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Implications of the Species-Area Relationship on Sampling Effort for Marsh Birds in Southern Ontario

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Abstract Coastal wetlands of southern Ontario are highly fragmented and exist as islands within a primarily urbanized and agricultural matrix. Given the large variation in size of remaining fragments, it is important to determine if species-area relationships exist for wetland birds, so that sampling effort can be adjusted for different sizes of wetlands and to develop appropriate size criteria for conservation. We surveyed marsh birds in 21 coastal wetlands of southern Ontario and found a positive species-area relationship (z-value=0.076), and a positive relationship between an index of biotic integrity and wetland area. Only the Marsh Wren, Swamp Sparrow, and all obligate wetland bird species combined showed area-sensitive distribution patterns. The number of points required to reveal 80% or 90% of the cumulative species richness for a given wetland varied directly with its size, indicating that sampling effort must be increased to avoid underestimating species richness in large wetlands. For example, one would need to conduct 9 point counts using 50-m radius circular plots to survey 90% of the wetland bird species in a marsh of 50 ha. We recommend conservation of coastal wetlands, regardless of size, because both small and large marshes provide habitat for high-integrity, wetland-dependent bird species.

Keywords Area-sensitive · Avian richness · Coastal wetlands · Index of biotic integrity · Index of marsh bird community integrity · Monitoring

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Introduction

Species-area relationships (SARs) are considered one of the few fundamental laws of ecology (Rosenzweig 1999). First identified empirically in plant communities (Jaccard 1912; Arrhenius 1921), this relationship has been extended to many organisms ranging from terrestrial mammals (Newmark 1986) to bacteria (Green et al. 2004; Horner-Devine et al. 2004). While many mathematical functions have been proposed to explain this relationship (Tjørve 2003; Martin and Goldenfeld 2006), the most widely accepted equation is the power curve $S = cA^z$ where S is the number of species, A is the area, and c and z are constants. An alternative form of this equation involves the log tranformation: $\log S = z \log A + \log c$ (Preston 1960). This form is often referred to as the Arrhenius equation where z represents the slope of the relationship and log *c* describes the intercept. It has been suggested that these constants have biological significance for both the organism and the environment it occupies (Martin 1981). SARs are useful tools for setting conservation priorities, as these curves may be used to predict the area needed to protect a certain level of biodiversity or predict extinction rates (Desmet and Cowling 2004; Thomas et al. 2004).

Coastal wetlands of the Laurentian Great Lakes in southern Ontario have been lost at an alarming rate over the past century with only 10% remaining in some areas (Snell 1987). The remaining coastal wetlands are highly fragmented creating islands within a primarily anthropogenic matrix. These wetlands perform important ecosystem functions such as controlling sediment and water quality, providing erosion protection, and flood attenuation. In addition to these ecosystem services, coastal wetlands provide important stopover sites for migratory birds, as well as breeding grounds for many wetland-dependent species. Identifying SARs in this region is extremely important in order to determine conservation priorities as the human population in this region continues to grow (Cohen 2003).

The North American Breeding Bird Survey shows continental-scale declines for wetland obligates (those that nest exclusively in wetlands) including the King Rail (*Rallus elegans*), American Bittern (*Botarus lentiginosis*), Black Tern (*Chlidonias niger*), American Coot (*Fulica americana*), and Common Moorhen (*Gallinula chloropus*) between 1966 and 2007 (Sauer et al. 2008). The King Rail, Yellow Rail (*Coturnicops noveboracensis*), and Least Bittern (*Ixobrychus exilis*) have been designated as species at risk and are federally listed in Canada as endangered, of special concern, and threatened, respectively (COSEWIC 2000, 2001a, b). Swamp Sparrow (*Melospiza georgiana*), Marsh Wren (*Cistothorus palustris*), Virginia Rail (*R. limicola*), and Pied-billed Grebe (*Podilymbus podiceps*) show significant population increases, while Least Bittern and Sora (*Porzana carolina*) populations are stable (Sauer et al. 2008).

SARs for birds have been established globally (Preston 1960) and for specific environments such as forest fragments (Blake and Karr 1987) and islands (Ricklefs and Lovette 1999). A significant positive relationship between species richness and wetland area has also been demonstrated for wetland birds in wet-meadow environments (Riffell et al. 2001), and in marshes (Tyser 1983; Findlay and Houlahan 1997; Paracuellos and Telleria 2004; Benassi et al. 2007; Craig 2008). The SAR has also been extended to Indices of Biotic Integrity, which are often used to indicate the quality of a wetland or other area of interest (DeLuca et al. 2004; Niemi and McDonald 2004). DeLuca et al. (2004) developed the Index of Marsh Bird Community Integrity (IMBCI) based on several life-history traits, including the migratory strategy of the species as well as its dependence on wetland habitat. They were one of the first to demonstrate the integrity-area relationship (IAR), showing a significant positive correlation between the IMBCI and wetland area for birds in Chesapeake Bay, USA.

Wetland area is not only useful as a predictor of species richness, but may also be used to determine species-specific area-sensitivity (Brown and Dinsmore 1986; Naugle et al. 1999; Riffell et al. 2001). Several species of wetland-dependent birds, including Swamp Sparrow, Pied-billed Grebe, and Black Tern, have been identified as area-dependent because they show a significant positive relationship between frequency of occurrence and marsh area (Brown and Dinsmore 1986; Naugle et al. 1999). By comparison, both the Virginia Rail and Sora exhibited area-independent trends (Brown and Dinsmore 1986). The American Coot, Marsh Wren, Least Bittern and American Bittern were identified as possibly area-dependent because they were associated with a positive though not statistically significant trend (Brown and Dinsmore 1986). However, this contrasts the finding of Tyser (1983) who found these to be the two most area-sensitive species. Such discrepancies point to the need for further studies on species-specific area-sensitivities (Riffell et al. 2001).

We found no evidence in the literature of SARs being used in wetland habitat to determine the number of samples needed to survey the bird community, despite sampling effort requirements being a principal motivation for developing SARs (Cain 1938; Connor and McCoy 1979). Hanowski et al. (2007) studied wetlands of varying sizes in order to determine optimal sampling effort for wetland bird monitoring programs. They suggested that three samples per wetland were sufficient to obtain precise estimates of species richness for wetlands of any size. The objectives of this study are three-fold. First, we will determine if a SAR, an abundance-area relationship, and an integrity-area relationship exist for wetland birds of southern Ontario. Secondly, we will investigate species-specific area-sensitivities for wetland birds, and thirdly, we will provide guidance on how SARs can be used to determine optimal sampling effort to provide accurate estimates of marsh bird communities in wetlands of different sizes.

Methods

Study Sites

We surveyed 21 coastal wetlands throughout southern Ontario between 2006 and 2008 ranging in size (Fig. 1). In 2006 and 2007 we surveyed wetlands ranging in size (4.1–5,963.6 ha) to identify a SAR for remnant wetlands in the anthropogenic matrix of southern Ontario. In 2008, we selected a subset of 11 wetlands ranging in size (3.5–63.5 ha) to examine within-wetland species-area relationships or "census patches" (Tjørve 2003), in order to use these relationships to predict effective sample sizes necessary to estimate the species richness of marsh bird communities. All wetlands were either riverine or open lacustrine coastal marshes dominated by emergent vegetation (primarily *Typha* spp.) and varied in the degree of eutrophication. The landscape of southern Ontario is dominated by agricultural and urban areas with a highly fragmented forest cover of only 11% (OMNR 2000).

We measured wetland size as the area of aquatic vegetation using the Southern Ontario Land Resources Information System (SOLRIS; OMNR 2008). SOLRIS defines a marsh as open, shrub and treed communities with a water table that is seasonally or permanently at, near, or above substrate surface with tree and shrub cover of ≤25% and dominated by emergent hydrophytic macrophytes.

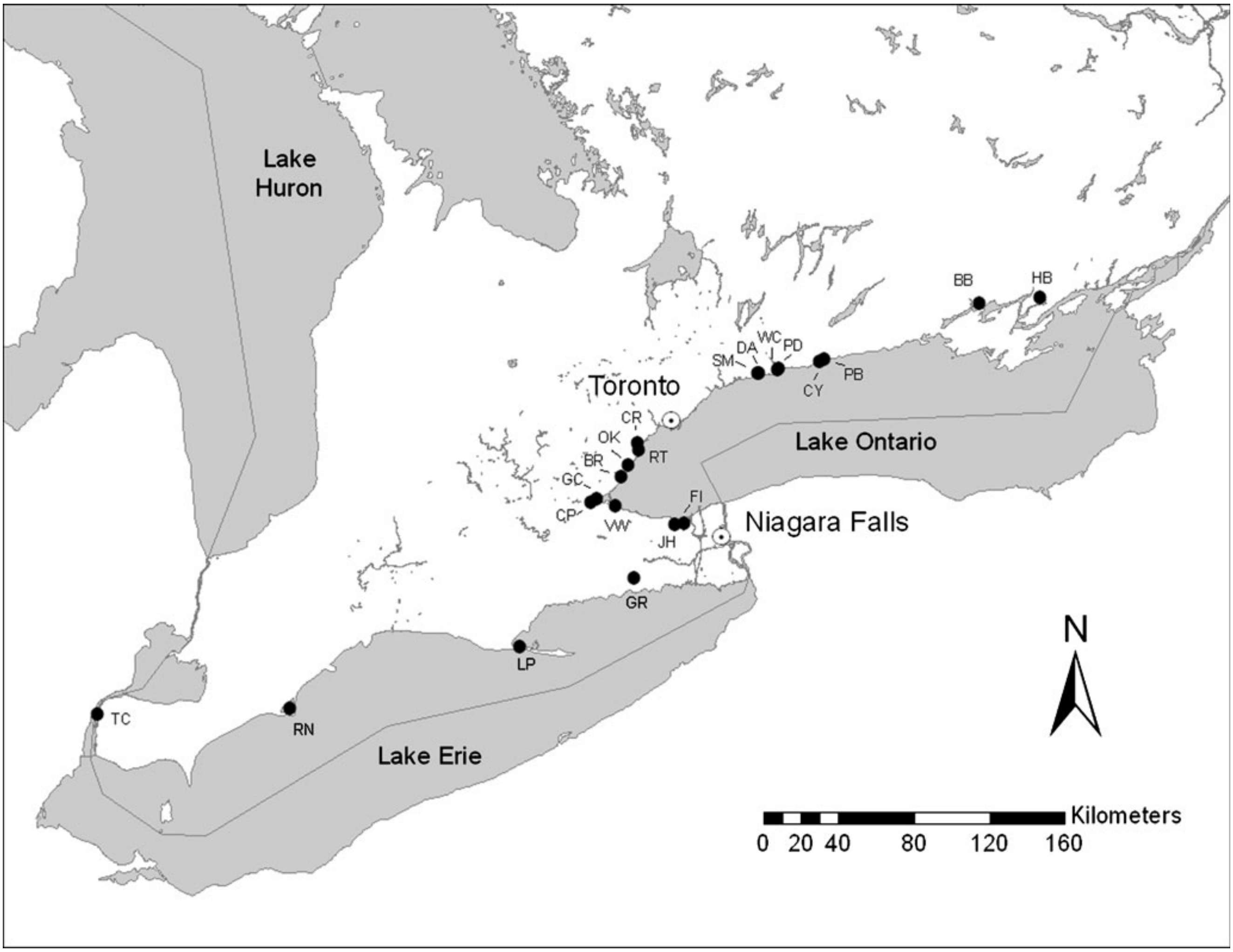

Fig. 1 A map of wetland study sites in southern Ontario surveyed between 2006 and 2008. In 2006 we surveyed Bronte Creek (BR), Credit River (CR), Grindstone Creek (GC), Cootes Paradise (CP), Grand River (GR), and Long Point (LP). In 2007 we surveyed Crysler Point (CY), Rattray Marsh (RT), Port Britain (PB), Van Wagner's Pond (VW), Turkey Creek (TC), Port Darlington (PD), Jordan Harbour (JH), Westside Creek (WC), Second Marsh (SM), Blessington Bay (BB), Hay Bay (HB), and Rondeau (RN). In 2008 we surveyed Oakville Marsh (OK), BR, RT, Darlington (DA), CR, GC, PD, Fifteen Mile Creek (FI), JH, CP, and SM

SOLRIS is a geographic information system that has delineated southern Ontario into digital polygons of varying land uses and types of natural areas using a combination of topographic maps, aerial photos, and satellite imagery from 2000–2002. We updated wetland polygons to reflect the most current size using Google Earth software with Digital Globe imagery dated between 2004 and 2007 (Google Earth 2007).

Bird Surveys

To meet our first and second objectives, we conducted point counts from a canoe between 1 May and 12 July, 2006 and 2007. Each count was conducted between sunrise and 4 h after sunrise, no surveys were conducted in high winds >20 km/h or during periods of rainfall, and each point was surveyed twice throughout the season. Point counts were 10 min in duration and a 25 m radius full circle was used.

The first sample point was located at least 25 m from the shore at the emergent vegetation-water interface closest to where the canoe was launched. We recorded all birds seen or heard regardless of sex and counted all individuals that landed, flushed, waded, perched, foraged or called within the point count area. We also counted bird species flying over the point count area but did not include these individuals in any analyses.

After a 10 min passive period, we broadcasted the calls of nine secretive species: American Coot, American Bittern, Least Bittern, Pied-billed Grebe, Sora, Virginia Rail, Common Moorhen, King Rail, and Yellow Rail in that

Table 1 Individual species scores for calculation of the Index of Marsh Bird Community Integrity (IMBCI)

Common name	Scientific name	Foraging habitat	Nesting substrate	Migratory status	Breeding range	S_{IMBCI}
American Goldfinch	*Carduelis tristis*	1	1	1	1	4
Mourning Dove	*Zenaida macroura*	1	1	1	1	4
European Starling	*Sturnus vulgaris*	1	1	1	1	4
American Robin	*Turdus migratorius*	1	1	1	1	4
Northern Cardinal	*Cardinalis cardinalis*	1	1	1	1	4
American Crow	*Corvus brachyrhynchos*	1	1	1	1	4
Herring Gull	*Larus argentatus*	1	1	1	1	4
Ring-billed Gull	*Larus delawarensis*	1	1	1	1	4
Gull spp.	*Larus* spp.	1	1	1	1	4
Black-capped Chickadee	*Poecile atricapillus*	1	1	1	1	4
Cedar Waxwing	*Bombycilla cedrorum*	1	1	1	1	4
Northern Flicker	*Colaptes auratus*	1	1	1	1	4
Blue Jay	*Cyanocitta cristata*	1	1	1	2	5
Turkey Vulture	*Cathartes aura*	1	1	2.5	1	5.5
Double-crested Cormorant	*Phalacrocorax auritus*	1	1	2.5	1	5.5
Mute Swan	*Cygnus olor*	1	2.5	1	1	5.5
Canada Goose	*Branta canadensis*	1	2.5	1	1	5.5
Song Sparrow	*Melospiza melodia*	1	2.5	1	1	5.5
Mallard	*Anas platyrhynchos*	2.5	1	1	1	5.5
Wood Duck	*Aix sponsa*	2.5	1	1	1	5.5
Duck spp.	Family: Anatidae	2.5	1	1	1	5.5
Common Grackle	*Quiscalus quiscula*	1	2.5	1	2	6.5
Eastern Phoebe	*Sayornis phoebe*	1	1	2.5	2	6.5
Chimney Swift	*Chaetura pelagica*	1	1	4	1	7
Killdeer	*Charadrius vociferus*	1	1	4	1	7
Spotted Sandpiper	*Actitis macularia*	1	1	4	1	7
Lesser Yellowlegs	*Tringa flavipes*	1	1	4	1	7
Semipalmated Plover	*Charadrius semipalmatus*	1	1	4	1	7
Tree Swallow	*Tachycineta bicolor*	1	1	4	1	7
Barn Swallow	*Hirundo rustica*	1	1	4	1	7
Purple Martin	*Progne subis*	1	1	4	1	7
Bank Swallow	*Riparia riparia*	1	1	4	1	7
Cliff Swallow	*Petrochelidon pyrrhonota*	1	1	4	1	7
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	1	1	4	1	7
Swallow spp.	Family: Hirundinidae	1	1	4	1	7
Caspian Tern	*Sterna caspia*	1	1	4	1	7
Baltimore Oriole	*Icterus galbula*	1	1	4	1	7
Belted Kingfisher	*Ceryle alcyon*	1	1	4	1	7
Yellow Warbler	*Dendroica petechia*	1	1	4	1	7
Willow Flycatcher	*Empidonax traillii*	1	1	4	1	7
Eastern Kingbird	*Tyrannus tyrannus*	1	1	4	1	7
Sedge Wren	*Cistothorus platensis*	1	2.5	2.5	1	7
Red-winged Blackbird	*Agelaius phoeniceus*	1	2.5	2.5	1	7
Common Loon	*Gavia immer*	1	2.5	2.5	1	7
Great Egret	*Ardea alba*	2.5	1	4	1	8.5
Common Moorhen	*Gallinula chloropus*	2.5	2.5	2.5	1	8.5
Common Yellowthroat	*Geothlypis trichas*	1	2.5	4	1	8.5

Table 1 (continued)

Common name	Scientific name	Foraging habitat	Nesting substrate	Migratory status	Breeding range	S_{IMBCI}
Gray Catbird	*Dumetella carolinensis*	1	2.5	4	1	8.5
Osprey	*Pandion haliaetus*	1	2.5	4	1	8.5
Common Moorhen/American Coot	*Gallinula chloropus/ Fulica americana*	2.5	3.25	2.5	1	9.25
Common Tern	*Sterna hirundo*	1	2.5	4	2	9.5
Swamp Sparrow	*Melospiza georgiana*	2.5	4	1	2	9.5
Black-crowned Night Heron	*Nycticorax nycticorax*	2.5	2.5	4	1	10
Great-blue Heron	*Ardea herodias*	2.5	2.5	4	1	10
American Coot	*Fulica americana*	2.5	4	2.5	1	10
American Bittern	*Botaurus lentiginosus*	2.5	4	4	1	11.5
Marsh Wren	*Cistothorus palustris*	4	4	4	1	13
Black Tern	*Chlidonias niger*	4	4	4	1	13
Sora	*Porzana carolina*	4	4	4	1	13
Virginia Rail	*Rallus limicola*	4	4	4	1	13
Least Bittern	*Ixobrychus exilis*	4	4	4	1	13

S_{IMBCI} represents the score for each species. Each category ranges from one to four with one representing marsh-feeding generalists, non-marsh nesters, resident species, and those distributed throughout North America. Species with a category score of four are marsh obligates, Neotropical migrants, and have a limited distribution within North America

order. Calls (70–85 dB 1 m from the source) were broadcast from speakers oriented directly into the emergent vegetation at a height of 1 m above the water surface. In the broadcast sequence, each species' call varied in duration (35 to 110 s), but each species call was separated by a 30 s pause. Call-broadcasts were played for a total of 14 min after the passive period and 2 min were left at the end of the call-broadcasts for us to listen for responses. Subsequent points were located arbitrarily by sampling locations that were at least 200 m apart in an attempt to avoid double-counting individuals. We conducted more point counts in larger wetlands in order to maintain increased sampling effort in larger marshes.

To meet our third objective, the general survey protocol remained the same except for the following modifications. We chose a subset of 11 marshes, and changed the point count radius to 50 m in order to survey each marsh in less time. We selected random point count locations prior to surveys, ensuring they were >200 m apart to minimize potential for double-counting. We also randomized the sequence in which points were surveyed to minimize bias. We only conducted one survey at each point between 12 May and 9 July in only 2008. In order to thoroughly sample large marshes, up to 15 points were needed, so we often needed multiple days to cover the full area (up to 3 days). We wanted to ensure that the species richness, abundance and the IMBCI were not changing between days, so prior to initiating this objective, we chose one wetland (Cootes Paradise) to examine temporal changes in variables. Between 5 May and 8 May 2008, we surveyed three points per day, and looked for changes in species richness, abundance, and the IMBCI.

Statistical Analysis

For the analysis of SARs at the landscape scale, we used simple linear regression after $\log_{10}$ transformation of all variables. For all regression analyses, we report adjusted R^2 values and corresponding P-values. We looked for a relationship between species richness, abundance, the IMBCI and wetland area. For species richness we used overall site presence/absence, and for abundance, we first took the average of the seasonally repeated point counts and then added these values for all the points at each marsh.

The IMBCI uses species-specific attributes including migration distance, where it nests and feeds, and its North American breeding range to assign a value for each species. We determined values for each species based on the Birds of North America online database (Poole 2005) using the scoring methods of DeLuca et al. (2004). A species associated with a high score would be a Neotropical migrant that nests and feeds only in wetlands, and has a limited breeding range in North America. A species associated with a low score would be a resident species that nests outside the wetland, occasionally feeds in wetlands, and is widely distributed throughout most of North America. Scores for individual species are shown in

Fig. 2 The relationship between wetland area and a) species richness: log y=1.0565+0.0755*log x, b) abundance: log y=1.1679+0.2402*log x, and c) W_{IMBCI}: log y=0.5025+0.1318*log x for 18 coastal wetlands of southern Ontario. Wetland area measurements before $\log_{10}$ transformation were in hectares

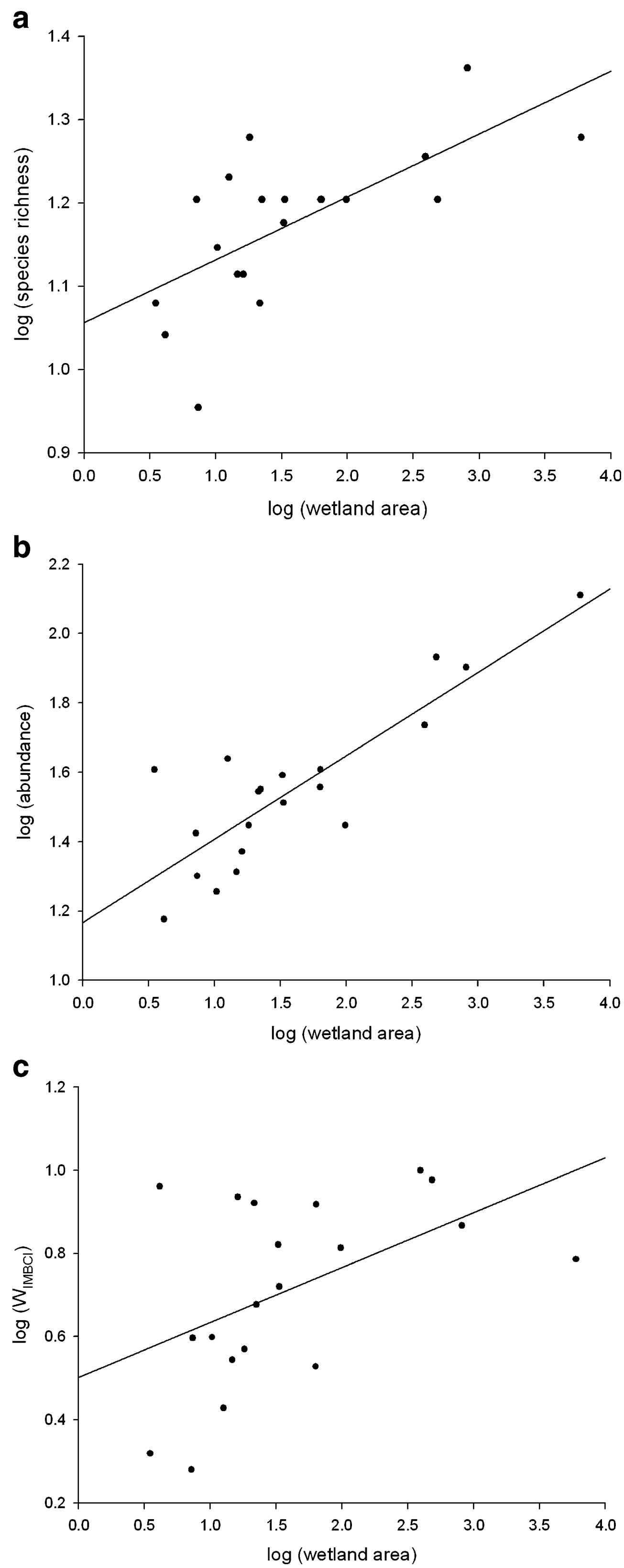

Table 1 and are produced by simply adding each life history trait. Next, a total W_{IMBCI} value can be calculated for the wetland as:

$$W_{IMBCI} = \left[\left(\frac{\sum S_{IMBCI}}{S_N}\right) + MO_N\right] - 4 \quad \text{DeLuca et al. (2004)}$$

where S_{IMBCI} is each species' individual score, S_N is the total number of species, and MO_N is the number of marsh obligate nesters detected (DeLuca et al. 2004).

We used logistic regression to examine species-specific area-sensitivity. Species were marked as either present (1) or absent (0) at a wetland, and our continuous predictor was wetland area that we $\log_{10}$-transformed. Logistic regression yields a χ^2 statistic where significance indicates that the probability of finding a certain species is dependent on the size of the wetland (Hosmer and Lemeshow 1989).

For the analysis of sampling effort, we first used a repeated measures analysis of variance to determine if surveys could be conducted over four consecutive days without any change in richness, abundance, or the IMBCI. We tested the data a priori to ensure they met the assumption of sphericity using the Mauchly sphericity test (Mauchly 1940). Each of the 11 wetlands was surveyed with more points surveyed at larger marshes. Within each wetland we determined the logarithmic relationship between the number of points and cumulative species richness. Using this function, we calculated the number of points needed to obtain 80% and 90% of the cumulative species richness at each of the 11 marshes. By surveying the entire marsh, we were assuming that the cumulative species richness after the last point count represented all the species. We next regressed the number of points needed to survey 80% and 90% of the species against wetland area to create two species-area functions.

Results

Species-area Relationships

Species richness increased significantly with wetland area (R^2=0.427, P=0.001) (Fig. 2a) and this trend was also seen for abundance (R^2=0.710, P<0.001) (Fig. 2b). We also found a significant relationship between the W_{IMBCI} and wetland area, indicating larger wetlands hold high integrity values (R^2=0.204, P=0.026) (Fig. 2c). Based on the log-

Table 2 Relationships between the presence/absence of obligate marsh-nesting bird species and wetland size

Species	Relationship	χ^2	*p*	Threshold (ha)	*n*	Consistency with previously published literature			
						Tyser (1983)	Brown and Dinsmore (1986)	Riffell et al. (2001)	Naugle et al. (1999)
Black Tern	–	1.498	0.221	–	1	✗*	✗*	–	✗*
Swamp Sparrow	Positive	8.335	0.004	11.06	13	✓	✓	✓	–
Marsh Wren	Positive	7.697	0.006	17.27	11	✓	✓	–	–
Sora	–	0.032	0.859	–	3	✓	✓	✗	–
Virginia Rail	–	0.867	0.352	–	7	✓	✓	✗	–
American Bittern	–	1.268	0.260	–	1	✗*	✗*	✗*	–
Least Bittern	–	0.139	0.709	–	4	✗	✗	–	–
Common Moorhen/ American Coot	–	1.602	0.206	–	5	–	–	–	–
All obligates combined	Positive	6.093	0.014	5.52	16	–	–	–	–

*Inconsistencies with other studies may be due to low detection rates in this study

Significant logistic regression results indicate that the probability of finding each species increases with increasing wetland area. The threshold represents the inflection point of the logistic curve and therefore the wetland size at which one would be equally likely to find or not find a certain species. Sample size (*n*) represents the number of sites (out of 18) at which each species was detected. Consistency with other literature is included where a "✓" indicates our results are consistent, and a "x" indicates our results are inconsistent with each respective paper

log relationships we obtained, we found z-values of 0.076 for species richness and 0.240 for abundance.

Area-sensitivity

Both the Swamp Sparrow and Marsh Wren were significantly more likely to be found in large wetlands than in small wetlands (Table 2). This area-sensitivity could not be demonstrated for any other species. However, this should be interpreted cautiously because of low detection rates for several species. The Black Tern and American Bittern were only found in a single wetland each, corresponding to the third (483 ha) and fourth (393 ha) largest wetland, respectively. All obligate marsh bird species combined also produced a positive relationship likely because marsh-obligate nesters were absent in smaller wetlands (Oakville; 3.49 ha, Bronte Creek; 7.18 ha, and Van Wagner's Pond; 12.60 ha).

Sampling Effort

We found no significant day-to-day variation in the species richness ($F_{3,6}$=1.277, P=0.364) (Fig. 3a), abundance ($F_{3,6}$= 1.278, P=0.364) (Fig. 3b), or W_{IMBCI} ($F_{3,6}$=1.141, P= 0.406) (Fig. 3c) values for wetland birds at Cootes Paradise. These findings show that surveying a wetland over four consecutive days (in order to survey the entire wetland) did not significantly affect the richness, abundance, or integrity values.

We used the logarithmic function to fit data for each wetland (those sampled in 2008) (Table 3). We have included a sample graph of Second Marsh to explain the calculation of the number of points needed to sample 80% or 90% of the species (Fig. 4). Based on these results, we have created two functions that can be used as an aid to determine the optimal number of points to accurately survey wetlands of different sizes in coastal wetlands of southern Ontario (Fig. 5). For example, one would need to conduct 9 point counts using 50-m radius circular plots to detect 90% of the wetland bird species in a marsh of 50 ha. It is important to note that the 80% and 90% detection levels in Fig. 5 are only meaningful relative to the conditions under which the functions in Table 3 were developed, and so this should be considered when designing any study.

Discussion

We found a significant species-area relationship for wetland birds in southern Ontario, and this is consistent with many published studies for birds in other habitats. We obtained a z-value of 0.076 for the logarea/logrichness relationship which is lower than published values in other studies of wetland birds: 0.23 (Brown and Dinsmore 1986), 0.24 (Findlay and Houlahan 1997), and 0.26 (Benassi et al. 2007). It has been suggested that these values are meaningless and merely a coincidence, but the literature shows more log/log z-values falling between 0.20 and 0.40 for all species than would be expected by chance (Connor and McCoy 1979). Even though many studies have shown similar results, there remain inconsistencies among studies

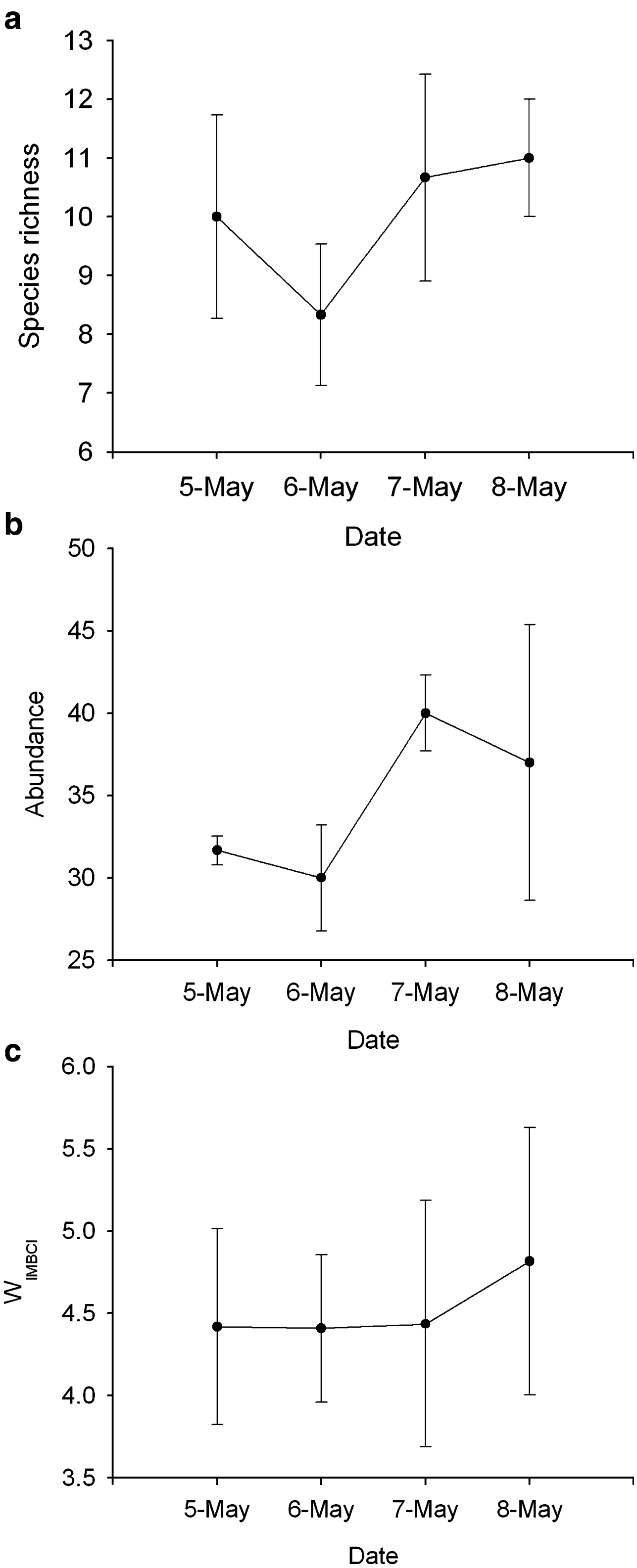

Fig. 3 The effect of sample date on **a** richness, **b** abundance, and **c** W_{IMBCI} of wetland birds taken at the same three points in a southern Ontario marsh, Cootes Paradise during 2008. Shown are means±SEs

(including this one) and caution is needed for the interpretation of z-values (Martin 1981). Studies only including a very small range of habitat sizes may yield z-values that do not accurately represent the rate of increase of species accumulation. When the larger wetlands were removed from the SAR in our study, the z-value increased, indicating potential inflation of z-values when only a small range of sizes are included (Martin 1981). We have addressed these concerns by including the full range of wetland sizes remaining in southern Ontario and by explaining our sampling methods as thoroughly as possible so that our values may be compared to other studies and used for the fundamental goal of understanding SARs.

Consistent with DeLuca et al. (2004), we found a significant positive relationship between the integrity index (IMBCI) and wetland area. Our sample size was considerably smaller than theirs (by 73 sites), but regardless, the scatter in our data (before transformation) is similar to their study. It is important to note that even though we found a significant positive relationship, some high integrity scores were found present in small wetlands (Fig. 2c). Southern Ontario wetlands truly are insular habitats, and it is likely that these remnants are habitats into which wetland-dependent species are “funnelled” due to the lack of choice.

Consistent with the literature (Table 2), we found that the Swamp Sparrow and Marsh Wren were significantly more likely to be found in larger than in smaller marshes (Tyser 1983; Brown and Dinsmore 1986; Riffell et al. 2001). Although we did not find significant area-sensitivity for other wetland-dependent species, results for the Black Tern and American Bittern should be interpreted with caution. While we detected these species only once each in a single wetland, these were the third and fourth largest wetlands, respectively, in our dataset and it is possible that there are too few marshes large enough to show area sensitivity for these species in southern Ontario.

When all marsh obligate species were combined, a significant positive relationship was produced, indicating that marsh obligate species, in general, are more likely to be detected in larger marshes. The inflection point of the logistic curve suggests that when a marsh is larger than 5.52 ha, there is a greater probability of detecting a marsh-nesting obligate than not detecting one (Table 2). These species-specific and guild-based area-sensitivities may aid in restoration efforts by setting goals for which species to expect in marshes of varying size.

Other species showing area-independence appear to reflect true patterns such as the Least Bittern, Virginia Rail and Sora that were all detected at more than three wetlands. These findings are consistent with other studies where the Sora and Virginia Rail were found in both small and large wetlands (Tyser 1983; Brown and Dinsmore 1986); however, Riffell et al. (2001) found these species to be

Table 3 The relationship between sampling effort (number of point counts) and cumulative marsh bird richness at each of 11 wetlands in southern Ontario

Wetland	Logarithmic function	R^2	*p*	*n*
Bronte Creek	s=5.08+18.98*log10(pc)	0.998	0.026	3
Oakville Marsh	s=5.99+16.75*log10(pc)	0.999	0.004	3
Rattray Marsh	s=6.10+25.30*log10(pc)	0.998	0.026	3
Darlington	s=8.75+16.39*log10(pc)	0.978	0.096	3
Grindstone Creek	s=5.08+26.07*log10(pc)	0.993	<0.0001	6
Fifteen Mile Creek	s=5.78+13.65*log10(pc)	0.934	<0.001	7
Credit River	s=8.71+14.63*log10(pc)	0.965	<0.0001	8
Port Darlington	s=8.89+16.34*log10(pc)	0.975	<0.001	6
Cootes Paradise	s=9.57+21.67*log10(pc)	0.981	<0.0001	14
Jordan Harbour	s=8.28+12.35*log10(pc)	0.976	<0.0001	11
Second Marsh	s=9.01+22.60*log10(pc)	0.983	<0.0001	15

Data were fit using logarithmic functions where s = cumulative species richness and pc = number of point counts. Shown are R^2 values, *p*-values, and *n* represents the number of point counts conducted per wetland

area sensitive. Inconsistencies remain for the Least Bittern as well, with one paper finding area sensitivity (Tyser 1983) and another showing only possible area-dependence (Brown and Dinsmore 1986).

One of the most significant findings of this study is that the number of points required to reveal 80% or 90% of the cumulative species richness for a given wetland varied directly with its size. This indicates that sampling effort must be increased when sampling large marshes to fully assess its species assemblage. We acknowledge that there is a trade-off between sampling effort within the wetland and the number of wetlands surveyed, and of course this should be taken into account when designing any monitoring program (Hanowski et al. 2007). Based on our results, we have created two functions that can be used to determine the appropriate number of point counts that should be used to estimate avian species richness in a wetland of a given size. These relationships are easy to use once the area of the wetland (in hectares) is substituted into the appropriate equation. In theory, the wetland SARs used to create this

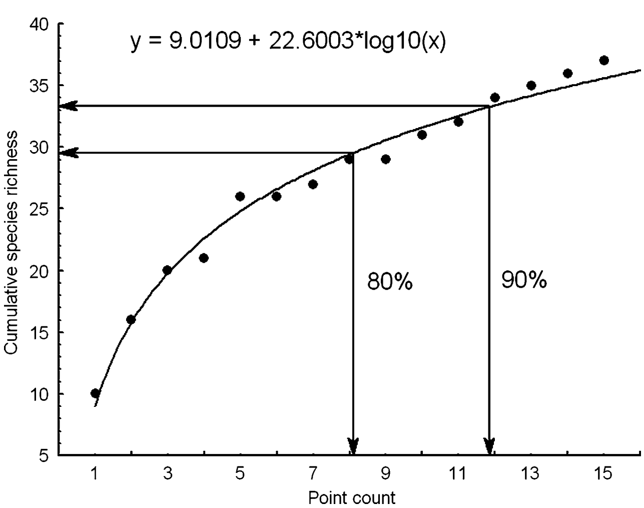

Fig. 4 Species accumulation curve with increasing number of point counts at Second Marsh, 2008. Vertical arrows represent the number of points needed to obtain 80% and 90% of the cumulative species richness calculated using the logarithmic function

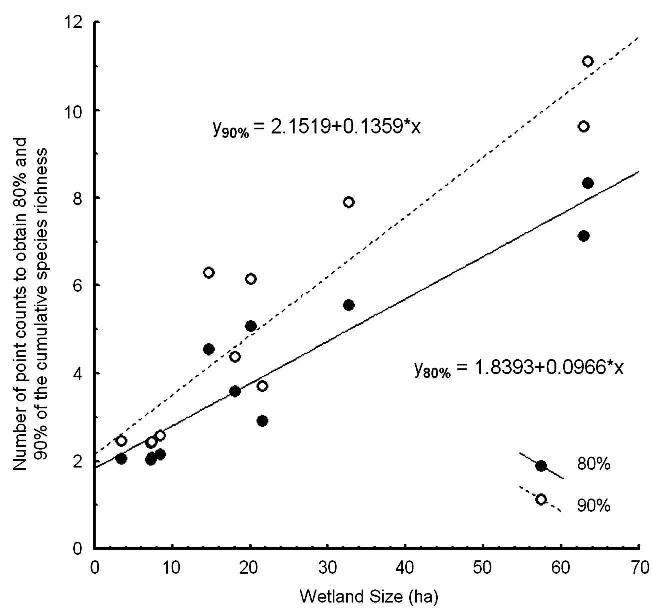

Fig. 5 The relationship between wetland size and the number of points needed to sample 80% and 90% of the cumulative marsh bird richness. The above functions may be used to determine how many point counts should be conducted at marshes of varying sizes to detect 80% and 90% of the marsh bird richness. 80%: R^2=0.859, P<0.0001; 90%: R^2=0.853, P=<0.0001

function (such as Fig. 4) should reach an asymptote. We encourage further studies to determine the applicability of these relationships outside the size range of wetlands sampled here (3.5–63.5 ha).

Even though this paper demonstrates that increased effort is required in larger marshes, we need to identify the limitations of the sampling approach. In this study, species richness for each wetland was based on the maximum of the SAR functions, which did not necessarily reach an asymptote and may therefore not represent all species. Therefore, the 80% and 90% detection levels may not represent the true 80% and 90% of all species potentially occurring in these wetlands. It is also important to note that these models should be used for studies with the goal to survey all avian species using the wetland habitat, and not those studies specialized to monitor secretive marsh birds only, where fewer species are of interest.

In conclusion, we have demonstrated the importance of both large and small wetlands as habitat for wetland birds because both contain species of high biological integrity. Small wetlands are often viewed as less important because they contain fewer species than larger wetlands, and therefore more small marshes remain unprotected (Connor and McCoy 1979; Naugle et al. 2000). The loss of small, isolated wetlands increases the distance between wetland patches and could lead to changes in metapopulation dynamics for many organisms. This could be through a reduction in gene flow, decreasing the probability of "rescue effects", and potentially leading to extirpation or extinction (Semlitsch and Bodie 1998).

Understanding SARs will be imperative in the future as humans continue to fragment natural areas into insular environments. Indices of biotic integrity are important to incorporate into SARs because they include species-specific life history traits, which are lost in the measurement of species richness. Although it is tempting to set fixed targets for habitat conservation based on SARs, this may only lead to "clearing down to target" by developers, a philosophy where once the target has been set, all other suitable habitat may be plundered (Desmet and Cowling 2004). Policy-makers must therefore recognize the growing body of scientific literature demonstrating the importance of small and large wetlands, and act accordingly in policy development.

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