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Associations between Breeding Marsh Bird Abundances and Great Lakes Hydrology

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ABSTRACT. *We used Great Lakes hydrologic data and bird monitoring data from the Great Lakes Marsh Monitoring Program from 1995–2002 to: 1) evaluate trends and patterns of annual change in May-July water levels for Lakes Ontario, Erie, and Huron-Michigan, 2) report on trends of relative abundance for birds breeding in Great Lakes coastal marshes, and 3) correlate basin-wide and lake-specific annual indices of bird abundance with Great Lakes water levels. From 1995–2002, average May, June, and July water levels in all lake basins showed some annual variation, but Lakes Erie and Huron-Michigan had identical annual fluctuation patterns and general water level declines. No trend was observed in Lake Ontario water levels over this period. Abundance for five of seven marsh birds in Lake Ontario wetlands showed no temporal trends, whereas abundance of black tern* (Chlidonias niger) *declined and that of swamp sparrow* (Melospiza georgiana) *increased from 1995–2002. In contrast, abundances of American coot* (Fulica americana)*, black tern, common moorhen* (Gallinula chloropus)*, least bittern* (Ixobrychus exilis)*, marsh wren* (Cistorthorus palustris)*, pied-billed grebe* (Podilymbus podiceps)*, sora* (Porzana carolina)*, swamp sparrow, and Virginia rail* (Rallus limicola) *declined within marshes at Lakes Erie and Huron/Michigan from 1995–2002. Annual abundances of several birds we examined showed positive correlations with annual lake level changes in non-regulated Lakes Erie and Huron/Michigan, whereas most birds we examined in Lake Ontario coastal wetlands were not correlated with suppressed water level changes of this lake. Overall, our results suggest that long-term changes and annual water level fluctuations are important abiotic factors affecting abundance of some marsh-dependent birds in Great Lakes coastal marshes. For this reason, wetland bird population monitoring initiatives should consider using methods in sampling protocols, or during data analyses, to account for temporal and spatial components of hydrologic variability that affect wetlands and their avifauna.*

INDEX WORDS: *Wetland birds, coastal marsh, Erie, Huron, Michigan, Ontario, water levels.*

INTRODUCTION

Coastal marshes of the Laurentian Great Lakes are important and sensitive habitats that support diverse faunal and floral communities. These wetlands and associated plant communities provide important breeding and migration habitat for many wetland-dependent bird species (Herdendorf 1992, Prince *et al.* 1992). Coastal marsh habitats and the wildlife these support are influenced by many different anthropogenic factors, including pollution,

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surrounding land uses, water level regulation, and wetland drainage (Smith *et al.* 1991, Herdendorf 1992, Brazner 1997, Burton *et al.* 1999). However, coastal marshes are also subjected to naturally occurring environmental phenomena, including seasonal and long-term habitat change and weather-induced hydrologic cycles (Bedford 1992, Mitsch 1992, Wilcox *et al.* 2002). All of these factors are likely important influences on bird behavior, and thus might influence bird abundance, occurrence, and community structure of resident breeding avifauna associated with coastal wetlands (Colwell and Taft 2000).

Hydrology is one of the most important abiotic factors responsible for maintaining wetland physical, chemical, and biological integrity and for driving complex ecological relationships within wetlands (Keddy 2000, Quinn 2002). Periodic flooding and drying of shallow wetlands are important processes that lead to diversification and constant change of wetland plant communities (Wilcox and Meeker 1991, Wilcox *et al.* 1992, Wilcox *et al.* 2002). Long-term, annual, and seasonal water level fluctuations tend to produce structurally complex wetland habitats and increased plant species diversity (Wilcox and Meeker 1991, Wilcox *et al.* 1992, Keough *et al.* 1999, Wilcox *et al.* 2002). These diverse habitat characteristics also tend to result in diverse and abundant bird communities (Weller 1999). In contrast, plant communities in wetlands associated with stable hydrologic regimes tend to become dominated by only a few plant species or become entirely monotypic (Keddy and Reznicek 1986, Wilcox *et al.* 1992), which may reduce bird abundance and species diversity (Fairbairn and Dinsmore 2001, Meyer 2003, Steen *et al.* 2006).

Availability and extent of water within wetlands each spring may be used as simple, proximate cues by some wetland-dependent birds to aid in broad scale habitat selection, which in turn affects their seasonal abundance (Kushlan 1987, 1989; Austin 2002). Annual water depth changes within Great Lakes coastal wetlands can affect breeding and foraging habitat suitability for a variety of wetland-dependent bird species, each of which is adapted to occupy specific niches within diverse wetland habitat structure (Riffell *et al.* 2001). Therefore, annual and long-term variation or stability in Great Lakes water levels that directly influence coastal wetland hydrology may affect species use and abundance within relatively dynamic coastal wetland communities.

Unlike Lakes Erie and Huron-Michigan, Lake Ontario water levels have been regulated since 1959 (Quinn 2002). Such control has caused Lake Ontario to have a reduced magnitude of annual and long-term water level change, and a general dissimilarity of lake level change to that of the other Great Lakes (Quinn 2002). Thus, Lake Ontario's coastal marshes and bird communities have been subjected to very different annual and seasonal hydrologic regimes as compared to those of Lakes Erie and Huron-Michigan (Wilcox *et al.* 1992, Steen *et al.* 2006).

Marsh bird populations, especially those of secretive species such as bitterns (Ardeidae: *Botaurus* sp. and *Ixobrychus* sp.), grebes (Podicipedidae), and rails (Rallidae), are challenging to effectively monitor and study throughout broad geographic areas (Conway and Timmermans 2005). Since 1995, the Great Lakes Marsh Monitoring Program (MMP) has collected bird abundance and distribution data throughout marsh habitats of the Great Lakes basin (Crewe *et al.* 2006). The MMP is the most extensive program designed specifically for long-term, broad-scale population monitoring of marsh-obligate and other wetland-dependent birds in the Great Lakes region.

We are unaware of any studies that have examined relationships between annual changes in breeding coastal marsh bird abundances and annual changes in Great Lakes water levels. Thus, our primary objectives were to: 1) evaluate patterns and trends (1995–2002) of Lakes Ontario, Erie, and Huron-Michigan water levels, 2) show relative abundance trends for breeding marsh bird species in coastal wetlands within each of these Great Lakes basins and compare these to trends in water levels, and 3) determine if there were associations between lake-specific annual marsh bird abundance indices and Great Lakes water levels.

METHODS

Study Area

The Great Lakes watershed basin encompasses more than 534,000 km^2 of total land area and more than 247,000 km^2 of total fresh water surface area (Quinn 2002). This basin consists of four hydrologically distinct Great Lakes (*i.e.*, Ontario, Erie, Huron-Michigan, and Superior), which are surrounded by one Canadian province and eight U.S. states. Compilation from several sources indicates that the Great Lakes contain at least 165,000 ha of coastal wetlands (Environment Canada and Ontario Ministry of Natural Resources 2004, Herdendorf *et*

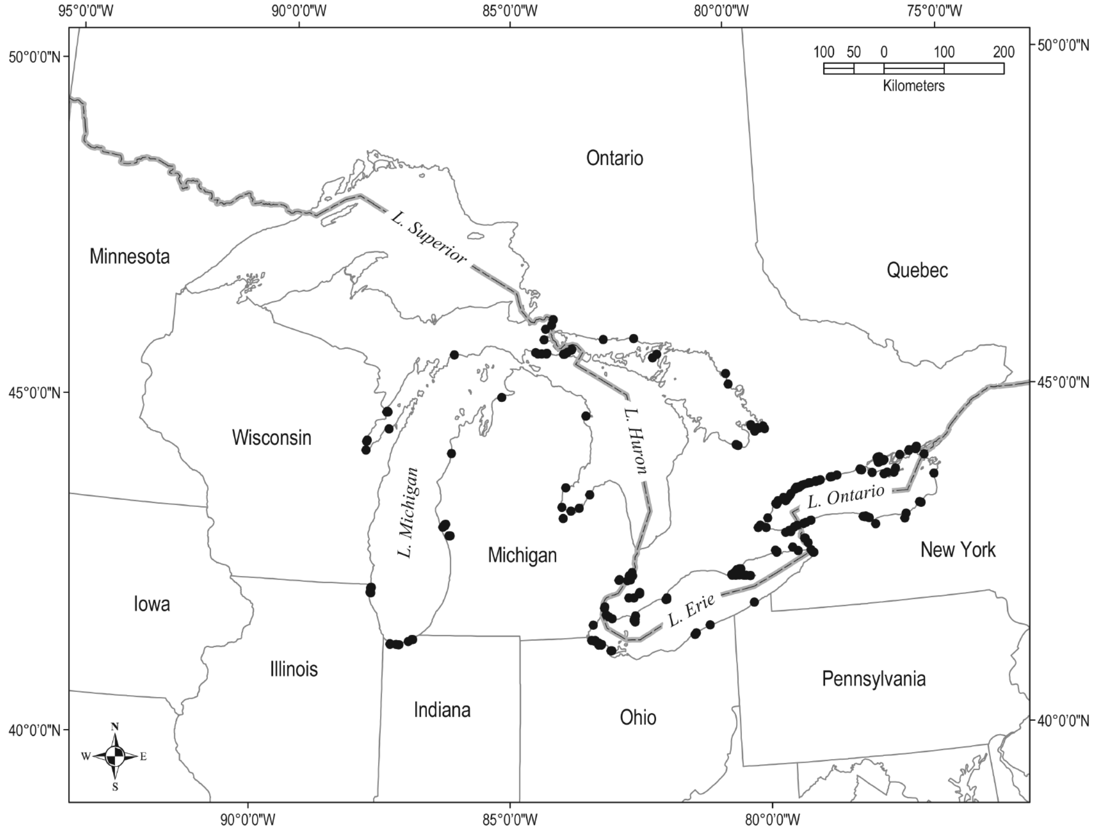

FIG. 1. Locations of Great Lakes coastal wetland MMP routes included in this study.

al. 1981, International Lake Erie Regulation Study Board 1981, Prince *et al.* 1992). These wetlands often are characterized by emergent aquatic plants, such as graminoids, sedges (*Carex* spp.), cattail (*Typha* spp.), bulrush (*Scirpus* spp.) and common reed (*Phragmites australis*), but also may contain many different species of submerged and floating aquatic macrophytes (International Lake Erie Regulation Study Board 1981, Dodge and Kavetsky 1995). During spring and early summer, emergent vegetation communities within Great Lakes coastal wetlands support numerous breeding passerines, waterfowl, and marsh-obligate birds, including rails, coots, and gallinules (Rallidae); bitterns; black tern (*Chlidonias niger*); Forster's tern (*Sterna forsteri*); and pied-billed grebe (*Podilymbus podiceps*) (Herdendorf 1992, Prince *et al.* 1992, Weeber and Valianatos 2000). The study area encompassed Lakes Huron-Michigan, Erie, and Ontario, but did not include Lake Superior because few MMP survey routes had been established in that basin (Fig. 1).

Great Lakes Water Level Trends

Great Lakes mean monthly water level (measured as meters above the 1985 International Great Lakes Datum or m IGLD85) data were obtained online from the Canadian Hydrographic Service, Department of Fisheries and Oceans (http://chswww.bur.dfo.ca/danp/network_means.html). These data were collected from 33 water level gauging stations located throughout Canadian and United States jurisdictions of the Great Lakes, and mean annual water levels derived for this study represent whole-lake averages across these multiple stations. Annual estimates of breeding season water levels were derived based on a 3-month mean water level for May, June, and July 1995–2002. Hereafter, any references to water levels are based on these three-month mean values.

Great Lakes MMP Bird Survey Protocol

Data used in this study were collected by MMP volunteer participants who surveyed bird abundance and occurrence throughout marsh habitats in the Great Lakes basin between 1995 and 2002. Prior to their first survey season (May, June, and July), participants were provided with training kits that included survey protocol instructions, data forms, instructional cassette tapes with examples of songs and calls of common marsh birds, and a call-broadcast tape that was used during surveys to elicit vocal responses from Virginia rail (*Rallus limicola*), sora (*Porzana carolina*), American bittern (*Botaurus lentiginosus*), least bittern (*Ixobrychus exilis*), common moorhen (*Gallinula chloropus*), American coot (*Fulica americana*), and pied-billed grebe (Weeber and Vallianatos 2000).

After reviewing survey protocol and completing a self-training exercise, participants established survey routes in wetlands ≥ 1 ha in size. Wetland sites included in this study were Great Lakes lacustrine shoreline associated (or coastal) and under direct or indirect influence of lake hydrology processes. All of these wetlands have been identified and inventoried as coastal wetlands by the Great Lakes Coastal Wetlands Consortium (Great Lakes Coastal Wetlands Consortium 2003). Depending on wetland size, survey routes consisted of one to eight different survey stations. Survey stations were defined as 100 m radius semicircles that contained ≥ 50% coverage of emergent vegetation (various types, persistent and non-persistent, wet-meadow) where birds were counted each year. The center of each survey station was the focal point from which observers recorded bird counts; these were permanently marked with a stake and metal tag to ensure relocation in subsequent visits within and among years. All stations were ≥ 250 m from each other, which minimized duplicate counts of individual birds within routes. Many routes were established at the interface/edge of wetland and drier upland habitats, but some participants also surveyed routes consisting of semi-circular plots in wetland interiors.

Each bird monitoring station was surveyed twice annually between 20 May and 5 July, and each of the two survey visits were separated by at least 10 days. Surveys were conducted after 1800 hours EST and on days when there was no precipitation, when the temperature exceeded 16°C, and when the wind speed was less than 20 km/hr (3 on the Beaufort scale). Birds were counted for 10 minutes during each survey station visit in the following manner. At each focal point, survey participants played a 5-minute call broadcast tape (each species call was separated by 30 seconds of silence) and recorded all birds heard and/or seen within each 100 m semi-circular survey station during the call playback period and during a 5-minute silent listening period immediately following the call playback period.

Species Selection

To examine potential relations between annual patterns and trends in bird species abundance and Great Lakes water levels, we selected species deemed to be highly or moderately sensitive to hydrologic change or stabilization in the Great Lakes (Steen *et al.* 2006), were known to be obligate marsh nesters (Meyer 2003), and for which the MMP was deemed to have adequate statistical power to detect annual changes in abundance among the lakes examined (see below). Thus, the species that we selected for our study included American bittern, American coot, black tern, common moorhen, least bittern, marsh wren, pied-billed grebe, sora, swamp sparrow (*Melospiza georgiana*), and Virginia rail.

Statistical Analyses

Only data collected from birds inhabiting coastal wetlands were used in calculating abundance indices and for evaluating temporal changes in bird relative abundance. Further, few MMP routes have been established in Lake Superior wetlands, so we did not include those data in our analyses. MMP data have adequate power (i.e., able to detect ≤ 3% annual change in a given species' abundance index) to detect long-term, basin-wide changes in marsh bird abundance (Francis and Chabot 1997). Bird abundance data were filtered to include only data from routes that were surveyed for at least 2 years during which a given species was detected at least once. Using these data, annual abundance indices were calculated only for bird species that occurred on ≥ 15 routes per lake stratum and that accounted for at least 20% of the total number of route-years over the 8-year period. Using MMP data analyzed in this study, these criteria were determined through power analyses which yielded a minimum power (which occurred for American bittern in Lake Erie) to detect at least a 3% year-to-year change (beta = 0.8; alpha = 0.05) in abundance indices (S. Timmermans, Bird Studies Canada, Port Rowan, ON, unpubl. data).

Bird abundance indices for Lake Ontario, and Lakes Erie and Huron-Michigan (combined) were calculated in the following manner. First, for each station within each route, we took the maximum count across the two annual survey visits, then averaged these counts across stations within each route to derive route-specific counts for each species. This yielded single annual abundance values for each species detected on each route. We used Generalized Estimating Equation (GEE) models with a Poisson error distribution (PROC GENMOD; SAS Institute Inc. 1990) to generate annual abundance indices for each species. Species count was the dependent variable and route and census year were treated as independent, class variables in these models. Models produced mean annual abundance estimates for each species. Survey routes were treated as repeated clusters in these models to account for within-route correlations in abundance among years (individuals may return to the same surveyed area each year to breed). Model variance estimates were adjusted for overdispersion by applying the Pearson scaling method, whereby the exponential family dispersion parameter was assumed to be given by Pearson's chi-square statistic divided by the degrees of freedom (PROC GENMOD, PSCALE option; SAS Institute Inc. 1990). Annual estimated species counts (i.e., class coefficients) were converted into abundance indices using the following formula (Link and Sauer 1994, Steen *et al.* 2006):

$$\text{Abundance Index} = e^{\mathrm{A} \times \mathrm{M}} \qquad (1)$$

where:

e = 2.7183 = the base of the natural logarithm,

A = annual estimated species count (i.e., class coefficients) from route-regression models,

M = mean number of individuals counted on all routes in the final survey year.

This transformation allowed us to determine relative (percent) annual differences in bird abundance indices scaled to the average value for the most recent survey year. These abundance indices were used to investigate correlations with Great Lakes water levels.

Species-specific relative abundance trends for birds counted in wetlands associated with each survey stratum during 1995–2002 were evaluated using GEE models (PROC GENMOD; SAS Institute Inc. 1990). The same input data, error distribution, and modeling structures and procedures as described above for calculating abundance indices were used for these analyses, except that the variable "Year" was included as a continuous variable to provide a linear estimated rate of change in each species' abundance through time. Survey routes were treated as repeated clusters in these models to account for within-route correlations in abundance among years. Species-specific slope estimates from these models (Link and Sauer 1994, Steen *et al.* 2006) were converted into relative indices of change (abundance trends) by using the following formula:

$$\text{Abundance trend} = 100 \times (e^{\beta} - 1) \qquad (2)$$

where:

β = Year coefficient from species-specific route-regression models.

This transformation allowed us to determine percent annual change in bird abundance indices during 1995–2002. These GEE models produced standardized residuals, which were plotted against the continuous "Year" variable to evaluate model fit (Collett 1994). All specified models adequately fit these data. Likelihood ratio tests were used to calculate the probability that year effects (slopes) differed from zero. To do this, differences in model deviance between those with and without year effects were calculated; those differences (based on 1 error degree of freedom) were used to obtain probabilities from a chi-squared distribution, which were subsequently converted (1 – chi-square probability) into p-values (Collett 1994).

Two different methods were employed to investigate possible relations between Great Lakes water levels and bird abundance indices. First, linear trends in annual Great Lakes water levels during 1995–2002 were compared to linear abundance trends of selected marsh birds recorded in coastal marshes during the same period. Linear regression was used to test for linear patterns in spring/summer water levels over those years (PROC REG; SAS Institute Inc. 1990). Analysis of Variance (ANOVA) was also used to determine if there was year-to-year variation in annual water levels (PROC GLM; SAS Institute Inc. 1990). Second, the direction (+/–) and strength of correlation coefficients (Pearson product-moment) were evaluated between species annual abundance indices and average May, June, and July water levels (PROC CORR; SAS Institute Inc. 1990). For these descriptive associations, we interpreted relationships to be biologically meaningful at $p \leq 0.10$. We also considered worthy of discussion the signs of correlation coefficients for species where the relationships were $0.10 < p < 0.20$.

RESULTS

Annual Variation and Trends in Water Levels 1995–2002

Average May, June, and July water levels in Lake Ontario during 1995–2002 were similar (about 75.2 m) in most years (1996–1998, 2000, and 2002), but were lower during 1995 (0.3 m), 1999 (0.4 m), and 2001 (0.2 m) (ANOVA: $F_{7,16} = 22.05$, $p < 0.01$). Water levels declined by 0.4 m between 1998 and 1999 ($p < 0.05$), reaching the lowest value recorded (74.8 m) during the 8-year period. The relatively stable water levels of Lake Ontario between 1995 and 2002 were reflected by a lack of a trend in water levels over that period (Fig. 2). From 1995–2002, Lake Ontario water levels were relatively low in 1995 (74.9 m) and 2001 (75.0 m), but were lowest in 1999 when its water level dropped to 74.8 m (i.e., 0.45 m drop from 1998 level).

Water levels of Lakes Erie (ANOVA: $F_{7,16} = 59.07$, $p < 0.01$) and Huron-Michigan (ANOVA, $F_{7,16} = 116.82$, $p < 0.01$) showed a substantial amount of annual variation and, relative to Lake Ontario, large annual water level fluctuations between some years (Fig. 2). During 1995–2002, Lakes Erie and Huron-Michigan also had the same overall pattern of hydrologic change and had comparable magnitudes of water level change between years. Similar to Lake Ontario, the largest change in both Lakes Erie and Huron-Michigan water levels occurred between 1998 and 1999, when lake levels dropped by about 0.5 m. However, water levels in Lakes Erie and Huron-Michigan continued to decline until 2001, whereas they generally increased during that period in Lake Ontario (Fig. 2). Water levels in Lakes Erie and Huron-Michigan increased from 1995 to 1997, but generally declined substantially thereafter, which contributed to the overall declining trends in water levels for these lakes during 1995–2002 (Fig. 2). Because of the similarities in hydrologic patterns and declining water levels (Erie-Huron-Michigan 1995–2002: Water level = 258.25–0.05 Year; $r^2 = 0.30$, $F_{1,22} = 9.54$, $p = 0.01$), we combined data for these lakes for all subsequent analyses involving bird annual abundance indices and their trends.

Wetlands associated with Lakes Erie and Huron-Michigan were affected by a much wider range of water level fluctuation and, on average, had generally declining water levels during 1995–2002 (see

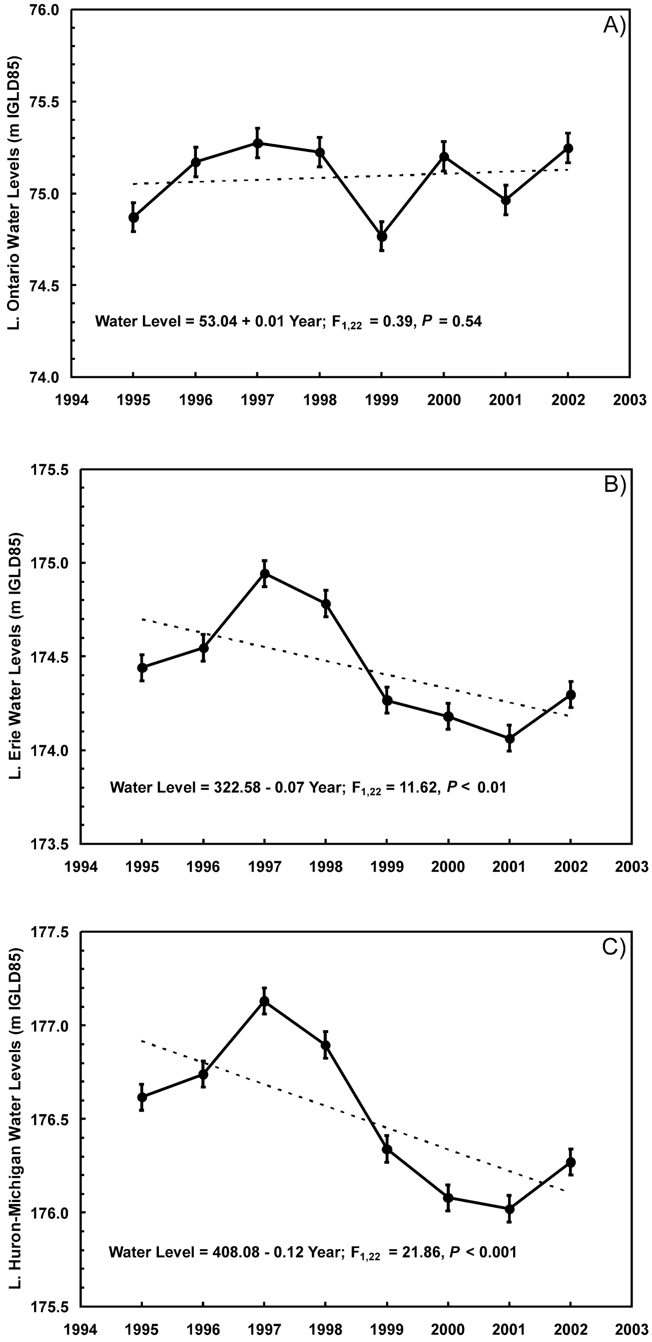

FIG. 2. Water levels (m IGLD85) averaged over the months of May, June, and July 1995–2002, for Lake(s): a) Ontario, b) Erie, and c) Huron-Michigan. Dashed lines show trends in spring/summer water levels during 1995–2002. Whiskers on points are ±95% Confidence Intervals.

TABLE 1. Abundance trends of birds in Great Lakes coastal marshes from surveys completed during May, June, and July 1995-2002.

	Lake Ontario			Lakes Erie and Huron-Michigan		
Species	Routes with species[a]	Route-years with species[b]	Trend[c]	Routes with species	Route-years with species	Trend
American bittern[d]				16	84	–1.7 (0.78)
American coot[d]				21	91	**–20.5** (0.04)
Black tern	11	55	**–32.0** (< 0.01)	26	128	**–19.3** (< 0.01)
Common moorhen	15	90	–5.6 (0.25)	25	112	**–15.2** (0.02)
Least bittern	9	65	–2.8 (0.78)	23	124	**–15.0** (0.03)
Marsh wren	23	110	+ 1.0 (0.75)	47	211	**–6.6** (< 0.01)
Pied-billed grebe[d]				32	139	**–21.3** (< 0.01)
Sora	15	81	+ 4.6 (0.57)	31	144	**–15.1** (< 0.01)
Swamp sparrow	22	102	**+ 5.1** (0.08)	51	230	**–6.5** (< 0.01)
Virginia rail	23	118	+ 1.8 (0.66)	40	182	**–10.0** (0.01)

[a] Total routes for Ontario, and Erie-Huron-Michigan = 32 and 61, respectively.

[b] Total route-years for Ontario and Erie-Huron-Michigan = 142 and 266, respectively.

[c] Percent (%) change per year for abundance indices of each species from 1995–2002; *p*-values for slopes are in parentheses.

[d] American bittern, American coot, and pied-billed grebe for Lake Ontario were not included because they only occurred on 9 and 5 routes, respectively, and were present in < 20% of total number of route-years.

Fig. 2). Lakes Erie and Huron-Michigan water levels were well above long-term (1952–2002) averages (Erie: 174.3 m, Huron-Michigan: 176.2 m, and combined: 175.3 m) during 1995–1998, but after peaking in 1997, levels declined by about 1.0 meter (Erie: 0.9 m and Huron-Michigan: 1.1 m) over the next 4 years to their lowest levels (Erie: 174.1 m, Huron-Michigan: 176.0 m, and combined: 175.3 m) recorded during the 8-year period.

Trends in Marsh Bird Abundance Indices 1995–2002

Five of seven (71%) marsh bird abundance indices recorded in Lake Ontario coastal wetlands did not change during 1995–2002 (Table 1); these trends were consistent with the lack of any trend in Lake Ontario water levels during that period (see Fig. 2). Although abundance indices of common moorhen, least bittern, marsh wren, sora, and Virginia rail were stable in Lake Ontario wetlands, relative abundance of black terns declined, while swamp sparrow increased during the 8-year period (Table 1). In contrast to Lake Ontario, nine of the ten marsh bird species trends that we considered in Erie-Huron-Michigan coastal wetlands declined during 1995–2002 (Table 1). These bird abundance trends were similar to the declining trend in Erie-Huron-Michigan water levels during that period (see Fig. 2). American bittern was the only species recorded in lakes Erie and Huron-Michigan coastal wetlands that had relatively stable numbers during this period.

Correlations between Bird Abundance Indices and Water Levels

Correlations between annual bird abundance indices and Lake Ontario water levels indicated that relative abundances of one species, Virginia rail, was positively correlated with annual water level fluctuations (Table 2 and Fig. 3). Relative abun-

TABLE 2. Correlations between annual abundance indices of marsh birds and Great Lakes basin water levels (average over May, June, and July) during 1995–2002.

	Lake Ontario			Lakes Erie and Huron-Michigan		
Species	*n*	*r* [a]	*p* [b]	*n*	*r*	*p*
American bittern[c]				8	+0.43	0.28
American coot [c]				8	**+0.62**	0.10
Black tern	8	+0.18	0.67	8	+0.42	0.30
Common moorhen	8	–0.13	0.75	8	+0.16	0.71
Least bittern	8	+0.24	0.57	8	**+0.83**	0.01
Marsh wren	8	+0.55	0.16	8	**+0.66**	0.07
Pied-billed grebe[c]				8	**+0.77**	0.03
Sora	8	+0.45	0.27	8	**+0.91**	< 0.01
Swamp sparrow	8	–0.22	0.60	8	+0.57	0.14
Virginia rail	8	**+0.63**	0.09	8	+0.55	0.16

[a] Pearson correlation coefficients.

[b] Correlation coefficients are considered biologically meaningful at $p \leq 0.10$.

[c] American bittern, American coot, and pied-billed grebe for Lake Ontario were not included because they only occurred on 5, 3, and 5 routes, respectively, and were present in < 20% of total number of route-years.

dances of the remaining six wetland-dependent birds, including black tern, common moorhen, least bittern, sora, and swamp sparrow, showed no significant correlation to Lake Ontario water levels. However, visual inspection of Figure 3 indicates that marsh wren and sora showed similar patterns of annual abundance changes to those of Lake Ontario water levels.

In contrast, relative abundances for 5 (American coot, least bittern, marsh wren, pied-billed grebe, and sora) of 10 species tested in Lakes Erie-Huron-Michigan coastal wetlands were positively correlated ($p < 0.1$, $r > 0.6$) with changes in water levels (Table 2 and Fig. 4). Two other species' trend relationships with water levels showed positive signs and relationships (swamp sparrow [$r = 0.55$; $p = 0.14$] and Virginia rail [$r = 0.57$; $p = 0.16$]) that also merit some consideration. Relative abundances of American bittern, black tern, and common moorhen did not correlate well (maximal $r = 0.43$) with annual water level changes, but the sign in each relationship was positive.

DISCUSSION

Several studies have shown a connection between short- (Kushlan 1987, Frederick and Callopy 1989, Licht 2001) and long-term (Vinicombe 1982, Musil and Fuchs 1994, Schogolev 1996, Austin 2002, Crozier and Gawlik 2003) hydrologic changes within wetlands and abundance, distribution, or behavior of wetland-dependent birds during their breeding seasons. In general, most of our results were consistent with the concept that annual fluctuations in water levels influence abundance of certain marsh birds. Specifically, our results suggest that annual relative abundance of several marsh birds recorded in coastal wetlands are generally positively associated with annual Great Lakes water levels. The consistent and positive correlations between several species abundance indices and annual changes in Lakes Erie and Huron-Michigan water levels provided the strongest support for hydrologic influences. MMP data analyses for this study were not collected in a manner that would permit us to use conventional methods (e.g., time-to-detection, distance sampling) to estimate annual detectabilities of the species examined in this study, so we were not able to determine if annual variability in species-specific detection rates accounted for any of the observed variability in annual abundance indices.

Results from Lake Ontario, however, suggest that there was not an association between relative abundance of most bird species and Lake Ontario water level patterns. The different results we observed for correlations between bird relative abundances and lake-specific water levels likely relates to the hydrologic patterns specific to Lakes Ontario, Erie, and Huron-Michigan, and how those specific changes affected habitat suitability for birds residing and nesting in each of these lake's coastal wetlands.

The relatively large, precipitous, and continuous drop in Lakes Erie and Huron-Michigan water levels during that period likely greatly reduced habitat suitability for many over-water nesting marsh birds (i.e., American bittern, American coot, black tern, least bittern, marsh wren, pied-billed grebe, sora, swamp sparrow, Virginia rail) primarily by causing reductions in the amount or extent of standing water in emergent vegetation (Tozer 2002, Meyer

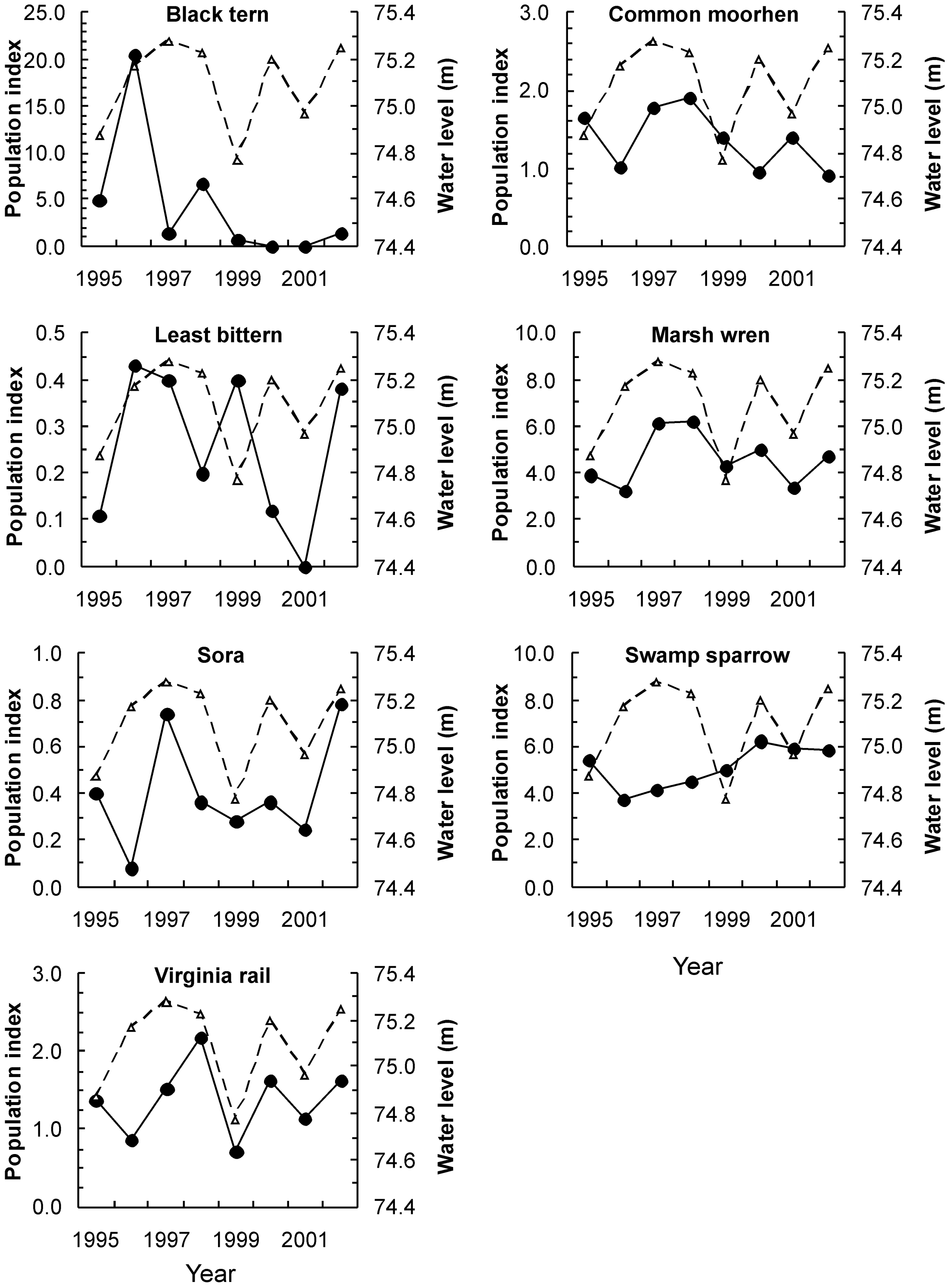

FIG. 3. Marsh bird abundance indices for Lake Ontario presented with annual average (May, June, and July) water levels (m IGLD85) during 1995–2002. Dark points and solid lines represent population indices; open triangles and dashed lines represent water levels.

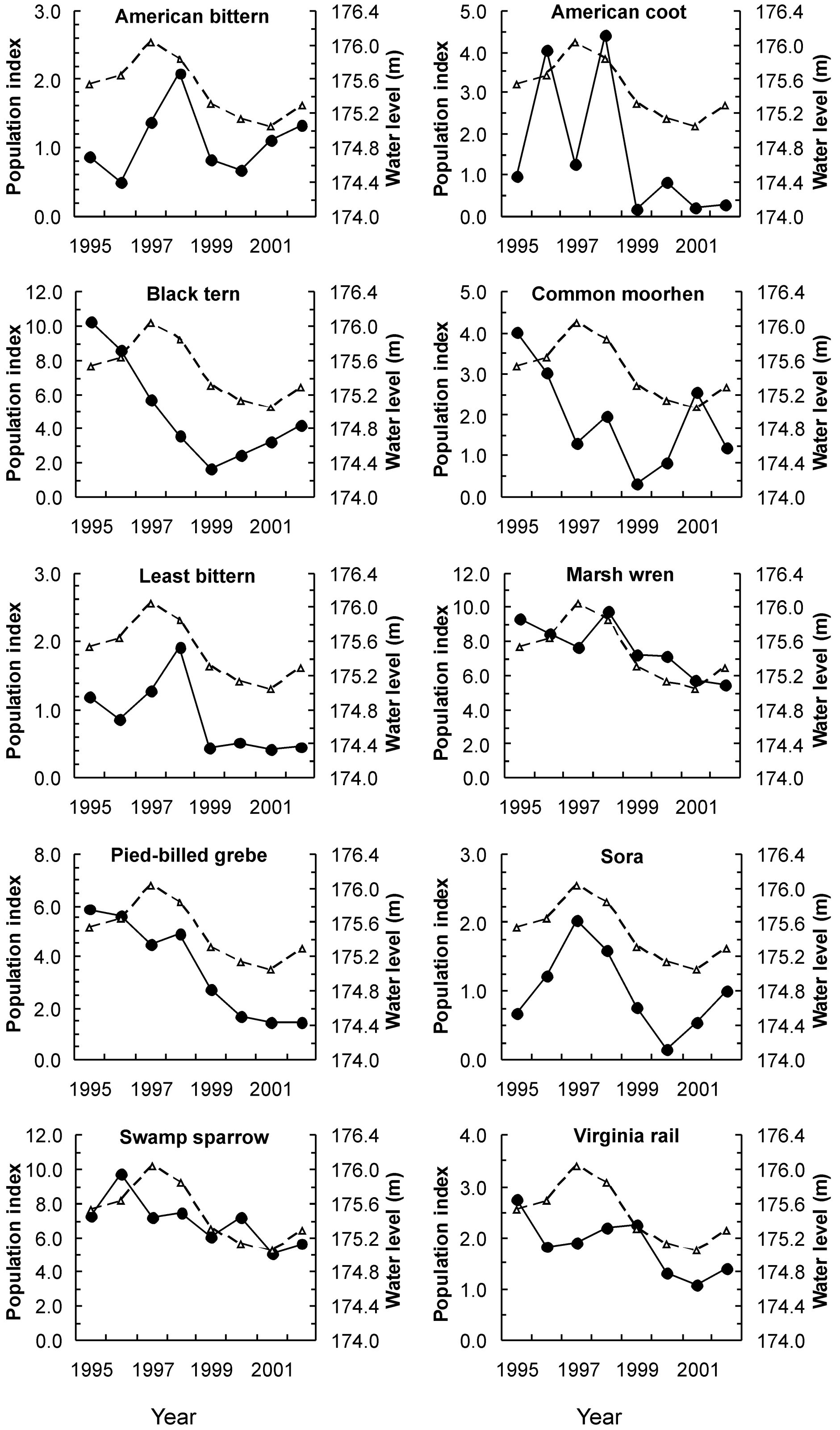

FIG. 4. Marsh bird abundance indices for Lakes Erie and Huron-Michigan (combined) presented with annual average (May, June, and July) water levels (m IGLD85) during 1995–2002. Dark points and solid lines represent population indices; open triangles and dashed lines represent water levels.

2003). In fact, studies of wetland-dependent birds conducted in coastal wetlands at Long Point, Lake Erie (Tozer 2002, Meyer 2003) and Matchedash Bay, Lake Huron (Tozer 2002), Ontario, from 1998–2003 verified that: 1) many suitable nesting habitat patches in wetlands associated with these lakes had extremely low water levels, and 2) wetland areas of higher elevation, especially near wetland-upland margins, contained emergent vegetation, but retained relatively little (if any) standing water.

In contrast, Lake Ontario water levels were comparatively stable during 1995–2002 and water levels generally fluctuated around the long-term (1952–2002) May, June, and July average of 75.0 m. The stability in Lake Ontario water levels is the result of anthropogenic regulation of its water levels that has occurred since 1959 (Quinn 2002). However, even at its lowest water level (1999), Lake Ontario still provided some flooded emergent habitat in most regions of the basin (J. Ingram, Environment Canada, Inuvik, NWT, unpubl. data). Thus, the relatively stable and suppressed hydrologic regime, combined with the lack of a consistent, long-term change in water levels, likely caused many MMP survey stations/routes in Lake Ontario wetlands to have some standing water present in most years. Relatively consistent year-to-year presence of standing water in wetland survey areas each year also may explain why abundances of black tern, common moorhen, least bittern, and swamp sparrow correlated poorly with suppressed annual water level changes that occurred in Lake Ontario.

Black tern, common moorhen, least bittern, and swamp sparrow typically nest and/or forage in vegetation over deeper water than do marsh wren, sora and Virginia rail (Gibbs *et al.* 1992a, Gibbs *et al.* 1992b, Dunn and Agro 1995, Muller and Storer 1999). In our study, Virginia rail exhibited a positive association, and to a lesser extent, marsh wren and sora exhibited tendencies to be positively associated with annual Lake Ontario water level changes, suggesting that these three “shallow-water” species may be more sensitive to habitat suitability changes caused by hydrological dynamics than other species examined in this study. Steen *et al.* (2006) identified sora and Virginia rail to be highly sensitive, and marsh wren to be moderately sensitive, to hydrologic stabilization of Lake Ontario.

Presence and depth of standing water within emergent vegetation is an important habitat feature for many marsh birds because it facilitates foraging activities, ground predator avoidance, and often dictates food or nest site availability (Kushlan 1987, 1989; Pickman *et al.* 1993; Flores and Eddleman 1995, Conway 1995, Melvin and Gibbs 1996, Kroodsma and Verner 1997). Further, most of the species in this study, with the exception of swamp sparrow (Mowbray 1997), nest almost exclusively within flooded emergent vegetation, and are particularly sensitive to year-to-year water level changes or stabilization (Steen *et al.* 2006) in wetlands where they breed. Thus, we suggest that year-to-year changes in availability of flooded emergent vegetation within wetlands, and/or plant species composition, particularly within survey stations on MMP routes, may have resulted in increased and decreased annual abundances of many species monitored during years of relatively high and low water, respectively, in this study. Even in Lake Ontario coastal wetlands, which tend to be dominated by dense monotypic stands of *typha* due to water level stabilization (Wilcox *et al.* 1992), changes in habitat suitability (i.e., degree of flooding in emergent vegetation) may explain the observed correlations between annual changes in Lake Ontario water levels and annual patterns of abundances for Virginia rail, marsh wren, and perhaps also for sora. Other larger scale phenomena such as regional or continental fluctuations in species populations may also explain the observed patterns and trends in abundances of species examined, but these species-specific data are lacking for the time period examined in our study (Milko *et al.* 2003).

Our results do not provide direct evidence that Great Lakes water levels influence marsh bird populations *per se*, but do suggest that annual water level fluctuations might at least affect distribution, if not abundance of wetland-dependent birds in the Great Lakes basin (see also Timmermans 2002). Many MMP routes are located near the edge of the wetland/upland interface (i.e., areas that tend to be shallower and prone to drying), whereas fewer are located in interior locations where in low water years emergent vegetation may still contain water (Tozer 2002). Therefore, birds may still be present in some wetlands monitored by the MMP, but simply not detected by observers recording birds within their 100 m survey stations. Alternatively, birds could relocate to wetlands further inland or settle into an entirely different geographic area with better water conditions (Conway and Timmermans 2005). This situation is analogous to when large numbers of breeding ducks (*Anas* spp.) settle into ephemeral prairie wetlands in years with adequate water conditions rather than continuing north to breed in parkland or boreal wetlands that have relatively stable annual water conditions (Austin 2002).

MMP routes do, however, cover a relatively broad geographic range and are located in coastal (and inland) wetlands of different sizes, bottom gradients, and ground elevations (thus water depths), and with different amounts, configurations and species of emergent vegetation (Weeber and Vallianatos 2000). This suggests that the results represent more than a simple biologically interpretable small-scale (i.e., route- or station-level) phenomenon. Further, many of the species that showed relatively strong associations with Great Lakes water levels in coastal wetlands in this study also showed similar relationships at inland wetland locations (Timmermans 2001). This suggests that broad-scale groundwater hydrology or winter/spring precipitation events, both of which are likely correlated with Great Lakes water levels, also may influence large-scale abundance and distribution of some wetland-dependent bird species. However, future research regarding MMP survey biases and their effects on bird abundance trends are needed to better assess how bird populations are responding to dynamics of the environment (Granholm 1983, Bart and Earnst 2002, Bogner and Baldassarre 2002, Farnsworth *et al*. 2002, Krzys *et al*. 2002, Conway and Timmermans 2005).

Regardless of what specific mechanisms are causing the apparent associations between relative abundance of many species and lake water levels, our results highlight the importance of accounting for effects of hydrologic change when developing long-term population monitoring programs for marsh birds and other wetland associated birds (Conway and Timmermans 2005). Accounting for population variation due to annual changes in water levels and/or other important habitat features that are temporally and spatially dynamic will provide a more robust and appropriate index for long-term, broad-scale monitoring of wetland bird populations and assessing wetland health (Wilcox *et al*. 2002, Conway and Timmermans 2005). Thus, broad-scale wetland bird monitoring initiatives should strive to employ methods in sampling protocols and/or data in analyses to account for temporal and spatial variation in hydrology, and/or other confounding factors that may affect wetlands and their avifauna.

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