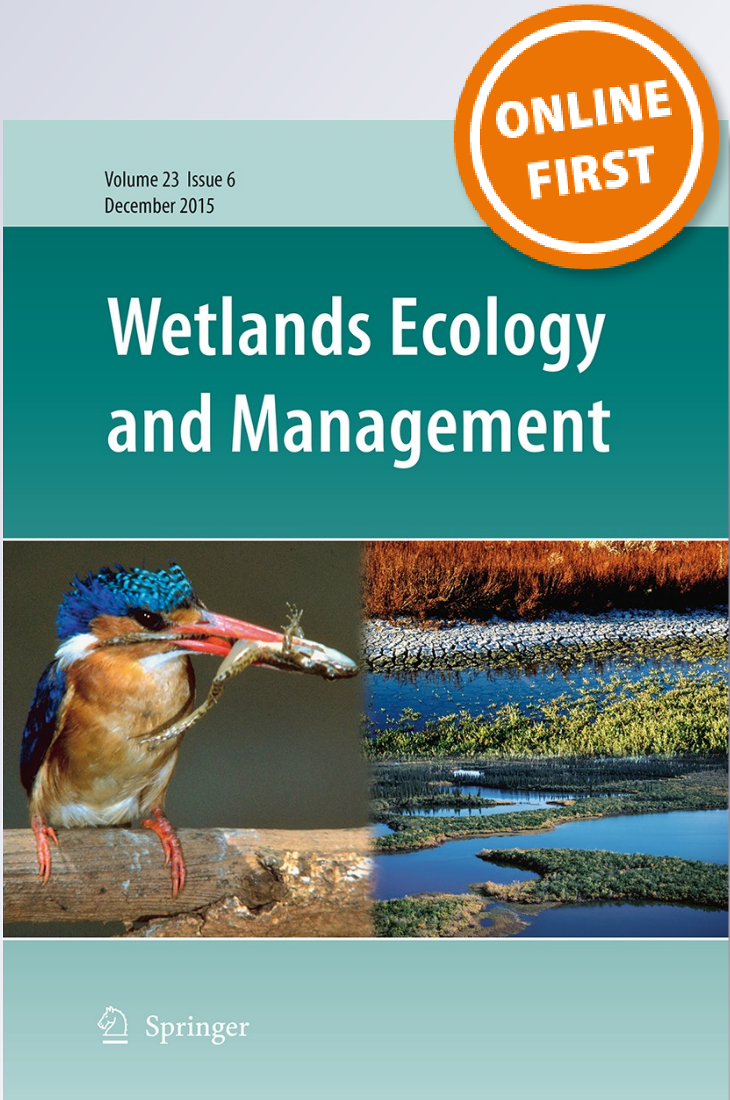

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ORIGINAL PAPER

An evaluation of rapid methods for monitoring vegetation characteristics of wetland bird habitat

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Abstract Wetland managers benefit from monitoring data of sufficient precision and accuracy to assess wildlife habitat conditions and to evaluate and learn from past management decisions. For large-scale monitoring programs focused on waterbirds (waterfowl, wading birds, secretive marsh birds, and shorebirds), precision and accuracy of habitat measurements must be balanced with fiscal and logistic constraints. We evaluated a set of protocols for rapid, visual estimates of key waterbird habitat characteristics made from the wetland perimeter against estimates from (1) plots sampled within wetlands, and (2) cover maps made from aerial photographs. Estimated percent cover of annuals and perennials using a perimeter-based protocol fell within 10 percent of plot-based estimates, and percent cover estimates for seven vegetation height classes were within 20 % of plot-based estimates. Perimeter-based estimates of total emergent vegetation cover did not differ significantly from cover map estimates. Post-hoc analyses revealed evidence for observer effects in estimates of annual and perennial covers and vegetation height. Median time required to complete perimeter-based methods was less than 7 percent of the time needed for intensive plot-based methods. Our results show that rapid, perimeter-based assessments, which increase sample size and efficiency, provide vegetation estimates comparable to more intensive methods.

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Introduction

Throughout their annual cycles, waterbirds (waterfowl, wading birds, secretive marsh birds, and shorebirds) depend on wetlands for a variety of resources, including food (Weber and Haig 1996), cover (e.g., Hohman et al. 1992), and nesting areas (Burger 1985). Loss and degradation of wetland habitat has imperiled waterbird populations (Brown et al. 2001; Kushlan et al. 2002). The conterminous United States lost approximately half of its original 89.5 million ha of wetlands between 1780 and 1980 (Dahl 1990), but more recently, wetland acreage appears to have stabilized or to have increased (Dahl 2006, 2011). Waterbird conservation and management plans recognize the need to protect, create, restore, and manage habitat to stabilize declining waterbird populations and to potentially grow them to target levels (Brown et al. 2001; Kushlan et al. 2002). Despite the acknowledged importance of habitat, many large-scale bird population monitoring programs do not include a robust habitat monitoring component. Consequently, linkages between changing bird populations and habitat conditions are difficult or impossible to make.

Selection of habitat assessment techniques must balance fiscal and logistic concerns against precision and bias of field measurements. Fiscal and logistic constraints pertain to staff, time, and financial resources required to collect, enter, and process habitat data into information that can meaningfully influence management decisions. Methods used to assess wetland habitat conditions range from visual assessments of vegetation extent and condition requiring relatively few resources (e.g., Naugle et al. 2001; Conway and Sulzman 2007) to more resource-intensive approaches, e.g., core-sampling to estimate seed production (Kross et al. 2008). Studies in varied ecosystems have shown that the precision and bias of habitat estimates can vary across techniques (Block et al. 1987; Meese and Tomich 1992; Etchberger and Krausman 1997; Kaufmann et al. 1999). The amount of time required to complete a habitat assessment directly affects the number of wetlands included in a study with more time-intensive methods reducing sample sizes. Ultimately, while assessments must be logistically feasible, levels of precision and bias for habitat estimates determine whether they can be used to assess the state of habitat features, evaluate the outcome of habitat management actions, or reduce key sources of uncertainty for an adaptive management program.

Large-scale monitoring programs for waterbirds and marshbirds often depend on biologists from natural resource management agencies and volunteers to collect waterbird and associated habitat data with the goals of informing management actions, establishing population status, and detecting trends (Conway 2009; Soulliere et al. 2013). Participants in these programs need protocols that are logistically feasible, and these programs often call for rapid, visual assessments of water conditions and plant community composition, structure, and extent from either the perimeter of the wetland or from a boat within the wetland. These habitat features partly determine potential food abundance and habitat diversity and can influence intra- and interspecific interactions (Colwell and Dodd 1995; Smith et al. 2004; Naylor et al. 2005). The degree of human judgment involved in visual assessments could lead to biased habitat estimates. To assess this bias, our goal was to quantitatively evaluate the concordance of rapid, perimeter-based estimates for vegetation composition, structure, and extent with estimates from an intensive, plot-based protocol or a classified cover map. Acknowledging that no assessment method is completely unbiased, we assumed that plot-based and cover map estimation techniques were less prone to errors of human judgment and were "gold standards" (Lesser and Kalsbeek 1999) against which to assess perimeter-based estimates.

Methods

Plant community composition and height

Sample units and sample selection

We evaluated perimeter-based assessments of vegetation composition and height through comparisons with intensive, plot-based assessments at wetlands on a mix of federal, state, and private lands. Our study was conducted in conjunction with an on-going, broad-scale monitoring initiative, the Integrated Waterbird Management and Monitoring Initiative (IWMM; Soulliere et al. 2013). We created a sampling frame using selected wetlands that are enrolled in IWMM in the following geographic areas: Illinois/Missouri border, west-central Minnesota, southern New Jersey coast, north-central New York, northern North Carolina coast, and southern South Carolina coast. Our sampling frame included only wetlands that observers could physically access: a necessity to execute the plot-based protocols (see below). For each area, we generated a list of accessible wetlands and then made a stratified random selection of wetlands (sample units) from the area list. We stratified by size because sample unit size can influence visual estimation errors (Sykes et al. 1983; Klimeš 2003). We digitized geospatial layers to determine wetland size and stratified wetlands into two size categories: "small" (≤median unit size) and "large" (>median unit size). For most areas, we chose 15 wetlands because we assumed that this was the maximum number that could be assessed within a two-week survey period prior to the end of the growing season, our target window for assessments. For North and South Carolina, logistic constraints limited initial selections to 6 and 14 total wetlands, respectively. For each area, we selected half of our wetlands from each category; if the total number of wetlands selected was odd, we randomly selected the final wetland regardless of size category. For some wetlands, inspections revealed unanticipated access or safety issues that required using replacements, which were selected following the process outlined above. We underestimated the time required to complete data collection and logistic constraints prevented us from sampling all wetlands that were selected from the sampling frame. A list of 44 wetlands included in the study is provided in Online Resource 1.

We established a grid of 30–35 subsampling points within emergent vegetation of each wetland. Using a random start point, we placed grids using geospatial layers that we created through visual inspection of aerial photographs and field visits. The final number of points and grid dimensions varied based on the area and configuration of emergent vegetation present; for example, some small wetlands with irregular shapes could not accommodate 35 sample points. Establishing subsampling points on a grid ensured that points were distributed across the wetland and increased movement efficiency for observers. We recognized that a single random start point may result in biased variance estimates depending on the spatial structures of vegetation characteristics, but we expected unbiased mean estimates (Thompson et al. 1998). While spacing between points varied as a function of emergent vegetation area, increasing grid density to maintain consistent spacing was not logistically feasible. If field inspection indicated that a grid point fell outside of emergent vegetation (e.g., in open water), the point was repositioned at the nearest point within emergent vegetation (16 % of points).

Data collection

Field data were collected by a single observer in each geographic area. The six observers varied in their previous experience conducting perimeter-based assessments of habitat characteristics for the IWMM. IWMM habitat assessments include cover estimates for plant types and height classes over entire wetland surfaces. Two observers had no previous IWMM habitat assessment experience whereas the remaining four observers had varying levels of experience, having conducted 49, 86, 124, or 617 IWMM habitat assessments. Prior to data collection, all observers received standardized, internet-based training providing an overview of study objectives, study design, and all protocols.

Field work was conducted during 1 October to 30 November 2012. Perimeter-based and plot-based assessments were completed on the same day for 36 of 44 wetlands, within approximately one week for 6 wetlands, and within approximately one month for 2 wetlands. In all cases, the lag between assessments was not expected to result in appreciable changes to vegetation characteristics assessed in this study. For each wetland, assessments using the perimeter-based protocol preceded assessments using the plot-based protocol so that knowledge gained via the plot-based protocol would not influence perimeter-based estimates.

We made perimeter-based estimates of plant composition and height from one or more vantage points around the perimeter of each wetland (distance from wetland edge: 17.1 m ± 50.0 SD); vantage points were selected such that ≥70 % of the wetland could be seen. To assess plant community composition, we estimated percent canopy cover for 3 plant types: perennials, annuals, and residual vegetation. Residual vegetation was defined as dead vegetation from previous years. To determine vegetation height, we visually estimated percent canopy cover for each of 7 height classes (Table 1). Cover was estimated based on the uppermost canopy layer, so cover estimates for plant types and height classes summed to 100 %.

To assess plant community composition and vegetation height with a plot-based protocol, we centered a 1-m^2 quadrat subsampling plot over each point of the sampling grid. In each subsampling plot, we estimated percent canopy cover for each emergent vegetation species (Online Resource 2); we treated residual vegetation as a separate "species". As with the perimeter-based estimates, canopy cover estimates were based on the uppermost vegetation layer and therefore summed to 100 % across all species. We measured emergent vegetation height by holding a 2-m Robel pole vertically at each corner of the subsampling plots and recording maximum height of vegetation (including residual vegetation) within 15 cm of the pole. The Robel pole was marked every decimeter; vegetation height was measured to the nearest decimeter if ≤2 m tall or visually estimated to the nearest meter if >2 m tall.

Data analysis

The perimeter-based protocol produced single cover estimates for annuals, perennials, and residual vegetation. To assess concordance of these estimates and plot-based estimates, we summarized plot-based data for each plant type using:

$$C_s = \frac{\sum_{i=1}^{n} E_i}{n}$$

where C_s is the average canopy cover of annual, perennial, or residual vegetation across all plots, n, in wetland s; and E_i is the percent cover estimate of annual, perennial, or residual vegetation in plot i. Each wetland thus had paired estimates, one from each protocol, for the three plant types. Data for three wetlands where observers recorded presence-absence data, not percent cover, were excluded from the analysis. For 41 remaining wetlands, we used paired t-tests to determine whether estimates for plant types differed between the two protocols. We applied a sequential Bonferroni procedure for a familywise Type I error rate equal to 0.10.

From the plot-based measurements of vegetation height, we calculated the proportion of a wetland within each vegetation height class using:

$$P_h = \frac{\sum_{i=1}^{m} w_i}{m}$$

where P_h is the proportion of the wetland in height class h, m is the total number of height measurements, and w is an indicator taking the value 1 if a measurement fell within height class h and 0 otherwise. Following these calculations, we had paired estimates for height classes, one from each protocol. We excluded 5 of 44 wetlands where an observer provided perimeter-based height estimates for the entire wetland surface rather than only for emergent vegetation. We used paired t-tests to examine differences between protocols for each height class and applied a sequential Bonferroni correction for a familywise Type I error rate equal to 0.10.

In a series of post hoc tests, we examined observer identity effects on differences in estimated percent cover for plant types and vegetation height. We considered only observers who produced paired estimates for at least five units (four observers);

Table 1 Median percent cover (and interquartile range) for height classes assessed using perimeter- and plot-based protocols (n = 39 wetlands)

Protocol	Class 1 <2.5 cm	Class 2 2.5–15 cm	Class 3 15–30 cm	Class 4 30–60 cm	Class 5 60 cm–3 m	Class 6 3–9 m	Class 7 >9 m
Perimeter-based	10.0	10.0	15.0	20.0	35.0	0	0
	(0, 15.0)	(0, 20.0)	(10.0, 20.0)	(10.0, 30.0)	(19.5, 45.0)	(0, 5.0)	(0, 0)
Plot-based	0	0.8	4.0	13.9	55.3	0	0
	(0, 0.8)	(0, 3.6)	(0, 11.0)	(0.4, 25.0)	(25.4, 70.2)	(0, 17.5)	(0, 3.6)

vegetation height data from one of the four observers was not included because the perimeter estimates were based on the entire wetland surface rather than only area of emergent vegetation. We eliminated height class 7 (>9 m) from analyses because plot-based estimates indicated that this class was effectively absent at wetlands surveyed by two of three observers. Variances were heterogeneous, so we used a Welch's ANOVA (Quinn and Keough 2002) to evaluate observer effects. When an observer effect was present, we used the Games-Howell test (Day and Quinn 1989) to conduct pairwise comparisons between observers and set the familywise Type I error rate equal to 0.10.

To evaluate effects of wetland area as a continuous predictor of concordance between protocols, we used a Spearman rank-order correlation (Harrell 2014) to examine the potential association between protocol differences and wetland size.

All analyses were carried out in the R programming environment (R Development Core Team 2012).

Cover types

Sample units and sample selection

As a separate validation effort from the study outlined above, we validated perimeter-based, visual assessments of cover types through comparisons with cover maps created using aerial photographs (Fig. 1). Cover types used in this study included emergent vegetation (annual and perennial combined), bare ground, and water. Aerial photographs were available for 41 managed wetlands located across Clarence Cannon National Wildlife Refuge in Missouri and the Delair Division of the Great River National Wildlife Refuge and Two Rivers National Wildlife Refuge in Illinois. Given the time required to create and validate cover maps, we selected a subset of the 41 managed wetlands for these comparisons. To ensure that we had a balanced selection of wetlands from across the spectrum of vegetation cover, we stratified wetlands by vegetation cover into the following classes using perimeter-based estimates: 35–50 %, 51–80 %, 81–90 %, 91–99 %, and 100 %. We defined strata based on natural breaks in the distribution of vegetation cover values for the wetlands. From each stratum, we randomly selected 3 wetlands, yielding a total sample of 15 wetlands. A list of the wetlands included

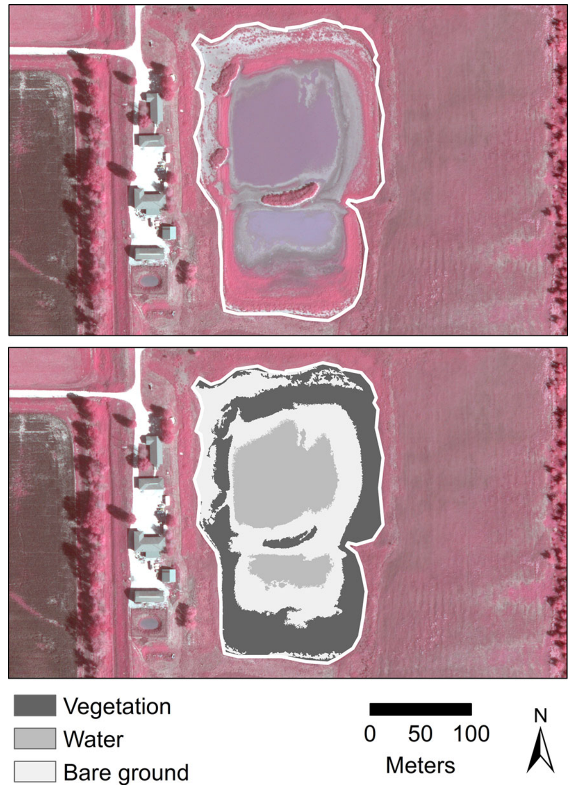

Fig. 1 Color infrared photograph (0.2-m ground sample distance) (*upper*) and cover map (*lower*) of "Display Pond" at Clarence Cannon National Wildlife Refuge, Missouri. Photograph provided by the U.S. Fish and Wildlife Service

in the cover type assessment can be found in Online Resource 3.

Data collection

On 12–13 September 2012, a single observer visually estimated percent canopy cover for annual vegetation, perennial vegetation, bare ground, and water from the perimeter at each of 41 wetlands located across the three refuges. Percent cover was based on total wetland area, and cover estimates summed to 100 % across cover types. Cover estimates were made at one or more perimeter vantage points that permitted ≥70 % of the wetland to be viewed.

We created cover type maps (Fig. 1) using image processing and analysis procedures in ArcMap 10.0 (ESRI, Redlands, California), a geographic information system. We based maps on TIF files derived from color infrared aerial photographs taken on 12

September 2012. TIF files contained multi-spectral data at a spatial resolution of 0.2 m. We mapped cell clusters with common spectral properties by applying an Iso Cluster unsupervised classification algorithm to TIF files. We nominally associated the mapped clusters with vegetation (annual and perennial), bare ground, and open water cover types through an overlay with and visual interpretation of original TIF files. We applied a 0.02-ha minimal mapping unit (MMU) to the maps; MMU is the "smallest area of the class to be delineated on the maps" (Congalton and Green 2009). MMU application facilitated validation of the maps as we could not confidently interpret cover types for areas <0.02 ha (see below).

We assessed the accuracy of cover type maps via comparisons with reference data from original TIF files. For this work, we created a grid with 0.02-ha cells for each map and used grid cells as our unit for comparing map and reference data. To sample cells for comparisons, we considered the placement and number of cells required (Congalton and Green 2009). We established a minimal distance between cells such that cover type areas no longer showed evidence of positive spatial autocorrelation. We also ensured selected cells did not overlap areas used to associate clusters with cover types, i.e., sampled cells were independent of those used to identify clusters as vegetation, bare ground, or open water. Observing these constraints, we selected up to 150 cells for accuracy assessments. Small wetland size and the required minimal distance between cells led to fewer than 150 cells for 9 of 15 wetlands (min to max: 15 to 141 cells for the 9 wetlands).

For each selected cell, we assigned a mapped cover type class and a reference cover type class using a majority-based rule, i.e., the cover type covering the largest area within the cell. For each wetland, we report overall map accuracy as the percentage of cells where mapped and reference cover types agreed.

Data analysis

Each wetland possessed paired estimates, one from the perimeter-based assessment and one from the cover map, for up to three cover types. Only 6 units had paired estimates for all three cover types, 8 units had paired estimates for vegetation and either water or bare ground, and 1 had paired estimates only for vegetation. We focused our analysis on vegetation for two reasons: (1) it was the only cover type present in all 15 wetlands and (2) for a majority of wetlands, water or bare ground complemented vegetation cover, i.e., they were not independent of vegetation. We calculated differences between paired estimates and explored the distribution of these differences using boxplots and histograms. One wetland appeared as an outlier on the boxplot with the perimeter-based assessment providing a value 58 % higher than the cover map. After reviewing data and discussions with the field crew leader, it became apparent that free-floating *Lemna spp.* were included in the vegetation cover estimate (M. Hanan, pers. comm.). As *Lemna spp.* cover could not be distinguished on TIF files and was absent from the cover type map, we excluded the wetland from further analyses. For remaining wetlands, differences were normally distributed, so we used a paired t test for statistical comparisons. We used a Spearman rank-order correlation test to examine the association between protocol differences and wetland size. All analyses were carried out in the R programming environment (R Development Core Team 2012).

Results

Plant community composition and height

We completed surveys for perimeter- and plot-based protocols at 44 wetlands. These sampling units were distributed as follows: 13 in Illinois/Missouri, 5 in Minnesota, 2 in North Carolina, 14 in New Jersey, 7 in New York, and 3 in South Carolina. Median times required to complete the perimeter- and plot-based protocols were 15 min (5–43 min) and 3.8 h (1.9–16.5 h), respectively. For the perimeter-based protocol, median percent of the wetland visible from perimeter vantage points was 100 % (70–100 %).

With the plot-based protocol as a reference, observers using the perimeter-based protocol significantly overestimated the percent cover of annuals ($t_{40} = 3.3$, $p < 0.01$) by an average of 8.1 % (95 % CI 3.1, 13.0 %) and significantly underestimated the percent cover of perennials ($t_{40} = -3.8$, $p < 0.01$) by an average of 9.1 % (−14.1, −4.2 %; Fig. 2; Table 2). With an average difference of 1.1 % (−1.2, 3.4 %), the two protocols did not significantly differ

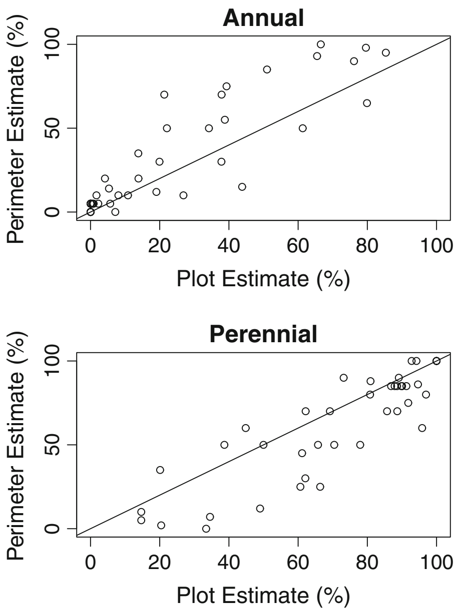

Fig. 2 Relationships between perimeter- and plot-based estimates for percent cover of annual (*upper*) and perennial (*lower*) vegetation (n = 41 wetlands). One-to-one lines are included for ease of interpretation

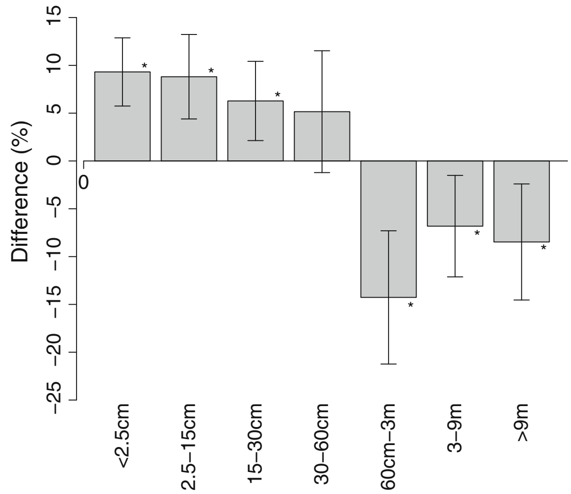

Fig. 3 Average differences between perimeter-based and plot-based percent cover estimates for seven vegetation height categories. Difference calculated as perimeter-based estimate minus plot-based estimate. Paired perimeter- and plot-based estimates were produced for 39 wetlands. *Error bars* represent 95 % confidence intervals. Differences marked by an *asterisk* differed significantly from zero (paired t-test, sequential Bonferroni procedure with familywise error rate equal to 0.10)

with respect to percent of residual vegetation ($t_{40} = 0.9$, $p = 0.35$).

In comparison to the plot-based protocol, the perimeter-based protocol on average resulted in overestimates of percent cover for short, and underestimates for tall, vegetation height classes (Fig. 3; Table 1). Estimates for the two protocols differed significantly for vegetation height class 1 ($t_{38} = 5.1$, $p < 0.001$), class 2 ($t_{38} = 3.9$, $p < 0.001$), class 3 ($t_{38} = 3.0$, $p < 0.01$), class 5 ($t_{38} = -4.0$, $p < 0.001$), class 6 ($t_{38} = -2.5$, $p < 0.02$), and class 7 ($t_{38} = -2.7$, $p < 0.01$). With sequential Bonferroni corrections applied, the difference was not significant for class 4 ($t_{38} = 1.6$, $p = 0.12$).

With respect to plant types, observer identity affected the average difference between protocols for annuals ($F_{3,14.8} = 6.3$, $p < 0.01$) and perennials ($F_{3,13.8} = 6.7$, $p < 0.01$; Fig. 4), but not for residual vegetation ($F_{3,12.6} = 1.5$, $p = 0.27$). On average for annuals, the perimeter-based estimate from observer 4 was lower than the plot-based estimate, and this observer differed significantly from observers 1 and 2 who both overestimated annuals from the perimeter. This result was inverted for perennials; observer 4 overestimated perennials from the perimeter and differed significantly from observers 1 and 2 who both underestimated perennials from the perimeter. No other pairwise comparisons between observers were significant for either annual or perennial percent covers.

Observer effects were present for height class 1 ($F_{2,12.2} = 4.5$, $p < 0.05$), class 4 ($F_{2,18.1} = 15.1$,

Table 2 Median percent cover (and interquartile range) for plant types assessed using perimeter- and plot-based protocols (n = 41 wetlands)

Protocol	Plant type		
	Annual (%)	Perennial (%)	Residual (%)
Perimeter-based	14.0 (5.0, 55.0)	70.0 (45.0, 85.0)	0 (0, 10.0)
Plot-based	13.8 (0.7, 38.8)	80.0 (60.7, 90.0)	0 (0, 9.6)

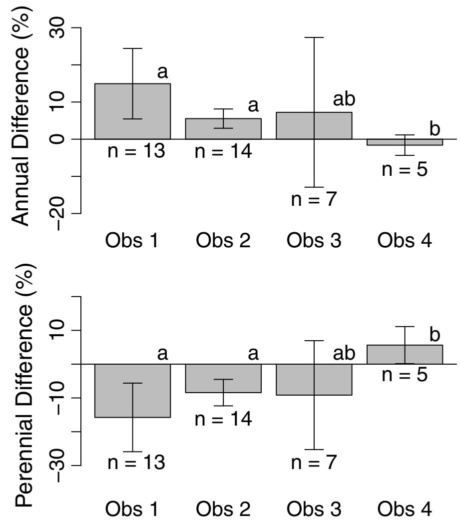

Fig. 4 Average difference between perimeter- and plot-based estimates for percent covers of annual (*upper*) and perennial (*lower*) vegetation across observers (Obs). Difference calculated as perimeter-based estimate minus plot-based estimate. *Error bars* represent 95 % confidence intervals. Observers with *different letters* were significantly different (Games-Howell pairwise comparisons, familywise type I error rate equal to 0.10)

$p < 0.01$), and class 6 ($F_{2,12.5} = 67.9$, $p < 0.01$; Fig. 5). All three observers overestimated percent cover for height class 1, but overestimates for observer 3 were greater than for observer 2. For height class 4, significant differences occurred between perimeter underestimates of observer 1 and the overestimates of observers 2 and 3. Observer 3 overestimated height class 6 and differed significantly from observers 1 and 2 who over and underestimated the class, respectively. There was no observer effect for height classes 2 ($F_{2,13.2} = 2.6$, $p = 0.11$), 3 ($F_{2,18.3} = 1.4$, $p = 0.27$), or 5 ($F_{2,17.3} = 1.5$, $p = 0.26$).

Wetland area did not affect the difference between protocols for plant types or height classes (Table 3).

Cover types

Overall map accuracy for cover type maps averaged 93 % (82–100 %). Perimeter-based estimates of emergent vegetation cover underestimated those from cover maps by an average of 4.7 % (95 % CI −10.9; 1.5 %), but this difference did not differ from 0

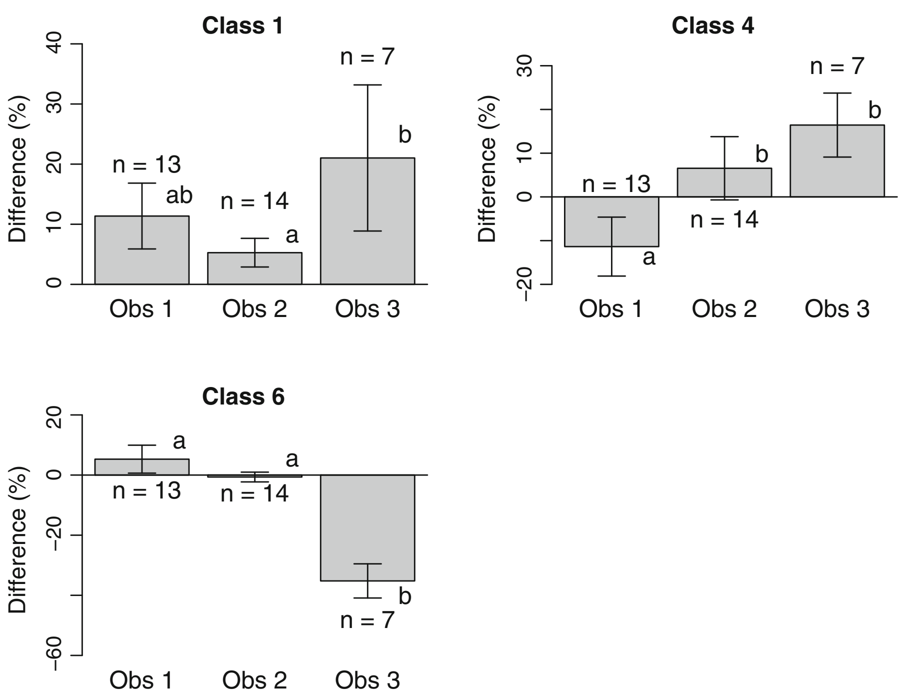

Fig. 5 Average differences between perimeter- and plot-based percent cover estimates for vegetation height classes across observers (Obs). Difference calculated as perimeter-based estimate minus plot-based estimate. Averages for three height classes, <2.5 cm (class 1), 30 to 60 cm (class 4), and 3 to 9 m (class 6), are shown. *Error bars* represent 95 % confidence intervals. Observers with *different letters* were significantly different (Games-Howell pairwise comparisons, familywise type I error rate equal to 0.10)

Table 3 Results of Spearman rank-order correlations evaluating the association of differences between perimeter-based and plot-based protocols and wetland area

Metric	r_s	df	p value
Annuals	0.09	39	0.58
Perennials	−0.11	39	0.50
Residual vegetation	0.22	39	0.17
Height class 1	0.01	37	0.94
Height class 2	−0.22	37	0.18
Height class 3	0.19	37	0.25
Height class 4	0.08	37	0.62
Height class 5	−0.23	37	0.16
Height class 6	0.11	37	0.49
Height class 7	0.11	37	0.50

($t_{13} = -1.6$, $p = 0.13$). Wetland size was unrelated to the difference between protocols ($r_s = -0.11$, df $= 12$, $p = 0.70$).

Discussion

For large-scale waterbird monitoring efforts, habitat monitoring techniques must be logistically feasible for observers and must produce estimates with sufficient precision and accuracy for their intended inferential purpose. Through comparisons with estimates from more intensive protocols, we evaluated the potential bias of perimeter-based cover estimates for plant types, vegetation height classes, and cover types. We identified differences for annuals, perennials, and 6 of 7 height classes, but on average, most perimeter-based estimates were within ±10 % of estimates from plot-based sub-samples or classified cover maps. We acknowledge that the bias of perimeter-based estimates may differ for wetlands in other regions or during other periods of the year. Our study indicates that perimeter-based monitoring can be used to assess vegetation characteristics of waterbird habitat and to inform wetland management.

Our results provide quantitative context for evaluating the use of perimeter-based estimates to inform management planning or to evaluate the outcome of management actions already implemented (Lyons et al. 2008). For example, wetland managers may establish a threshold in exotic, invasive plant cover above which they employ techniques to reduce invasive cover and to restore cover of desirable plants. In this situation, confidence in the use of perimeter-based monitoring of invasive plant cover depends on the placement of the threshold. With measurement errors within ±10 %, perimeter-based assessments would be suitable if the threshold was set at, say, 40–70 % cover of desirable plants, but such assessments would not be appropriate if the threshold was set at 10 %. In the latter case, the relative magnitudes of measurement error and threshold make it more likely that required management actions will be delayed and the cost of management increased as a result of increased invasive plant cover (Rejmánek and Pitcairn 2002). Therefore, while perimeter-based assessments are likely to be useful in many management scenarios, their use needs to be critically evaluated as is true with any habitat assessment technique (Block et al. 1987; Meese and Tomich 1992; Etchberger and Krausman 1997).

Wetlands in "hemi-marsh" conditions (Weller 1999) possibly provide greater waterbird habitat diversity, more food resources, and reduced antagonistic-conspecific interactions (Voights 1976; Smith et al. 2004). Consequently, reliable monitoring of hemi-marsh conditions is useful to wetland managers. We found that our rapid, perimeter-based estimates of vegetation cover did not differ statistically from estimates derived from cover maps. Because mapped cover for all but three units exceeded 70 %, future research should investigate whether these results apply to units with less vegetation cover. Kennedy and Addison (1987) provided some evidence that measurement errors may be larger for low cover values (but see Sykes et al. 1983). Additionally, Klimeš (2003) questioned the reliability and repeatability of visual cover estimates, which are influenced by many factors, including plot size and plant morphology (Kennedy and Addison 1987; Klimeš 2003). Logistic constraints prevented us from assessing the repeatability of perimeter-based assessments for vegetation cover, so additional work is needed under a wider range of cover conditions.

The perimeter-based protocol offered advantages in the field over the plot-based protocol. The median time required to complete the perimeter-based protocol was 15 min against 3.8 h for the plot-based protocol. The decreased time required in the field would allow for a greater sample size of wetlands in studies of management effects, increasing precision of parameter estimates and power of statistical tests. Concerns about research activities disturbing vegetation and nesting birds (Lenington 1979; Riffell et al. 1996) would be alleviated to a degree because perimeter-based protocols do not involve direct physical entry into wetlands. Some wetlands are difficult to access and may be included in a study only if perimeter-based methods are employed. Finally, travel through a wetland is strenuous and presents several physical dangers that could be avoided via monitoring from the wetland perimeter.

The nature of observed errors when assessing plant types and vegetation height suggests ways to improve perimeter-based methods. For example, overestimates of annuals and underestimates of perennials suggest that perennials may be mistaken for annuals at a distance. Training for observers should couple hands-on identification of species in the field with visual recognition of monospecific stands from a distance. In addition, we found that perimeter-based methods overestimated percent cover of short vegetation and underestimated percent cover of tall vegetation. An observer with a low vantage point may be unable to see across and perceive the extent of tall vegetation patches, leading to underestimates of tall vegetation and overestimates for short vegetation patches. Thus, the importance of elevated vantage points whenever possible should be stressed in perimeter-based protocols. Additionally, reference gauges placed in the wetland during training could help to improve observer ability to assess vegetation height.

We found preliminary evidence that observer identity affected the magnitude of errors for perimeter-based assessments of plant types (annual vs. perennial) and vegetation height. Prior to the study, all observers received standardized, internet-based training providing an overview of study objectives, study design, and field data collection methods. It is not uncommon for volunteer-based ecological monitoring programs to employ internet-based training methods, and it is an open question as to whether field-based training would lead to higher quality data (Dickinson et al. 2010). Observers varied in their previous experience visually estimating cover for plant types and vegetation height classes, but level of experience did not appear to be related to level of concordance. A small sample size and other uncontrolled regional factors (e.g., wetland type) may have contributed to observed differences in concordance across observers. Consequently, future studies should directly evaluate effects of observer identity on the accuracy and precision of habitat estimates (e.g., Block et al. 1987) and should evaluate training alternatives that are logistically feasible for a large-scale monitoring program.

There is wide recognition that stabilizing and growing waterbird populations will partly depend on monitoring and managing habitats to meet the needs of waterbirds throughout their annual cycles (Brown et al. 2001; Kushlan et al. 2002). Our data can be used to inform tradeoff evaluations among perimeter-based and other assessment techniques when establishing waterbird monitoring programs. Our results show that simple habitat assessments, which allow for greater sample sizes and increased survey efficiency, need not compromise data accuracy.

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