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Considerations for Monitoring Breeding Birds in Great Lakes Coastal Wetlands

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ABSTRACT. *One goal in indicator development is to implement long-term monitoring that will track the relative condition of the indicator over time. Among the first steps in establishing a monitoring program is to develop a sampling design that adequately characterizes the indicator to be monitored as well as the cost-effectiveness of the program. We used breeding bird data collected in Lake Superior and Lake Michigan coastal wetlands (riverine, lacustrine, barrier-protected) to determine: 1) how to select individual wetlands for sampling, 2) optimum number of sample points per wetland, 3) optimal daily sampling period, 4) how many times to sample, and 5) the costs associated with implementing a monitoring program for breeding bird communities of wetlands across the Great Lakes. We found that wetlands selected for sampling should represent the range of wetlands sizes available for monitoring and that the most cost-effective strategy would be to sample a maximum of three points, even in the largest wetlands. Because surveys conducted in the morning recorded a much higher ($P < 0.001$) number of species and individuals, we recommend that morning surveys should be conducted. Increasing number of wetlands sampled should be the first priority because sample precision is more improved at a higher cost ratio than by adding counts to the same wetland. Multiple visits to wetlands should be considered only after maximizing the number of individual wetlands visited with money available for surveys. We calculated that the average costs would be approximately 50.00 USD/year (2001 dollars) to monitor one wetland using one morning survey for breeding birds.*

INDEX WORDS: *Wetland, birds, indicator, monitoring, design, cost.*

INTRODUCTION

Breeding birds have long been used as indicators of environmental condition in many ecosystem types across North America (Morrison 1986, Niemi and McDonald 2004). For the past decade, bird and amphibian community metrics (species richness and numbers of individuals) have been used as indicators of condition of the Great Lakes, especially wetland ecosystems (Weeber and Vallianatos 2000, Crewe and Timmermans 2005). However, compared with many aquatic taxa, wetland birds have not been used extensively for development of indicators of biotic integrity (IBIs) (DeLuca *et al.* 2004). Recently, two wetland bird IBIs have been

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developed independently for evaluating current condition and monitoring future condition of Great Lakes wetlands (Howe *et al.* 2007, Crewe and Timmermans 2005). Both indices use breeding bird community data from wetlands to create an IBI that is used to estimate and track the ecological wetland condition. A comparison of the two wetland IBIs is provided by Howe *et al.* (2007).

A marsh bird monitoring task group has provided information to help design monitoring programs for marsh birds and this information can be used as a first step in planning a Great Lakes marsh bird monitoring program (Ribic *et al.* 1999). The purpose of this paper is to address issues that should be considered in the design and implementation of a marsh bird monitoring program that will collect survey data to be used in either a quantitative IBI or to track relative abundance of certain species over time. We address five key questions that will help managers design a marsh bird-based biomonitoring program specific to Great Lakes coastal wetlands: 1) How should wetlands and samples within wetlands be selected in terms of wetland size? 2) How many sample points should be surveyed in large wetlands? 3) When should surveys be conducted (morning or evening)? 4) How many times should a given wetland be visited? 5) What is the expected cost associated with implementing a monitoring program for a wetland bird indicator across the Great Lakes?

METHODS

Study Area

We carried out a pilot study of breeding birds in 2001 using 24 points in 20 wetlands in southwestern Lake Superior and 129 points in 14 wetlands in western Lake Michigan. Wetlands surveyed were a subset of wetlands that were surveyed in 2002 and 2003 across the Great Lakes and data from these sites were used to develop the wetland bird IBI (Howe *et al.* 2007). Wetlands surveyed were from one to several hundred ha in area and number of survey points ranged from one to 26 points per sites, depending on the wetland area (see Hanowski *et al.* 2007 for a description of wetland types sampled).

Bird Surveys

The sampling methodology used for this study was designed to answer specific questions that would allow us to recommend a design for the most cost-effective wetland bird monitoring program in the Great Lakes. We used the protocol established and being tested by a marsh monitoring workshop (Ribic *et al.* 1999) for wetland breeding bird surveys and conducted surveys during June through early July 2001. Surveys were done by trained observers (Hanowski and Niemi 1995), between 0500 and 0930 (morning surveys) or between 1830 and 2100 CDST (evening surveys), and on days with no precipitation and winds below 18 kph. Half-circle sample points at least 250 m apart were placed in each wetland depending on size. Each point was sampled with an initial 5 minute passive count, followed by a tape playback of least bittern (*Ixobrychus exilis*), Virginia rail (*Rallus limicola*), sora (*Porzana carolima*), common moorhen (*Gallinula chloropus*), and pied-billed grebe (*Podilymbus podiceps*), followed by an additional 5 minute passive listening. The audio tape was made by the Cornell Laboratory of Ornithology and all observers used the same tape and a playback recorder of similar wattage to control for volume output. Data were entered into an Access database and double-entered to assure accuracy.

Points were sampled from one to six times during summer 2001. Most points were surveyed three times, with two morning and one evening survey. In total, breeding bird survey data were collected on 72 morning and 46 evening point counts for Lake Superior and on 236 morning and 100 evening counts for Lake Michigan. When possible, morning and evening surveys were collected on the same date to control for seasonal variation in bird activity. See Howe *et al.* (2007 this issue) for a map of the study sites.

We used one-way mixed-model analysis of variance (SAS Institute 2002) to test for differences in morning versus evening surveys with four dependent variables: species richness, total number of individuals, wetland-dependent (see Table 1) species richness, and wetland-dependent total number of individuals. All four dependent variables were calculated per survey and were transformed with ln (count + 1) to help satisfy assumptions of normality and equal variance. Wetlands and points within wetlands were considered random effects because they were sampled from the larger population of wetlands and points in the coastal region. Tests were carried out separately for Lake Superior and Lake Michigan surveys.

We assessed sample variability for one and two morning surveys by calculating coefficient of variation (CV) for individual species using data from 33 wetlands. For the two-morning surveys, the maximum count was used as the response variable for each species. Because there were unequal numbers of morning and evening samples and points within wetlands, we did permutations on these data. Each permutation contained 33 wetlands and 66 total points (the fact that 66 is a multiple of 33 in this case is a pure coincidence). Thus, a CV was computed for each permutation and the mean of these across the 100 permutations is reported. The CV estimates the site-to-site variability for the pilot season, with different numbers of points for different sized wetlands (from one for small sites to a maximum of three for large sites).

Sampling Efficiency

Great Lakes coastal wetlands vary in size and could be sampled with one or more points. Our goal was to calculate the optimum number of samples that should be collected in the largest wetlands and how to select wetlands for sampling based on this size differential. This information would allow us to recommend the most cost-efficient sampling strategy for a monitoring program in this region. For these analyses we assumed that there is a fixed amount of money to conduct the bird surveys and that we are interested in sampling birds among wetlands with different areas with (A_i) denoting the area of the ith wetland. We plan to sample in n_w wetlands and pick n_i sites within ith wetland for a total of $n_{sites.}$sites overall. The total cost of the monitoring is taken to be $n_w\ C_w + n_{sites}\ C_s$ where C_w is the cost of adding an additional wetland and C_s is the cost of each additional wetland site.

The optimal number of sites within a wetland depends only on the relative costs C_w/C_s. For sampling in our region the relative cost was estimated to be $C_w/C_s = 2.5$. Our cost ratio of 2.5 (it would cost 2.5 times as much to visit another wetland than to conduct another survey in the same wetland) was determined by keeping track of time to complete each survey (converted to effort in terms of salary), and average time and miles (converted to cost) to visit another wetland. In the next step we explored two possible sampling schemes. The first was to consider a simple random sample of all wetlands and then to choose the number of sites within a wetland proportional to wetland size. We call this the SRS sampling scheme, denoting a simple random sample of wetlands. The second considered was to choose wetlands with probabilities proportional to wetland size and then to choose a fixed number of sites within each wetland. We call this the PPS sampling scheme for sampling wetlands proportional to size. We assumed that variances of the measured variables are the same in all wetlands and that measured variables do not depend on wetland area.

Let σ_B^2 be the variance between wetlands, the variance of true wetland means. Let σ^2 be the variance within a wetland. The corresponding correlation between samples in the same wetland is given by

$$\frac{\sigma_B^2}{\sigma_B^2+\sigma^2}.$$

The relative merits of sampling schemes for wetlands or sampling clusters of unequal size are covered in section 9A.5 of Cochran (1977). Advantages of the PPS method results were first developed by Hansen and Hurwitz (1943). Here, we give formulas written in terms of $\bar{A}$, the average wetland area and CV_{Area}, the coefficient of variation of the wetland areas for the case where both means and variances of individual measurements do not depend on wetland area. For each sampling scheme we give the optimal number of samples that should be collected per wetland. For the SRS sampling scheme the optimal number of sites per wetland is

$$n_i=\frac{A_i}{\bar{A}}\sqrt{\frac{1}{1+CV_{Area}^2}}\sqrt{\frac{C_W\sigma^2}{C_S\sigma_B^2}}$$

where $\bar{A}$ is the average wetland area. The resulting variance of the estimated mean value is

$$\begin{gathered} C_w\left(1+CV_{Area}^2\right)\sigma_B^2+C_s n\sqrt{1+CV_{Area}^2} \\ \sigma_B^2+C_w\sqrt{1+CV_{Area}^2}\,\frac{\sigma^2}{n}+C_S\sigma^2 \end{gathered}$$

For the PPS sampling scheme the optimal number of sites per wetland is

$$n_i=\sqrt{\frac{C_W\sigma^2}{C_S\sigma_B^2}}$$

and the resulting variance of the estimated mean value is

$$C_w\sigma_B^2+C_s n\sigma_B^2+C_w\frac{\sigma^2}{n}+C_S\sigma^2$$

The optimal number of samples per wetland is the usual optimal allocation formula in nested ANOVA, e.g., in Sokal and Rohlf (1994).

TABLE 1. Frequency of occurrence on AM vs. PM counts and mean abundance (with coefficient of variation, CV) on one AM vs. two AM counts for bird species observed on more than five occasions in Lake Michigan and Lake Superior in 2001. Asterisks indicate wetland-dependent species. Values for frequency of occurrence, mean abundance, and CV were computed from bootstrap permutations of the raw data to account for unbalanced sampling effort (see METHODS).

			Proportion of observations		Mean abundance			
Common name	Scientific name	*n*[1]	AM	PM	One AM count	CV	Two AM counts	CV
Red-winged Blackbird	*Agelaius phoeniceus*	1441	0.50	0.50	3.11	81	5.38	94
Swamp Sparrow*	*Melospiza georgiana*	613	0.57	0.43	1.14	103	2.00	84
Common Yellowthroat	*Geothlypis trichas*	569	0.58	0.42	1.28	61	2.08	53
Tree Swallow	*Tachycineta bicolor*	526	0.49	0.51	0.91	176	2.47	154
Song Sparrow	*Melospiza melodia*	315	0.56	0.44	0.59	124	1.25	100
Yellow Warbler	*Dendroica petechia*	300	0.60	0.40	0.67	110	1.37	85
Sedge Wren*	*Cistothorus platensis*	257	0.67	0.33	0.64	127	1.35	101
Cliff Swallow	*Petrochelidon pyrrhonota*	256	0.77	0.23	1.83	368	2.70	311
Common Grackle	*Quiscalus quiscula*	220	0.69	0.31	1.09	529	1.89	491
Barn Swallow	*Hirundo rustica*	175	0.41	0.59	0.20	265	0.82	212
American Goldfinch	*Carduelis tristis*	173	0.51	0.49	0.27	209	0.82	137
Marsh Wren*	*Cistothorus palustris*	133	0.64	0.36	0.24	345	0.55	267
Canada Goose*	*Branta canadensis*	102	0.27	0.73	0.07	516	0.31	468
Gray Catbird	*Dumetella carolinensis*	101	0.59	0.41	0.18	196	0.52	135
Mallard*	*Anas platyrhynchos*	88	0.42	0.58	0.16	311	0.59	280
American Robin	*Turdus migratorius*	84	0.38	0.62	0.09	287	0.31	182
Northern Cardinal	*Cardinalis cardinalis*	65	0.66	0.34	0.07	303	0.28	239
Cedar Waxwing	*Bombycilla cedrorum*	63	0.23	0.77	0.06	400	0.19	282
Black-capped Chickadee	*Poecile atricapillus*	58	0.62	0.38	0.10	278	0.33	191
Bank Swallow	*Riparia riparia*	58	0.43	0.57	0.04	518	0.18	491
Willow Flycatcher*	*Empidonax traillii*	57	0.84	0.16	0.08	313	0.32	248
American Redstart	*Setophaga ruticilla*	55	0.54	0.46	0.25	195	0.53	140
Wood Duck*	*Aix sponsa*	53	0.44	0.56	0.04	574	0.21	574
House Wren	*Troglodytes aedon*	41	0.86	0.14	0.08	380	0.30	304
Alder Flycatcher*	*Empidonax alnorum*	38	0.90	0.10	0.17	214	0.41	170
Veery	*Catharus fuscescens*	37	0.64	0.36	0.04	439	0.14	344
Mourning Dove	*Zenaida macroura*	36	0.47	0.53	0.04	360	0.13	263
American Crow	*Corvus brachyrhynchos*	34	0.75	0.25	0.05	387	0.18	309
Eastern Kingbird	*Tyrannus tyrannus*	31	0.47	0.53	0.06	401	0.19	322
Sandhill Crane*	*Grus canadensis*	28	0.49	0.51	0.03	553	0.16	517
Indigo Bunting	*Passerina cyanea*	27	0.29	0.71	0.01	528	0.06	458
Brown-headed Cowbird	*Molothrus ater*	26	1	0	0.05	365	0.23	277
Warbling Vireo	*Vireo gilvus*	26	0.65	0.35	0.06	344	0.19	234
Sora*	*Porzana carolina*	26	0.60	0.40	0.16	391	0.25	326
Purple Martin	*Progne subis*	24	0.33	0.67	0.02	497	0.08	417
Chimney Swift	*Chaetura pelagica*	21	0.61	0.39	0.03	455	0.19	366
Blue Jay	*Cyanocitta cristata*	20	0.89	0.11	0.06	373	0.17	290
Red-eyed Vireo	*Vireo olivaceus*	20	0.75	0.25	0.08	350	0.16	241
Downy Woodpecker	*Picoides pubescens*	19	0.76	0.24	0.04	433	0.15	313
Great Crested Flycatcher	*Myiarchus crinitus*	19	0.54	0.46	0.02	438	0.11	312
Northern Flicker (Yellow-shafted)	*Colaptes auratus*	18	0.52	0.48	0.02	458	0.08	352
Baltimore Oriole	*Icterus galbula*	18	0.46	0.54	0.02	498	0.14	425
Virginia Rail*	*Rallus limicola*	18	0.45	0.55	0.07	445	0.19	342
Green Heron*	*Butorides virescens*	17	0.85	0.15	0.03	521	0.10	437
Yellow-headed Blackbird*	*Xanthocephalus xanthocephalus*	15	1	0	0.07	574	0.12	574

TABLE 1. Continued.

			Proportion of observations		Mean abundance			
Common name	Scientific name	n[1]	AM	PM	One AM count	CV	Two AM counts	CV
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	15	0.38	0.62	0.05	513	0.14	394
Chestnut-sided Warbler	*Dendroica pensylvanica*	14	0.42	0.58	0.06	391	0.15	256
Great Blue Heron*	*Ardea herodias*	13	0.82	0.18	0.04	491	0.18	422
Wood Thrush	*Hylocichla mustelina*	13	0.37	0.63	0.01	574	0.04	574
House Finch	*Carpodacus mexicanus*	11	1	0	0.01	574	0.08	574
Black-crowned Night-Heron*	*Nycticorax nycticorax*	11	0.78	0.22	0.04	542	0.15	497
Herring Gull	*Larus argentatus*	10	0.70	0.30	0.03	550	0.14	496
Eastern Towhee	*Pipilo erythrophthalmus*	10	0.41	0.59	0.01	574	0.04	574
Black-and-white Warbler	*Mniotilta varia*	8	1	0	0.04	470	0.10	345
European Starling	*Sturnus vulgaris*	8	1	0	0.01	558	0.04	553
Clay-colored Sparrow	*Spizella pallida*	7	1	0	0.05	510	0.08	446
Ring-billed Gull	*Larus delawarensis*	7	1	0	0.05	516	0.12	426
Spotted Sandpiper	*Actitis macularia*	6	1	0	0.01	542	0.04	519
Chipping Sparrow	*Spizella passerina*	6	0.77	0.23	0.05	440	0.09	333
Least Flycatcher	*Empidonax minimus*	6	0.43	0.57	0.01	530	0.05	447

[1] n = total number of observations

RESULTS

Morning versus Evening Surveys

On average, significantly more ($P < 0.01$) individuals per survey were counted in morning counts in Lake Michigan (13.5 individuals/survey) compared with evening counts (10.6 individuals/survey) (Fig. 1). The same pattern of higher numbers of individuals and species being counted in morning versus evening surveys was also observed in counts conducted in Lake Superior; 11.4 individuals were counted in the morning versus 7.0 individuals in evening counts (Fig. 1). The average number of species recorded in morning counts in Lake Michigan was 6.5 and 4.6 species/survey in the evening counts. Numbers of species observed/survey were slightly lower in Lake Superior than in Lake Michigan but were also higher in the morning (5.6 species/survey) than in the evening (3.9 species/survey) (Fig. 1). Significantly more ($P < 0.001$) wet-

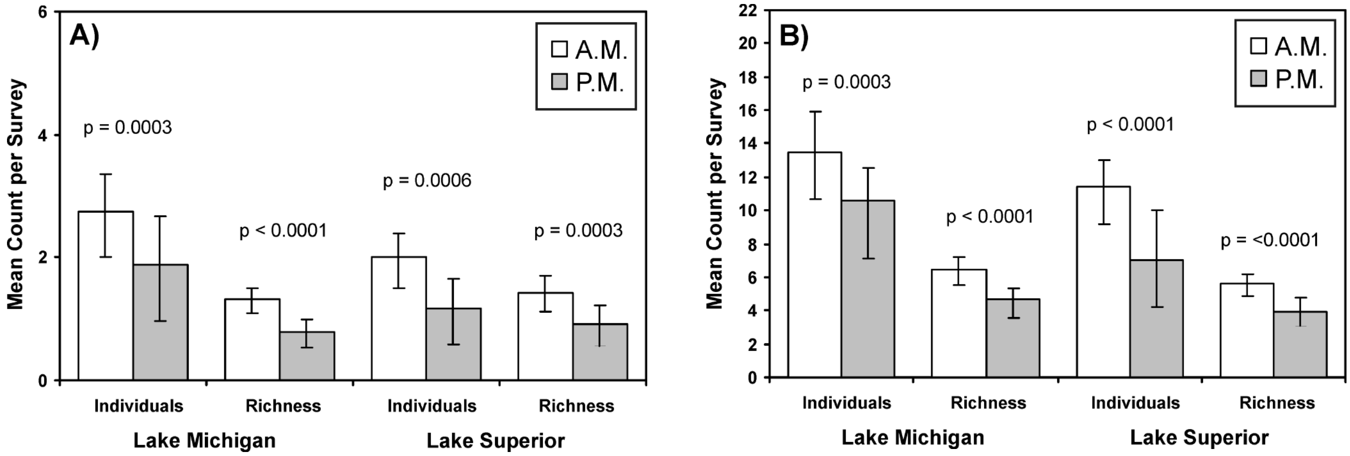

FIG. 1. Mean species richness and total number of individuals (with 95% confidence intervals) for A) wetland-dependent species and B) all species observed in AM vs. PM surveys.

TABLE 2. Standard error as percent of species abundance for common bird species calculated for three different wetland sample sizes (N = 20, 40, or 80). See Table 1 for species scientific names.

Species	Abundance/ 100 sites	SE as % of abundance N = 20	SE as % of abundance N = 40	SE as % of abundance N = 80
Common Yellowthroat	125.4	12.8	9.0	6.4
Red-winged Blackbird	200.7	21.3	15.1	10.7
Song Sparrow	68.2	21.4	15.1	10.7
Yellow Warbler	42.9	23.4	16.6	11.7
Swamp Sparrow	105.6	24.8	17.6	12.4
Tree Swallow	60.7	26.9	19.1	13.5
Barn Swallow	29.7	29.9	21.2	15.0
Gray Catbird	16.3	31.2	22.1	15.7
Sedge Wren	30.8	35.0	24.9	17.6
American Goldfinch	19.9	39.3	27.9	19.8
Marsh Wren	31.5	43.6	31.0	22.0
Willow Flycatcher	11.6	44.4	31.5	22.3

land-dependent individuals and species were also observed in morning counts than in evening counts in surveys conducted in both Lakes Michigan and Superior (Fig. 1). Species richness and total numbers of wetland-dependent birds were significantly higher ($P < 0.001$) in morning than in evening counts in both Lake Superior and Michigan (Fig. 1).

We observed 64 species on at least five occasions, 42 (64 %) of which had a higher probability of detection in morning surveys and 22 which had a higher probability of detection during evening surveys (Table 1). Nine species were only observed on morning surveys, and most wetland-dependent species were more commonly observed in morning than in evening surveys. Many species detected more often in the evening were those that do not regularly vocalize or sing (e.g., swallows and ducks) (Table 1).

One Versus Two Morning Surveys

We observed 85 species at wetland points sampled during at least two morning surveys (Table 1). Mean counts were higher and coefficients of variation for individual bird species were 20% lower for two morning samples compared to one morning sample for more abundant species (Table 1). For the most common species, the red-winged blackbird (*Agelaius phoeniceus*), CV was slightly higher with two versus one morning survey. For uncommon species (those with means < 0.3/survey), two surveys did not result in a substantial decrease in CV from one morning to two morning surveys (Table 1). For the 21 most abundant species, a doubling of sample effort (two surveys versus one) resulted in a 20% reduction in CV (Table 1).

Optimal Sample Design

We determined that the optimal sampling scheme for a Great Lakes wetland bird monitoring program is the PPS design, and that three samples/wetland is the maximum number of samples that should be placed in an individual wetland of any size. The optimal design was chosen to optimize the precision over all wetland bird species in the $\ln(\text{count} + 1)$ scale. This focused on the relative precision of each bird species with the addition of 1 to all counts, guarding against putting too much weight on attempting to achieve very good precision for uncommon species. Precision of the sample estimated abundance for 12 species and three sample sizes for the number of wetlands (n_w = 20, 40 and 80) indicated that relative precision increased linearly with sample size and bird abundance (Table 2). Precision was highest for the common yellowthroat (*Geothlypis trichas*), the second most abundant species, and lowest for the willow flycatcher (*Empidonax traillii*), the least abundant species. When effort was doubled by increasing sample size (number of wetlands sampled), precision of counts increased on average by 30% for the 12 most abundant bird species (Table 2).

Cost of Monitoring

Based on results of analyses of data collected during the pilot study we determined that the most cost-effective sample design would be to conduct one morning survey at a maximum of three points in even the largest wetlands in the Great Lakes basin. Based on time (effort converted to salary) and travel costs, we calculated that it would cost approximately $50.00/wetland (U.S. dollars in 2001) to conduct one morning survey for marsh birds in this region. This figure was based on salary and travel rates for 2001.

DISCUSSION

Our objective was to recommend a wetland bird monitoring strategy that could cost-effectively be used in Great Lakes coastal wetlands to track wetland condition using breeding birds (see Howe *et al.* 2007 this issue). We addressed five sampling issues that will help managers design a monitoring program that is specific to Great Lakes coastal wetlands. However, the methods that we used here for Great Lakes coastal wetlands can be used for any monitoring program. This information is useful because, unfortunately, few publications have addressed these questions with pilot study data prior to recommending a sampling strategy. For example, a national workshop to develop methods for marsh bird monitoring (Ribic *et al.* 1999) identified a need to develop sampling strategies for selecting individual wetland sample sites and to conduct surveys in the most cost-effective manner.

Bart (2006) recently suggested that more experience and information is required to design sampling plans for large wetlands. The approach that we used here to design our sampling scheme maximized the efficiency of counts (samples/wetland) based on cost. Our results suggest that in the Great Lakes region, the most cost-effective sampling scheme is to randomly select wetlands proportionally to wetland size, and that a maximum of three samples (counts) should be situated in the largest wetlands. The method that we used here to determine this strategy could be employed in any region, especially where wetlands are delimited. However, in areas such as some National Wildlife Refuges that are entirely comprised of wetlands, this strategy may not be appropriate.

Current marsh monitoring programs in North America use both morning and evening surveys (Conway and Timmermans 2005); however, morning surveys are prevalent among the current programs. The exception is the evening survey design used by the Marsh Monitoring Program (Weeber and Vallianatos 2000). In their current review, Conway and Timmermans (2005) suggest that both morning and evening surveys could be included in a marsh monitoring program. Our results provide support for morning surveys because more total individuals and species as well as wetland-dependent individuals and species are recorded at this time. In addition, because more information is gathered during morning surveys, counts conducted during the morning are more cost-effective.

The current national marsh monitoring protocol suggests that three annual surveys be conducted at each point (Conway 2003). Our results suggest that increasing the number of wetlands sampled should be the first priority in a monitoring design because sample precision is improved at a higher cost ratio than by adding counts to the same wetland. For example, multiple counts will lower individual species CVs by approximately 20%, but doubling sample size (number of wetlands visited) will results in a 30% increase in precision of species counts. Multiple visits to wetlands should be considered only after maximizing the number of individual wetlands visited with money available for surveys. If your study area is relatively small and monetary resources are available, sampling more than one time would increase the number of uncommon birds recorded in the survey, but uncommon species often provide limited information for development of robust biotic indicators (Howe *et al.* 2007 this volume).

The framework that we used here to calculate the most cost-effective and efficient manner to sample wetlands could be used to design a sampling program in any ecosystem type. Monetary resources available to conduct annual monitoring programs will constrain any sampling design, but considerations of these limitations should be the first step in the development of the program. In an ideal situation, a pilot study should be employed to collect preliminary data from the study area, or if available, survey data from a similar area to determine the most cost-effective survey design. Our cost ratio of 2.5 (it would cost 2.5 times as much to visit another wetland than to conduct another survey in the same wetland) was determined by tracking time to complete a survey and the average time and miles to drive to another wetland. This value would vary depending on the study area where monitoring is desired. We previously reported on cost-effectiveness and design of sampling programs for breeding bird surveys using line transects (Hanowski *et al.* 1990) and for sampling large forested areas with point counts (Hanowski and Niemi 1995). In the latter study, using the same cost equation that we used here, we found that two points was the optimum number of subsamples that should be used for sampling forest habitats. For Great Lakes wetlands, our recommendation of a maximum of three samples for the largest wetlands or fewer samples for smaller wetlands should be relevant to other wetlands in the basin.

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