MARSH BIRD RESPONSE TO HYDROLOGIC ALTERATION AND RESTORATION OF WETLANDS IN THE BOREAL HARDWOOD TRANSITION

Final Report

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ABSTRACT

Wetlands of the boreal hardwood transition zone, or Bird Conservation Region (BCR) 12, provide important breeding habitat for several marsh bird species of conservation concern. Agencies have attempted to restore the hydrology to some altered sites, yet numerous partially drained and impounded wetlands remain. We compared use by 15 marsh bird species of altered (raised and lowered), rehabilitated, and reference wetlands within the BCR 12 portion of Michigan to better understand the effects of hydrologic alteration on these species. We examined bird data from 1,798 point counts conducted during 2010-2017 at 212 survey stations. Vegetation and physical conditions were sampled at 1,286 0.25-m^2 quadrats for comparison among the four hydrologic categories. Eleven species were detected at lowered points, 14 species at raised, 12 species at rehabilitated, and 14 species at reference points. Swamp Sparrow was the most common species in all four hydrologic categories. Pied-billed Grebe and Sora were detected more often at raised points, whereas Sedge Wren and Le Conte's Sparrow were observed at greater rates at lowered points. American Bittern, Virginia Rail, Sandhill Crane, and Wilson's Snipe were most often detected at rehabilitated points. Non-metric multidimensional scaling (NMS) indicated no visual distinction in the marsh bird data according to our four hydrologic categories, whereas multi-response permutation procedures (MRPP) analysis indicated differences in bird assemblages. Similarly, NMS analysis of wetland characteristics and surrounding land cover variables did not exhibit clustering by hydrologic category, yet MRPP tests suggested differences among the four types. Two of the eight species detected often enough to facilitate statistical comparison differed significantly among the four hydrologic categories. Abundance of Wilson's Snipe was greatest at rehabilitated points compared to the other wetland types. Sedge Wren abundance was similar between lowered and raised points and greater than rehabilitated and reference wetlands. Eight of the 26 wetland characteristics measured during quadrat sampling differed by hydrologic category. Lowered points had significantly lower percent cover of open water and greater percent cover of litter. Depth of organic sediments was greater at altered sites (lowered and raised) compared to rehabilitated and reference points. Water depth and percent cover of submersed plants, moss, persistent shallow-water emergents, and *Phragmites* differed among the hydrologic categories, but pair-wise comparisons suggested complicated relationships and substantial variance among the wetland types. In logistic regression analysis, water depth, vegetation height, and percent cover of moss appeared to be important predictors of occurrence for several marsh bird species at the fine scale, whereas proportion of emergent wetland within 200 m was the variable most often selected at the larger spatial scale. For the species considered, our abundance and occupancy results suggest that wetlands with altered (lowered or raised) and rehabilitated hydrology supported marsh bird use at levels similar to or greater than reference sites.

INTRODUCTION

Across much of North America, including the Upper Midwest, wetlands loss due to multiple land-use factors has been profound (Dahl and Johnson 1991, Dahl 2006, Moreno-Mateos et al. 2012). These anthropogenic changes have led to a cascade of effects on biodiversity and ecosystem function. In particular, concern about declining marsh bird populations has been growing and there is substantial interest in reversing these population trends (Kushlan et al. 2002, Soulliere et al. 2007, Wires et al. 2010). Unfortunately, conservation efforts are often hampered by a lack of biological and ecological data for use in planning and management (Soulliere et al. 2007, 2018). In the Great Lakes region and upper Midwest, only a few studies have evaluated marsh bird response to restoration and management activities and examined relationships to ecological processes, such as hydrology (Galloway et al. 2006, Monfils et al. 2014a, Glisson et al. 2015, Tozer et al. 2018). The Upper Mississippi River and Great Lakes Region Joint Venture (hereafter Joint Venture) and Midwest Marsh Bird Working Group have identified research and monitoring priorities to address these knowledge gaps (Soulliere et al. 2007, Larkin et al. 2013).

The boreal hardwood transition zone (Bird Conservation Region [BCR] 12) is characterized by coniferous and northern hardwood forests, nutrient-poor soils, and numerous clear lakes, bogs, and rivers (U.S. North American Bird Conservation Initiative Committee 2000). The region also contains large peatlands and coastal marshes that provide important breeding habitat for several marsh bird species, including three Joint Venture focal species, Yellow Rail (*Coturnicops noveboracensis*), Black Tern (*Chlidonias niger*), and Wilson's Snipe (*Gallinago delicata*), and other species with special regional and/or State status. This transitional zone covers the northern 21% of the Joint Venture region (UMRGLR JV 2007). The conditions of wetlands of this region are varied, including sites partially drained by ditches, wetlands flooded by dikes and water control structures, sites restored via ditch plugs or other means, and relatively undisturbed, pristine wetlands, some of which are Federal Wilderness Areas and/or National Natural Landmarks (U.S. Fish and Wildlife Service [USFWS] 2009). Given the importance of the boreal hardwood transition zone to marsh bird species of concern, more work is needed to understand the response of marsh birds to hydrologic alteration and restoration. The presence of altered, restored, and undisturbed wetlands proximal to one another provides an opportunity to assess marsh bird response to hydrologic disturbances and restoration as compared to undisturbed reference wetlands.

Compared to many other bird groups, much remains unknown about secretive marsh bird habitat use, limiting factors, and response to wetland alteration, restoration, and management at multiple spatial scales. Soulliere et al. (2007, 2018) noted information was lacking for many marsh birds when biological models were developed for focal species to inform conservation planning. Our research aimed to address two high priority research needs regarding marsh bird ecology in the Joint Venture region: (1) determine the relationship between particular habitat conservation actions and population responses, plus potential tradeoffs between species for a given action; and (2) determine habitat and landscape preferences of waterbird groups, particularly the secretive marsh birds, during breeding and migration periods. The Joint Venture Science Team noted in the research priorities that "especially important is the need to assess the effects of wetland restoration, enhancement, and management on marsh bird abundance and reproductive success."

Furthermore, we study addressed one of the priority research questions identified by the Midwest Marsh Bird Working Group: how does marsh bird use of restored wetlands compare to naturally-occurring wetlands, and what aspects of restored wetlands maximize use by marsh birds (Larkin et al. 2013)? We are not aware of studies attempting to evaluate marsh bird use of wetlands across the range of reference and altered states examined in our study, even though such research will inform restoration efforts and increase our understanding of marsh bird habitat needs. Our goal was to sample sites within several landscape contexts, emergent wetland types, and hydrologic regimes representative of the boreal hardwood transition zone to inform conservation planning and implementation.

Our first research objective was to compare breeding marsh bird use among four hydrologic categories of wetlands: (1) altered – raised water levels (managed impoundments); (2) altered – lowered water levels (affected by ditches or upstream dikes); (3) rehabilitated (actions taken to restore hydrology); and (4) reference (no known hydrologic alteration). Our second objective was to investigate possible associations between marsh bird use and wetland variables measured at the sites, such as vegetation structure and physical conditions. By analyzing avian habitat associations, we hoped to better understand the factors important in determining marsh bird occupancy across a range of altered, rehabilitated, and intact reference wetlands.

METHODS

Study Area

We evaluated marsh bird use of wetlands with altered (i.e., raised or lowered water tables) and rehabilitated hydrology as compared to reference wetlands within BCR 12, including three publically-owned wetland complexes (Seney National Wildlife Refuge [NWR], Munuscong State Wildlife Management Area [SWMA], and Sturgeon River Sloughs SWMA; Figure 1). In addition, we analyzed data collected from several sites within BCR 12 as part of the Michigan Marsh Bird Survey (MMBS; Figure 1). Since 2010, portions of BCR 12 have been sampled for marsh birds as part of the MMBS, offering a substantial data set to explore marsh bird use across a range of hydrologic conditions. Data on vegetation and other wetland characteristics were also available for a subset of the MMBS points from a complimentary study (Monfils et al. 2014b). In addition, we chose to conduct additional marsh bird and habitat sampling in three areas within BCR 12 to better capture the range of conditions within altered and reference wetlands and facilitate sampling within previously drained wetlands where efforts had been made to rehabilitate the hydrology.

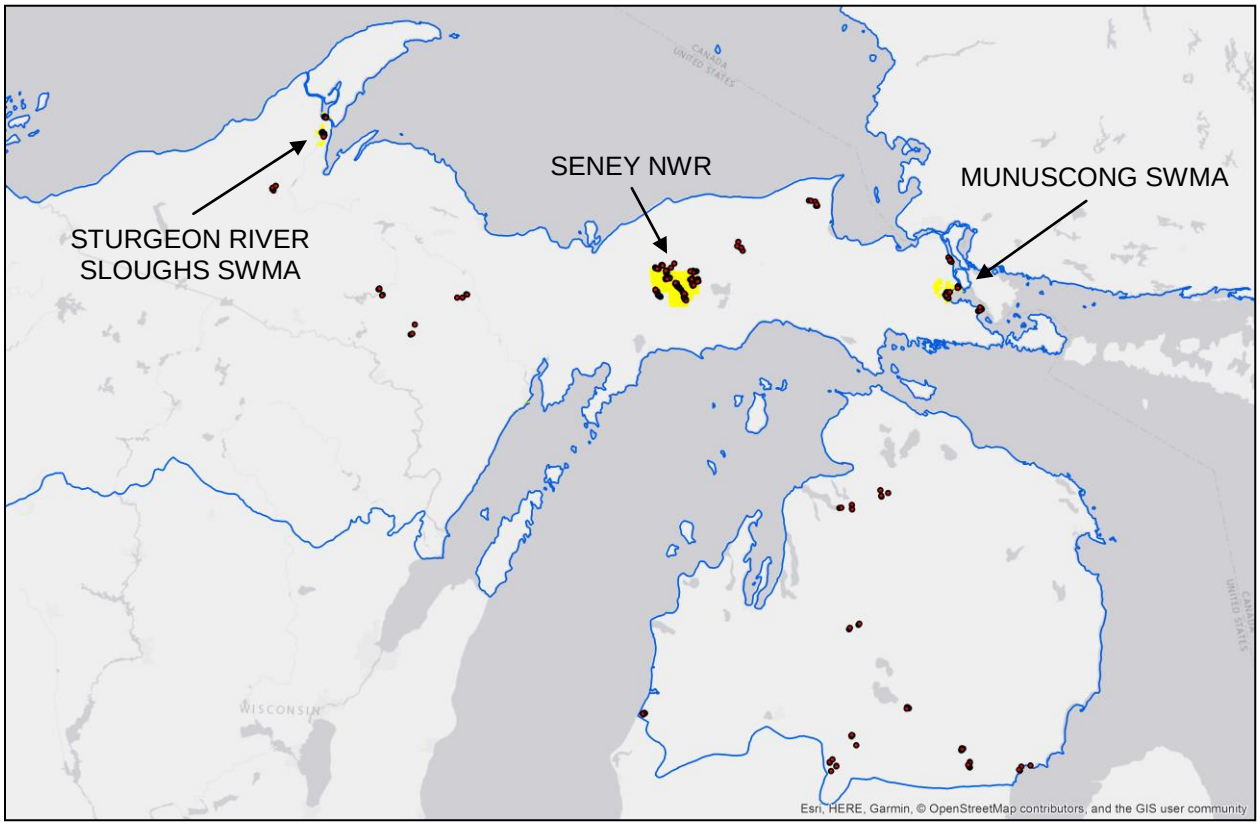

Figure 1. Survey point locations (red circles) used to examine marsh bird use of wetlands with altered, rehabilitated, and reference hydrology within the boreal hardwood transition (BCR 12; indicated by blue lines). Sites where points were added for this study are indicated by yellow shading and labels.

Seney National Wildlife Refuge (NWR)

Seney NWR encompasses approximately 38,541 ha, of which 10,178 ha comprise the Seney Wilderness Area and its Strangmoor Bog National Natural Landmark (USFWS 2009). The Wilderness Area and Strangmoor Bog represent some of the largest expanses of unaltered wetlands in Michigan (USFWS 2009), with hydrology and fire history being within the natural range of variability for most of the area (Drobyshev et al. 2008). These areas provide potential reference sites for restoration and the opportunity to compare marsh bird use with nearby sites already undergoing restoration treatments and those being conserved in their altered states. One of Michigan's largest wetland drainage projects was initiated in 1912 to convert the Seney Swamp to agriculture. This effort consisted of a series of drainage ditches, the largest of which was Walsh Ditch. These linear drainages significantly altered the hydrology of much of the area and resulted in wetland loss and degradation. In 2002-2003, Seney staff installed 16 earthen plugs within Walsh Ditch to stop the linear flow of water out of the system and restore the hydrology to drained wetlands. Studies documented the relative success of these treatments in promoting more natural plant successional pathways, with some of the success likely a product of the landscape context in which the work was done (Bork et al. 2013). Several impoundments were developed during the late 1930s – late 1950s to provide habitat for waterfowl by building dikes to intercept surface flow and increase open water surface area. Wilcox et al. (2006)

examined one of these pools and found the dike elevated the water table in upstream wetlands and lowered it in downstream wetlands. Kowalski and Wilcox (2003) found the altered hydrology resulted in reduced plant species richness in wetlands below the dike. In 2013, Seney staff constructed three water crossings along a main dike in the western third of the refuge to restore surface and sub-surface water flow to the Driggs River and potentially rehabilitate upstream wetlands. Although studies are being conducted (M. Jackson *In Prep.*) to evaluate the hydrologic effects of these treatments on plant communities and ecosystem functions, no studies of marsh bird community responses have been conducted. Seney therefore provided a unique opportunity to evaluate marsh bird use of altered (both partially drained and impounded), restored, and reference wetlands and relate the same to ecological processes critical to wetland functions.

Munuscong State Wildlife Management Area (SWMA)

Munuscong SWMA covers approximately 5,832 ha of lowland deciduous, coniferous, and mixed forest and emergent wetlands associated with Munuscong Bay of the St. Mary's River (Figure 1). The Great Lakes coastal wetland complex associated with Munuscong Bay encompasses over 4,000 ha of wet meadow, emergent marsh, and shallow aquatic bed wetlands (G. Soulliere, USFWS, personal communication). This area has a long history of waterfowl management and provides an important stopover for migrant waterfowl. The Michigan Department of Natural Resources (MDNR) developed three impoundments in coastal wetland on Munuscong Bay through the construction of a system of dikes and control structures, which were managed for waterfowl through the mid-1990s. The MDNR reestablished connections between these impoundments and the St. Mary's River in 1995 by excavating several openings in the dike system. Our examination of aerial photographs taken after the dike openings were constructed indicates expansion of emergent wetland within the northernmost impoundment during a recent period of low Great Lakes water levels, whereas the southern two impoundments appear to remain partially flooded by the remnant dike system and beaver activity. We have found no investigations of marsh bird or wetland response to these hydrologic reconnections as compared to the vast area of relatively undisturbed wetlands of Munuscong Bay. There are also areas now in state ownership that were partially drained via shallow surface furrows and ditches to facilitate agricultural use (forage production and pasture) when in private ownership. This area provided an opportunity to compare marsh bird use of rehabilitated, altered (lowered and raised), and reference coastal wetlands.

Sturgeon River Sloughs SWMA

Sturgeon River Sloughs SWMA consists of approximately 3,135 ha of peatlands (e.g., bog, muskeg, poor fen), some of which are managed by MDNR for waterfowl using dikes and water control structures constructed in the 1970s – 1990s. A portion of the wildlife area was previously farmed for forage crops as part of a dairy operation (G. Soulliere, USFWS, personal communication). The area also includes reference wetlands along the Portage River, which transects the Keweenaw Peninsula and is connected to Lake Superior. We know of no evaluations of secretive marsh bird use of the managed or reference wetlands in this wetland complex. Sturgeon River Sloughs SWMA facilitated comparisons of marsh bird use of altered wetlands managed for waterfowl with nearby reference sites representative of conditions prior to the installation of water control infrastructure.

Birds

We conducted surveys between mid-May and late June according to the Standardized North American Marsh Bird Monitoring Protocols (Conway 2011). Surveys were completed at randomly selected points within emergent wetlands using the sample design described by Johnson et al. (2009), with survey stations spaced by ≥400 m (Conway 2011). Ten-min surveys consisted of an initial five-min passive listening period followed by one-min audio broadcast periods for five secretive marsh bird species (American Bittern [*Botaurus lentiginosus*], Least Bittern [*Ixobrychus exilis*], Virginia Rail [*Rallus limicola*], Sora [*Porzana carolina*], and Yellow Rail). Surveys were done during three time periods spaced across the breeding season according to Conway (2011). We surveyed eight focal species (Pied-billed Grebe [*Podilymbus podiceps*], American Bittern, Least Bittern, Virginia Rail, Sora, Yellow Rail, American Coot [*Fulica americana*], and Wilson's Snipe) and seven "non-focal" species, (Sandhill Crane [*Grus canadensis*], Black Tern, Forster's Tern [*Sterna forsteri*], Sedge Wren [*Cistothorus platensis*], Marsh Wren [*Cistothorus palustris*], Le Conte's Sparrow [*Ammodramus leconteii*], and Swamp Sparrow [*Melospiza georgiana*]), which is consistent with ongoing marsh bird survey programs in the region (e.g., Michigan Bird Conservation Initiative 2015). Surveyors estimated distances from count stations to birds using a laser rangefinder; distances to focal species were estimated to the nearest five meters, whereas observations of non-focal species were recorded in one of three distance categories (≤50 m, >50-100 m, and >100 m).

Wetland Characteristics

We surveyed wetland characteristics at a subsample of survey points to facilitate analyses of relationships between marsh bird occurrence and wetland variables. We characterized marsh bird habitat at all study sites following the methodology of Monfils et al. (2014b) by sampling three randomly selected 0.5 m × 0.5 m (0.25 m^2) quadrats within 25 m of each point count station. Quadrat sampling occurred between mid-June and mid-August. We estimated percent cover of six plant taxa (cattail [*Typha* spp.], bulrush [*Schoenoplectus* spp.], sedge [*Carex* spp.], rush [*Juncus* spp.], common reed [*Phragmites australis*], and grass [other than common reed]) and the following structural groups: emergents (all herbaceous emergent plants combined), persistent deep-water emergents (e.g., *Typha* spp., *Schoenoplectus* spp.), persistent shallow-water emergents (e.g., *P. australis*, *Carex* spp.), non-persistent deep-water emergents (e.g., *Sagittaria* spp., *Zizania* spp.), non-persistent shallow-water emergents (e.g., *Eleocharis* spp., *Polygonum* spp.), floating-leaved and free-floating vegetation (e.g., *Nuphar* spp., *Lemna* spp.), and submersed aquatic species (e.g., *Potamogeton* spp., *Chara* spp.). We also measured water depth, depth of organic sediments, and maximum height of standing live or dead vegetation, and counted live and dead shrub and tree stems > 2 m tall within 2.5 m of the quadrat center (Riffell et al. 2001). Depth of organic sediments was estimated to the nearest cm by pushing a 1.25-m wooden rod (2-cm diameter, graduated in cm) to the bottom of the organic layer and measuring the depth of the sediments minus water depth. We also counted the number of cattail, bulrush, and common reed stems within each quadrat.

Analysis

We assessed bird use of our four hydrologic categories of wetlands (altered – raised, altered – lowered, rehabilitated, and reference) using multivariate, mixed model, and logistic regression analyses. Bird abundance and occupancy were determined using detections within 100 m of each point. The 100-m radius threshold was selected because we were confident all species could be accurately detected and distances estimated within this area. Data collected specifically for this project (2015-2017) were combined with results of surveys conducted within BCR 12 for the Michigan Marsh Bird Survey (2010-2017). All points were categorized according to the four hydrologic categories defined for this study based on aerial photo interpretation and onsite visits.

Multivariate: We used nonmetric multidimensional scaling (NMS) to explore possible patterns in relative abundance of marsh bird species among our four hydrologic types. To minimize the influence of rare or nonbreeding transient species, we only included bird species detected at >5% of the points (McCune and Grace 2002), which resulted in eight species (American Bittern, Sandhill Crane, Sora, Virginia Rail, Wilson's Snipe, Sedge Wren, Marsh Wren, and Swamp Sparrow) being included. We averaged bird abundance (detections within 100 m) by year and point before analysis. Because coefficients of variation were > 100, we relativized the bird and habitat data prior to analysis (McCune and Grace 2002). We performed NMS using the Bray-Curtis distance measure, 250 runs on the original data matrix, and a maximum of 500 iterations. A final solution was achieved when an instability value of 0. 0000001 was obtained or after 500 iterations.

We then investigated potential associations of overall bird use with wetland characteristics measured during quadrat sampling and surrounding land cover variables using correlations with bird NMS axis scores. Only those wetland characteristics occurring at >10% of the points were included and we removed variables highly correlated with other variables ($r \geq 0.50$), resulting in 13 variables examined for correlations with NMS scores. In addition, we used land cover data from the Coastal Change Analysis Program (C-CAP; National Oceanic and Atmospheric Administration 2018) to characterize a larger area surrounding the survey points. We estimated the proportion of the area within 200 m of each point falling within each C-CAP class. A buffer distance of 200 m was selected to avoid overlap with nearby survey points. We only used land cover variables occurring within >10% of the point buffers and removed variables highly correlated ($r \geq 0.50$) with other cover classes, which resulted in nine variables being included in analyses. Thus, a total of 22 potential habitat variables were used to explore possible associations with the marsh bird NMS scores.

We also conducted a separate NMS analysis to assess patterns in wetland characteristics and land cover variables among the four hydrologic categories using the 13 wetland characteristics and 9 land cover variables described above. The same approach used to run the marsh bird NMS were used for this analysis.

We conducted two multi-response permutation procedures (MRPP) analyses: 1) to test for differences in assemblages of the eight bird species among our four hydrologic categories; and 2) to test for differences in the variables used to describe the potential marsh bird habitat and surrounding the point count stations (i.e., wetland characteristics and surrounding land cover).

We used Bray-Curtis distance measures and natural weighting ($n_i/\Sigma n_i$; Mielke 1984) in the MRPP analysis. In addition to comparing all four groups, we completed pair-wise MRPP comparisons of all possible pairs of the hydrologic categories. We conducted NMS and MRPP analyses using PC-ORD v.6.08 (McCune and Mefford 2011).

Bird Abundance Comparisons: Because some species were rarely detected, we only analyzed eight species detected on at least 10% of the points surveyed across all years. We used a mixed model (PROC MIXED, SAS Institute, Cary, NC) to compare mean abundance per point among the hydrologic categories. The mixed model consisted of hydrologic category and survey period (i.e., early, mid, and late season) as fixed effects, and year, site, and point count station as random effects. We included a repeated measures component to account for multiple surveys at the same point. Four commonly used covariance structures were evaluated for each species: variance components, autoregressive order 1, compound symmetric, and unstructured (Littell et al. 1996, Kincaid 2005). For each species, we compared the four models with the different covariance structures and selected the best-approximating model using Akaike's Information Criterion (AIC). If residuals from initial models using untransformed data were not normally distributed, we log transformed ($\log_e[x + 1]$) abundance in the final analysis.

Wetland Characteristic Comparisons: Variables collected during quadrat sampling were also compared among the hydrologic categories using mixed models. We arcsine-square root transformed ($\arcsin\sqrt{p}$) percent variables and log transformed ($\log_e[x + 1]$) all other variables. We conducted analyses using a mixed model with hydrologic category as a fixed effect and year, site, and point count station as random effects.

Logistic Regression: To assess the potential influence of habitat variables on species' occurrence, we conducted logistic regression analysis for each of the eight marsh bird species analyzed using mixed models. The same 13 variables examined for correlations with NMS scores were included in the regression analysis. Hydrologic category was included in the analysis as a categorical variable, with models evaluating the influence of hydrologic type (i.e., lowered, raised, and rehabilitated) on probably of occurrence as compared to reference points. Bird detections were summarized by point and year; points having a species detected during at least one visit within 100 m were assigned a "1", whereas points lacking detections of the species were given a "0". Variables were selected using a forward stepwise procedure, with the maximum *P*-value for model entry being 0.20.

RESULTS

Marsh bird use was assessed using data from nearly 1,800 point counts conducted during 2010-2017 at over 200 points within the boreal hardwood transition zone representing a range of hydrologic conditions (Figure 1, Table 1). We created 88 new marsh bird survey points specifically for this study in the eastern and western Upper Peninsula and conducted 591 point counts at these points during 2015-2017. In addition, we summarized data from 124 points surveyed within BCR 12 as part of the Michigan Marsh Bird Survey, which provided information from another 1,207 point counts during 2010-2017.

All 15 of our survey species were detected during our study period (2010-2017; Table 2), with 11 species detected on lowered points (Pied-billed Grebe, American Coot, Black Tern, and Forster's Tern not detected), 14 species at raised (Forster's Tern not detected), 12 species at rehabilitated (Yellow Rail and Forster's Tern not detected), and 14 species at reference points (American Coot not detected). Swamp Sparrow was the most commonly observed species in each of the four hydrologic categories. Pied-billed Grebe and Sora were detected more often at raised points, whereas Sedge Wren and Le Conte's Sparrow were observed at greater rates at lowered points compared to the other hydrologic categories. American Bittern, Virginia Rail, Sandhill Crane, and Wilson's Snipe were most often detected at rehabilitated points. Pied-billed Grebe, Least Bittern, Yellow Rail, American Coot, Black Tern, Forster's Tern, and Le Conte's Sparrow were only rarely detected, regardless of hydrologic category.

Table 1. Number of points surveyed and point counts conducted for marsh birds during 2010-2017 by location and hydrologic category within the boreal hardwood transition zone in Michigan.

		Points Surveyed					Point Counts				
State Zone	Wetland Location	Lowered	Raised	Rehabilitated	Reference	Total	Lowered	Raised	Rehabilitated	Reference	Total
E. Upper Peninsula	Inland	10	17	19	41	87	81	116	120	265	582
	Coastal	7	7	6	18	38	55	71	51	180	357
W. Upper Peninsula	Inland	0	15	0	14	29	0	147	0	215	362
	Coastal	0	0	0	5	5	0	0	0	45	45
N. Lower Peninsula	Inland	1	21	0	21	43	9	168	0	203	380
	Coastal	0	5	0	5	10	0	41	0	31	72
Total		18	65	25	104	212	145	543	171	939	1,798

Table 2. Proportion of points occupied by marsh bird species surveyed during 2010-2017 within the boreal hardwood transition zone in Michigan (*n* indicates the number of point counts conducted).

	Lowered (n = 145)	Raised (n = 543)	Rehabilitated (n = 171)	Reference (n = 939)
Pied-billed Grebe	---	0.05	0.03	0.03
American Bittern	0.30	0.35	0.52	0.15
Least Bittern	0.02	0.05	0.05	0.03
Yellow Rail	0.02	0.01	---	0.01
Virginia Rail	0.02	0.18	0.19	0.10
Sora	0.06	0.24	0.21	0.10
American Coot	---	0.01	---	---
Sandhill Crane	0.09	0.19	0.22	0.08
Wilson's Snipe	0.19	0.23	0.35	0.06
Black Tern	---	0.02	0.10	0.02
Forster's Tern	---	---	---	0.01
Marsh Wren	0.04	0.09	0.14	0.08
Sedge Wren	0.69	0.38	0.35	0.18
Swamp Sparrow	0.83	0.82	0.90	0.58
Le Conte's Sparrow	0.11	0.02	0.02	0.01

Initial NMS analysis of marsh bird abundance suggested the data were best represented by three dimensions. After rerunning NMS with only three dimensions, 69.4% of the variation in the original distance matrix was explained (final stress of 16.34). Dimension one scores were positively correlated with water depth and negatively associated with percent cover of persistent shallow-water emergents and proportion of forested wetland within 200 m. In the second dimension, NMS scores were positively associated with vegetation height and water depth and negatively correlated with percent cover of moss and proportion of scrub-shrub wetland within 200 m. Although there was no visual distinction in the marsh bird data according to our four hydrologic categories for any of the three dimensions (Figure 2), MRPP analysis indicated differences in bird assemblages among the four types (T = -14.15, A = 0.02, $P < 0.0001$). Pair-wise permutation tests also suggested that bird use of each hydrologic category was significantly different from the other three ($P \leq 0.0010$).

Our NMS analysis of wetland and land cover variables was also best represented by three dimensions, which explained 73.7% of the variation in the original distance matrix (final stress = 19.43). The first dimension largely represented a gradient of surrounding land cover, with NMS scores being positively related to the proportion of emergent wetland within 200 m and negatively associated with the proportion of coniferous forest, deciduous forest, and herbaceous cover within 200 m. Dimension two was positively correlated with water depth, proportion of open water, proportion of bare land, and percent cover of submersed plants, and negatively associated with proportion of scrub-shrub wetland within 200 m. There was no visual separation

of the sample points by hydrologic category in any of the three dimensions (Figure 3). Permutation tests suggested differences in the habitat variables among the four types (T = -18.70, A = 0.02, P < 0.0001), and all pair-wise MRPP comparisons were significantly different (P < 0.0001).

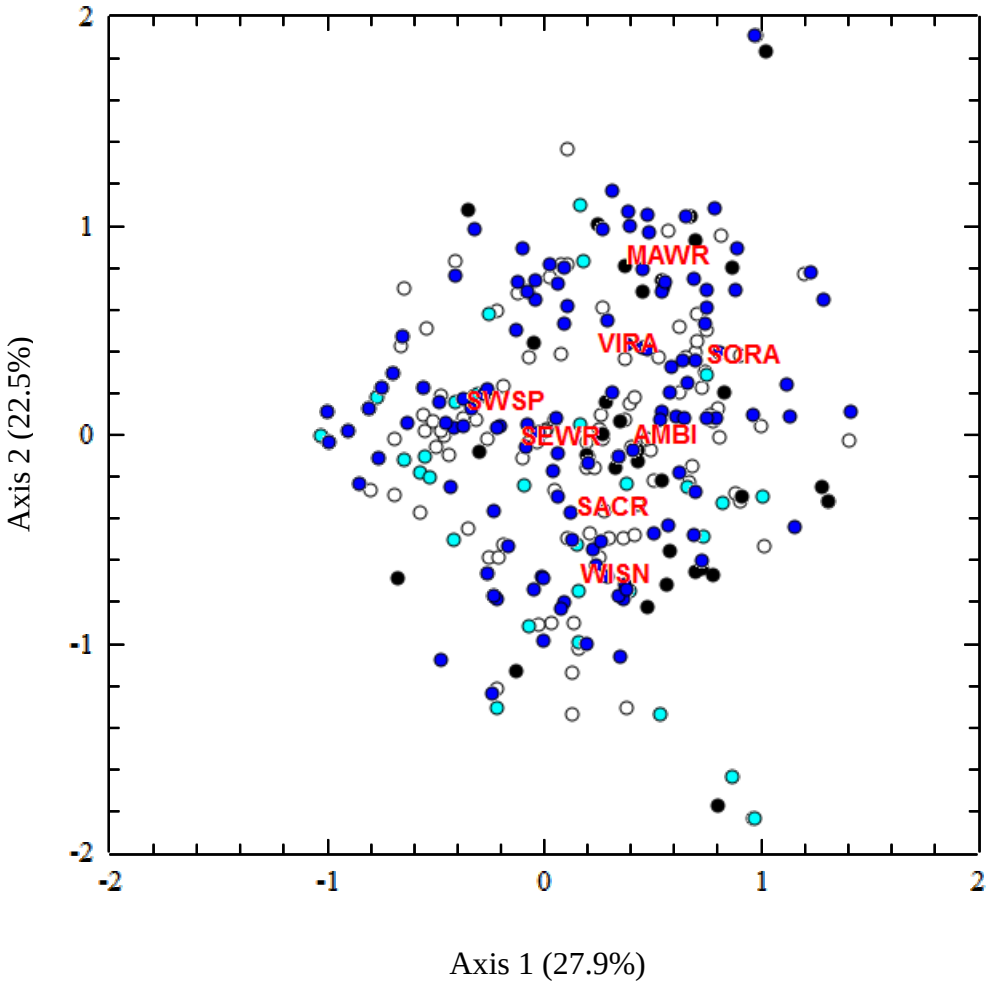

Figure 2. Biplot of first and second dimensions from non-metric multi-dimensional scaling of secretive marsh bird abundance in BCR 12 during 2012-2017. Points are coded by hydrologic category as follows: black = lowered; blue = raised; light blue = rehabilitated; and white = reference. Species are coded as follows: AMBI = American Bittern; MAWR = Marsh Wren; SACR = Sandhill Crane; SEWR = Sedge Wren; SWSP = Swamp Sparrow; VIRA = Virginia Rail; and WISN = Wilson's Snipe.

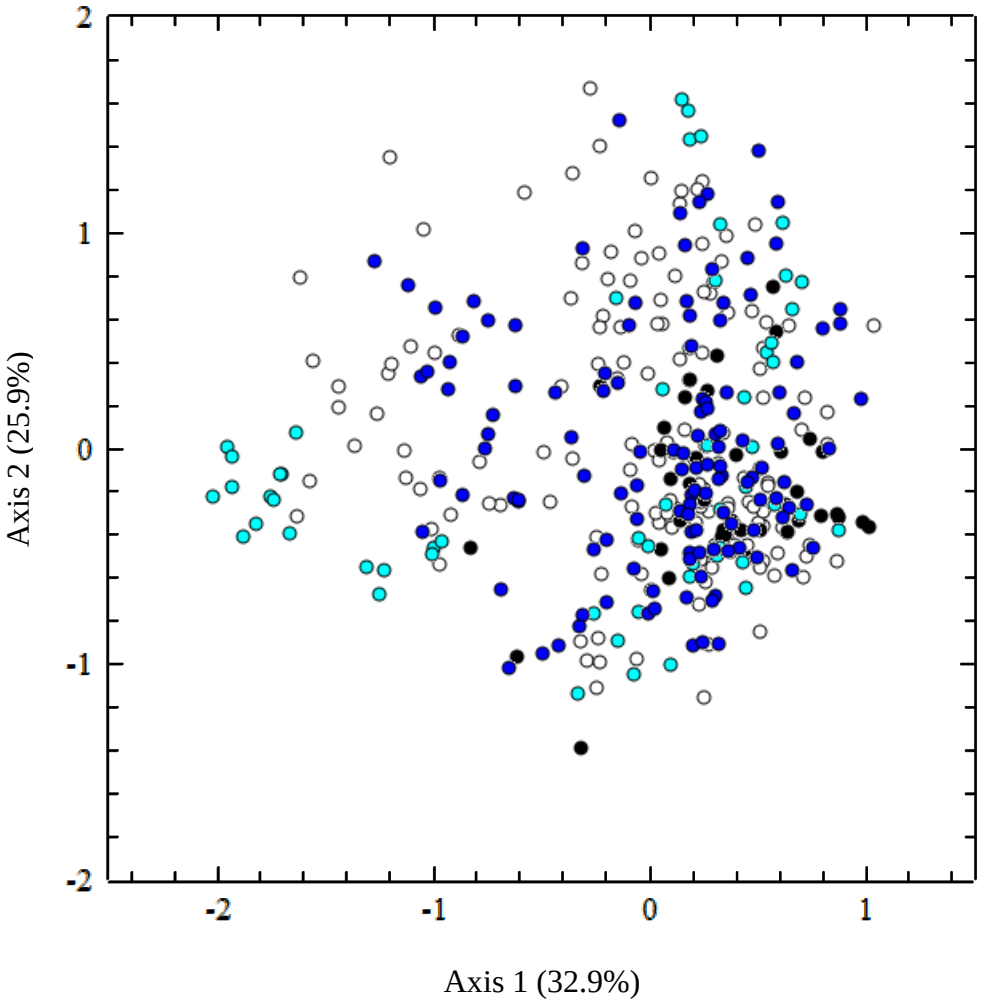

Figure 3. Biplot of first and second dimensions from non-metric multi-dimensional scaling of wetland characteristics and surrounding land cover at points surveyed for secretive marsh birds in BCR 12 during 2012-2017. Points are coded by hydrologic category as follows: black = lowered; blue = raised; light blue = rehabilitated; and white = reference.

Eight of the species surveyed were detected often enough to facilitate statistical comparison, of which two differed significantly among the four hydrologic categories (Table 3). Abundance of Wilson's Snipe was greatest at rehabilitated points compared to the other wetland types ($F_{3, 1577}$ = 4.74, P = 0.0027). Sedge Wren abundance was similar between lowered and raised points and greater than abundance at rehabilitated and reference wetlands ($F_{3, 1577}$ = 8.09, P < 0.0001). Estimated abundances for all other species were similar among hydrologic types (Table 3).

Mean values of eight (31 %) of the 26 wetland characteristics measured during quadrat sampling differed among the four hydrologic categories (Table 4). Lowered points had significantly lower percent cover of open water ($F_{3, 1086}$ = 4.48, P = 0.0039) and greater percent cover of litter ($F_{3, 1086}$ = 4.73, P = 0.0028) compared to the other types. Depth of organic sediments was greater at altered sites (lowered and raised) compared to rehabilitated and reference points ($F_{3, 1074}$ = 6.34, P = 0.0003). Although the five remaining variables, water depth and percent cover of submersed plants, moss, persistent shallow-water emergents, and *Phragmites*, differed among the hydrologic categories, pair-wise comparisons indicated complicated relationships and substantial variance and overlap among the types (Table 4).

Table 3. Comparison of marsh bird mean abundance (detections within 100 m) by hydrologic category within the boreal hardwood transition of Michigan during 2010-2017 (*n* indicates the number of point counts conducted). Significant *P*-values ($P < 0.05$) are bolded and means preceded by the same letter were not significantly different ($P > 0.05$).

	Lowered (n = 145)				Raised (n = 543)				Rehabilitated (n = 171)				Reference (n = 939)			
Species		Mean	LCL	UCL		Mean	LCL	UCL		Mean	LCL	UCL		Mean	LCL	UCL	*P*-value
Pied-billed Grebe		---	---	---		0.03	---	---		0.02	---	---		0.01	---	---	NA
American Bittern		0.05	-0.03	0.13		0.11	0.05	0.18		0.14	0.04	0.25		0.12	0.07	0.18	0.2169
Least Bittern		0.01	---	---		0.03	---	---		0.02	---	---		0.01	---	---	NA
Yellow Rail		<0.01	---	---		<0.01	---	---		---	---	---		<0.01	---	---	NA
Virginia Rail		<0.01	-0.08	0.05		0.09	0.05	0.13		0.06	-0.01	0.14		0.06	0.02	0.09	0.0579
Sora		<0.01	-0.12	0.05		0.08	0.02	0.14		0.07	-0.03	0.19		0.09	0.03	0.14	0.0716
American Coot		---	---	---		<0.01	---	---		---	---	---		---	---	---	NA
Sandhill Crane		0.03	-0.03	0.09		0.08	0.04	0.12		0.12	0.05	0.20		0.05	0.02	0.08	0.1304
Wilson's Snipe	A	0.05	<0.01	0.11	A	0.06	0.02	0.10	B	0.17	0.10	0.25	A	0.03	<0.01	0.06	**0.0027**
Black Tern		---	---	---		0.01	---	---		0.35	---	---		0.01	---	---	NA
Forster's Tern		---	---	---		---	---	---		---	---	---		<0.01	---	---	NA
Marsh Wren		<0.01	-0.09	0.09		0.04	-0.02	0.10		0.02	-0.07	0.13		0.09	0.04	0.14	0.2026
Sedge Wren	A	0.54	0.32	0.79	A	0.38	0.24	0.54	B	0.17	-0.03	0.40	B	0.11	0.01	0.21	**<0.0001**
Swamp Sparrow		0.77	0.45	1.15		0.89	0.63	1.20		0.78	0.39	1.27		0.64	0.44	0.88	0.2799
Le Conte's Sparrow		0.06	---	---		0.01	---	---		0.01	---	---		<0.01	---	---	NA

Table 4. Comparison of mean wetland characteristics by hydrologic category within the boreal hardwood transition of Michigan during 2012-2017 (*n* indicates the number of quadrats sampled). Significant *P*-values ($P < 0.05$) are bolded and means preceded by the same letter were not significantly different ($P > 0.05$).

Wetland Characteristic		Lowered (*n* = 126)				Raised (*n* = 393)				Rehabilitated (*n* = 168)				Reference (*n* = 599)			*P*-value
		Mean	LCL	UCL		Mean	LCL	UCL		Mean	LCL	UCL		Mean	LCL	UCL	
Percent cover																	
Emergent		56.7	36.6	75.7		44.4	26.4	63.1		45.2	25.0	66.4		43.2	25.7	61.7	0.0887
Open water/ aquatic bed	A	0.7	-2.4	10.1	B	18.4	6.2	35.2	B	16.4	2.6	38.7	B	17.05	5.86	32.52	**0.0039**
Submersed	A	<0.1	<0.1	<0.1	BC	0.1	<0.1	0.3	AC	<0.1	-0.2	0.1	B	0.1	<0.1	0.4	**0.0072**
Floating		<0.1	-0.1	0.1		0.1	<0.1	0.3		<0.1	<0.1	0.21		<0.1	<0.1	0.1	0.1325
Algae		<0.1	-0.2	0.2		0.1	<0.1	0.3		<0.1	-0.2	0.3		<0.1	<0.1	0.2	0.8217
Moss	A	7.6	1.7	17.2	BC	0.6	-0.2	3.9	BC	<0.1	-3.8	3.3	AC	3.0	0.4	8.1	**0.0093**
Bare substrate		<0.1	<0.1	0.3		0.1	<0.1	0.3		<0.1	<0.1	0.5		0.3	0.1	0.5	0.2893
Litter	A	79.4	60.6	93.2	B	56.6	42.0	70.6	B	42.4	21.6	64.8	B	43.2	30.6	56.2	**0.0028**
Persistent deep		0.1	<0.1	0.8		0.3	0.1	0.9		0.2	<0.1	1.0		0.2	<0.1	0.6	0.8757
Persistent shallow	A	40.1	27.2	53.9	AB	29.1	19.7	39.5	B	18.3	8.3	31.0	B	25.6	17.2	35.0	**0.0191**
Non-persistent deep		<0.1	<0.1	<0.1		<0.1	<0.1	<0.1		<0.1	<0.1	<0.1		<0.1	<0.1	<0.1	0.6122
Non-persistent shallow		2.6	0.6	5.8		1.9	0.6	3.8		2.7	0.7	6.0		2.2	0.9	4.0	0.8786
Woody plants		6.1	0.9	15.3		3.8	0.5	10.0		9.3	2.5	19.9		4.9	1.0	11.3	0.3155
Typha spp.		0.1	<0.1	0.7		0.2	<0.1	0.7		0.1	<0.1	0.8		0.2	<0.1	0.5	0.9596

Table 4. Continued.

Wetland Characteristic		Lowered (*n* = 126) Mean	LCL	UCL		Raised (*n* = 393) Mean	LCL	UCL		Rehabilitated (*n* = 168) Mean	LCL	UCL		Reference (*n* = 599) Mean	LCL	UCL	*P*-value
Schoeno-plectus		<0.1	<0.1	<0.1		<0.1	<0.1	<0.1		<0.1	<0.1	<0.1		<0.1	<0.1	<0.1	0.5377
Phragmites australis		<0.1	-0.1	0.1		<0.1	<0.1	<0.1		<0.1	-0.1	0.1		<0.1	<0.1	0.1	0.1145
Carex spp.		16.1	8.1	26.1		14.6	8.2	22.4		10.4	3.7	19.9		11.0	5.8	17.7	0.3474
Juncus spp.		0.1	-0.2	0.8		0.3	<0.1	1.3		0.7	<0.1	2.4		0.1	-0.1	0.7	0.1009
Grasses combined		10.5	1.7	25.5		5.0	0.2	15.7		6.5	0.2	20.6		5.6	0.4	16.4	0.3356
Stem density																	
Typha[1]		0.3	-0.1	0.8		0.4	0.1	0.8		0.3	-0.1	0.8		0.3	0.1	0.6	0.9312
Schoeno-plectus[1]		0	0	0		0.4	0.1	0.7		0.3	-0.2	0.7		0.1	-0.1	0.4	0.4356
Phragmites australis[1]	A	<0.1	-0.1	0.1	A	<0.1	-0.1	0.1	AB	<0.1	-0.1	0.2	B	0.1	<0.1	0.2	**0.0441**
Woody plants[2]		0.5	0.0	1.2		0.5	0.1	0.9		0.6	0.1	1.3		1.0	0.5	1.5	0.1079
Vegetation height (cm)		107.3	89.5	128.6		112.6	96.3	131.7		117.7	95.2	145.3		114.4	98.5	132.8	0.7875
Water depth (cm)	A	0.6	-0.3	2.7	B	4.4	1.8	9.6	B	2.8	0.6	8.0	AB	4.0	1.7	8.5	**0.0022**
Organic sediment (cm)	A	53.1	37.9	68.3	A	60.3	48.4	72.1	B	41.8	24.0	59.7	B	36.0	25.0	47.0	**0.0003**

[1]No. stems per 0.25 m^2 quadrat.
[2]No. stems >2 m tall per 20 m^2 (i.e., within 2.5-m radius of quadrat center).

Of the 23 potential variables included in logistic regression analyses, 17 were selected in the model of at least one species (Table 4). Six of the eight species showed a positive association with raised points as compared to reference sites. Wilson's Snipe, Sedge Wren, and Swamp Sparrow appeared to occur more often at lowered, raised, and rehabilitated points than in reference wetlands. American Bittern was detected more often at raised and rehabilitated points as compared to reference points. Sora and Virginia Rail were positively associated with raised points than at reference sites.

Thirteen variables collected during quadrat sampling were included in regression analyses, with three variables, vegetation height, water depth, percent cover of moss, being selected in at least half of the models. American Bittern, Sora, Virginia Rail, and Marsh Wren occurrence was positively associated with water depth, whereas Sedge Wren was negatively related to water depth. The occurrence of three species (Virginia Rail, Marsh Wren, and Swamp Sparrow) was positively related with vegetation height, but Wilson's Snipe was negatively associated with height. American Bittern, Wilson's Snipe, Sedge Wren, and Swamp Sparrow were all negatively related to percent cover of moss. Six of the other wetland characteristics were selected in one or two of the species' models (Table 4).

Of the nine land cover variables included in analyses, the proportion of emergent wetland within 200 m was selected most often, with six species being positively associated with the variable. Three species, American Bittern, Sora, and Marsh Wren, were also positively related to the proportion of open water within 200 m of the points. Five of the remaining land cover variables were selected in one or two of the models (Table 4).

Table 4. Variables included in stepwise logistic regression analyses conducted using wetland characteristics from quadrat sampling and land cover information for eight marsh bird species detected during surveys in Michigan, 2012—2017. Positive and negative signs indicate direction of association between probability of occurrence and variable. The total number of species having a given variable selected in the models is listed.

Variable	American Bittern	Sandhill Crane	Sora	Virginia Rail	Wilson's Snipe	Sedge Wren	Marsh Wren	Swamp Sparrow	No. species
Hydrologic category									
Lowered vs. Reference					+	+		+	3
Raised vs. Reference	+		+	+	+	+		+	6
Rehabilitated vs. Reference	+				+	+		+	4
Wetland Characteristic									
Vegetation height				+	-		+	+	4
Water depth	+		+	+		-	+		5
Organic sediment depth				-					1
% Submersed									
% Floating			-						1
% Moss	-				-	-		-	4
% Bare substrate								-	1
% Persistent deep	-								1
% *Carex* spp.		+			+				2
% *Juncus* spp.									0
% Persistent shallow		-							1
% Non-persistent shallow									0
% Woody plants									0
Land Cover Class (proportions)									
Low-intensity development									0
Grassland/herbaceous					+		+		2
Deciduous forest									0
Coniferous forest		-							1
Bare land				+	+				2
Palustrine forested	-								1
Palustrine scrub-shrub	+				+				2
Palustrine emergent	+		+	+		+	+	+	6
Open water	+		+				+		3

DISCUSSION

We evaluated marsh bird use in the boreal hardwood transition zone at sites representing a range of hydrologic conditions, from partially drained to impounded and rehabilitated. Our goal was to compare marsh bird use of sites with altered and rehabilitated hydrology with unaltered reference wetlands to better understand the influence of hydrology on marsh birds and their habitats and inform future wetland management and restoration. Although multivariate MRPP tests indicated differences in marsh bird assemblages among the four hydrologic types examined, our NMS analysis showed no visual separation of points according to hydrologic category and we found abundances only differed for two species. McCune and Grace (2002) cautioned that significant differences can result from MRPP even when the effect size (*A*) is small in cases of large sample size (e.g., >200), leaving the researcher to consider the ecological significance of such results. For the species considered in this study, our abundance and naïve occupancy results suggest that sites with altered (lowered or raised) and rehabilitated hydrology supported marsh bird use at levels similar to or greater than reference wetlands. Logistic regression analysis indicated that six of eight species were more likely to occur at altered or rehabilitated points than at reference locations. Tozer et al. (2018) found probability of occupancy for several marsh bird species was greater within conservation projects (i.e., wetlands with managed water levels) compared to unmanaged wetlands in the southeastern Great Lakes. Galloway et al. (2006) similarly observed greater indices of abundance for marsh-nesting obligate birds, marsh-nesting generalists, and area-sensitive marsh-nesting obligates in diked compared to undiked coastal wetlands in southern Ontario. In Wisconsin, probability of occupancy by American Bittern, Virginia Rail, and Sora was greater in natural compared to restored sites, which were characterized by greater abundance of reed canarygrass (*Phalaris arundinacea*) and lower average coefficients of conservatism (Glisson et al. 2015). In Michigan coastal wetlands of Saginaw Bay and the St. Clair Flats, densities of American Bittern, Least Bittern, and Common Gallinule were greater in diked compared to undiked wetlands, whereas American Coot and Forster's Tern were more abundant in undiked marshes (Monfils et al. 2014a).

Although our results indicate positive marsh bird response to activities implemented to restore wetland hydrology in BCR 12, our study was limited by the availability of suitable restoration projects, which resulted in a relatively small sample size of rehabilitated points located in the eastern Upper Peninsula. We chose sites where large-scale restoration of the original hydrology was the primary goal, which we only found in large inland and coastal wetland complexes. We examined restoration projects in other parts of the region (e.g., western Upper Peninsula), but these sites were small (< 5 ha), often included activities to increase water depths above original levels (i.e., excavation, berm construction), and likely resulted in wetland types different than what occurred historically. These and similar sites would have resulted in an "apples to oranges" comparison with altered and reference wetlands of the region, such as those of Seney NWR, Sturgeon River Sloughs, and along the St. Mary's River and Lake Huron. Although assessment of restored and compensatory mitigation wetlands is sorely needed, our study highlights the difficulties in defining and identifying restored wetlands and finding appropriate reference sites for comparison. For example, wetland restoration projects in the Great Lakes/Midwest usually consist of small ditch plugs and/or drain tile removals on private lands and often include shallow excavation, berm construction, and water control structure installation. In addition to plugging ditches and removing tiles, larger projects sometimes include more elaborate systems of berms,

dikes, and water control structures. Such projects are not likely to be considered as restoration by ecologists (see International Primer on Ecological Restoration [Society for Ecological Restoration International 2004]) and may better be defined as replacement or reclamation (see definitions in Bradshaw 1996). Consistency in terminology and approaches to the assessment of restoration projects is needed in the conservation community. Strategic habitat conservation, that is, the iterative cycle of planning, implementation, and evaluation, would benefit from a regional approach to defining and assessing conservation actions. Further, research similar to this study should be replicated in other parts of the Great Lakes and Midwest regions, because the results are likely to differ in more degraded landscapes, as indicated by the Glisson et al. (2015) study in southern Wisconsin.

We used logistic regression to understand the potential influence of wetland characteristics (within 25 m of points) and land cover variables (within 200 m of points) on the occurrence of marsh birds. Water depth, vegetation height, and percent cover of moss appeared to be important predictors of occurrence for several marsh bird species at the fine scale, which is consistent with previous research. For example, Baschuk et al. (2012) observed American Bittern density to be positively associated with water depth in boreal wetlands of Manitoba. In western New York, Lor and Malecki (2006) found average water depth was a significant variable in their best-approximating American Bittern, Virginia Rail, and Sora models, and vegetation height was a variable in the Virginia Rail and Sora models. Occurrence of four species was negatively associated with percent cover of moss in our study, but we found no previous research indicating significant relationships between moss cover and marsh bird metrics. Moss is not a major component of many emergent marsh systems and in our review of past studies, we did not see it being sampled or included in analyses. However, moss (e.g., *Sphagnum* spp.) is regularly found in emergent wetlands of the boreal hardwood transition zone and was often observed in the wetlands sampled for this study.

With regard to land cover variables, the proportion of emergent wetland within 200 m was the variable most often selected in our logistic regression models (six species), followed by proportion of open water (three species). Although the scale at which variables were estimated varied widely (e.g., 500 – 5,000 m), several researchers noted associations between marsh bird metrics or indices of marsh bird communities and the amount of emergent wetland in the surrounding landscape (Craig and Beal 1992, Naugle et al. 1999, Fairbairn and Dinsmore 2001, Rehm and Baldassarre 2007, Smith and Chow-Fraser 2010, Panci et al. 2017). Some studies also found relationships between marsh bird use and percentage of open water within the wetlands being surveyed (Craig and Beal 1992, Murkin et al. 1997, Moore et al. 2009).

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