DEVELOPMENT OF AVIAN METRICS

TO MONITOR SALT MARSH INTEGRITY

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Salt marshes are dynamic, highly productive ecosystems that have historically experienced a variety of anthropogenic alterations. Such changes have caused a number of endemic species to become high conservation priorities in the United States. Salt marsh condition must be monitored to develop successful management strategies for wildlife conservation. Avian community structure was evaluated and used to create a Marsh Bird Community Integrity Index (BCI) to assess marsh condition at 184 points across nine Northeast national wildlife refuges (NWR) and refuge complexes. Mean refuge BCI was greatest at E.B. Forsythe NWR and mean survey point BCI was significantly different between marshes of different marsh management types (e.g. ditched, tidal restricted, reference) at four refuges. At the local scale, BCI was positively influenced by percent cover of high marsh and negatively influenced by percent cover of open water. At the landscape scale, BCI was negatively influenced by percent cover of forest, development, and palustrine wetland. A BCI scale can be used to monitor temporal and spatial variations in BCI and to attribute condition labels, "Good", "Caution", and "Concern", to refuge marshes.

Monitoring plays an integral role in wildlife conservation efforts; however most monitoring programs are fiscally constrained and must determine how to acquire needed information with minimal resources. Monitoring objectives may be achieved by supplementing costlier intensive assessment metrics with appropriate cost-efficient rapid metrics, and by monitoring specific taxa as indicators of ecosystem health. A subset of the 184 points, located at the Coastal Delaware NWR Complex, was used to evaluate differences in rapid versus intensive avian assessment metrics. Overall, occupancy and relative abundance estimations for four tidal marsh obligate species increased as number of visits increased, however there was a greater positive effect of number of visits on differences between relative abundance estimates than occupancy estimates. Comparisons between metrics of a potential indicator species, Seaside Sparrow, resulted in significant positive relationships between the rapid metric relative abundance and intensive avian metrics, nest density, fledgling density, and territory density. This research supports using birds to monitor the ecological condition of the surrounding salt marsh to improve management decisions and maximize conservation gains.

INTRODUCTION

Tidal marsh ecosystems form the interface between the ocean and the land, playing a vital role in marine and terrestrial ecological processes (Bertness 1999). Although tidal marshes extend across thousands of kilometers of coastline in predominately temperate latitudes, the actual worldwide area extent of marshes only covers approximately 45,000 km^2 (Greenburg 2006). Naturally extreme hydrology, salinity, and soil conditions, and the narrow linear nature of salt marshes have meant that few species are truly restricted to salt marsh habitats. In spite of these conditions, North American tidal salt marshes boast a high proportion of endemic taxa and are one of the most productive ecosystems in the world (Greenburg 2006). Unfortunately, minimal pristine salt marsh habitat remains and local, regional, and global changes to the environment have lead to a disproportionately high number of endemic species becoming conservation priorities in the U.S. (Pashley et al. 2000, Greenburg 2006).

Coastal national wildlife refuges (NWRs) protect over 1 million acres of salt marsh habitat in tidal marsh ecosystems in the lower 48 states (CCSP et al. 2008). The National Wildlife Refuge System (NWRS) is managed according to the National Wildlife Refuge System Administration Act of 1966 as amended by the National Wildlife Refuge System Improvement Act of 1997, 16 U.S.C. 668dd-668ee (Refuge Administration Act). The law establishes wildlife conservation as the fundamental mission of the NWRS, and that this mission be achieved by maintaining, and where appropriate, restoring the biological integrity, diversity, and environmental health of each refuge for the benefit of present and future generations of Americans. Appropriate methods to assess and monitor the biological integrity, diversity, and environmental health of refuge salt marsh habitats are necessary in order for refuge staff to develop successful management strategies that will maintain and, when appropriate, improve marsh condition to meet the NWRS mission (Neckles et al. 2008).

The goal of this research was to develop avian metrics as indicators of salt marsh condition. To accomplish this goal I analyzed marsh bird data at both the community and species levels. At the marsh bird community-level, I surveyed the bird community to determine the presence of marsh generalist and specialist species, as well as the relative abundance of tidal marsh obligate species, and used these data to develop a community-level method to evaluate salt marsh integrity. At the species-level, I evaluated differences in rapid versus intensive assessment metrics typically used to monitor salt marsh birds to determine which metrics were most appropriate and feasible for tidal marsh bird monitoring programs. This project is a component of a larger effort lead by the U.S. Geological Survey to develop habitat-based indicators of tidal marsh condition that can be incorporated into a multi-metric index to evaluate ecosystem integrity at national wildlife refuges. The incorporation of the avian metrics determined here into the multi-metric index will enhance the utility of the tool for assessing and monitoring the overall habitat value of tidal marshes for wildlife conservation.

Chapter 1

USING THE MARSH BIRD COMMUNITY AS AN INDICATOR OF SALT MARSH INTEGRITY

INTRODUCTION

Birds are sensitive to alterations to their habitat and as a result changes in bird populations have been shown to be good indicators of environmental change (Verner 1984, Morrison 1986). Birds respond to changes in habitat structure (Riffell et al. 2001) and to disturbances at lower trophic levels (Pettersson et al. 1995). Bird assemblages have been used as effective indicators of biological integrity in forests (O'Connell et al. 1998, Canterbury et al. 2000), rangelands (Bradford et al. 1998), riparian-wetland habitats (Croonquist and Brooks 1991, Bryce et al. 2002), and wetland ecosystems (DeLuca et al. 2004). Additional support for birds as indicator taxa of ecosystem condition stems from the fact that birds are relatively easy and cost-effective to survey, extensive literature on avian biology and life histories exists, and their popularity with the public garners critical support.

Avian community structure in salt marsh ecosystems may be evaluated and used to create an Index of Biological Integrity (IBI) to monitor marsh condition. The U. S. Fish and Wildlife Service (USFWS) defines biological integrity as biotic composition, structure, and functioning at genetic, organism, and community levels comparable with historic conditions, including the natural biological processes that shape genomes, organisms, and communities (U.S. Fish and Wildlife Service 2001). This concept is based on the assumption that the more an ecosystem and its processes are altered by human activities, the less biological integrity the ecosystem will hold, and, if changes occurred naturally over time the integrity of the system would remain unimpaired in the absence of human influence. The IBI and its component metrics may be viewed as ecological dose–response curves, providing an integrative measure of the cumulative biological response to human influences in an area (Karr 2006). Karr (1991) first applied the concept of an IBI to assess ecosystem condition when he linked the structure and function of freshwater fish communities to water quality.

The objectives of this project were to: 1) develop a Marsh Bird Community Integrity Index (BCI) and evaluate marsh bird community integrity, 2) evaluate the effectiveness of the BCI to discriminate among different marsh management treatments, 3) determine if BCI scores were influenced by local and landscape habitat variables, and 4) determine how the BCI could be used as an effective salt marsh integrity monitoring tool.

METHODS

Study Areas

I conducted this research in salt marshes at nine national wildlife refuges and refuge complexes of the USFWS Northeast Region in 2008 (n = 7 refuges) and 2009 (n = 9 refuges). These marshes were classified as Northern Atlantic Coastal Plain Tidal Salt Marsh and range from the southern coast of Maine to the mouth of the Chesapeake Bay, Virginia (Comer et al. 2003). This system of salt marshes occurs on the bayside of barrier beaches and along the outer mouth of tidal rivers where salinity has not been strongly impacted by freshwater. A typical tidal salt marsh profile can be characterized as a low regularly flooded marsh strongly dominated by smooth cordgrass (*Spartina alterniflora*); a higher irregularly flooded marsh dominated by saltmeadow cordgrass (*S. patens*) and saltgrass (*Distichlis spicata*); low hypersaline pannes characterized by glasswort (*Salicornia* spp.); and a salt scrub ecotone characterized by marsh elder (*Iva frutescens*), groundsel tree (*Baccharis halimifolia*), and switchgrass (*Panicum virgatum*). Slightly higher elevated areas also may support eastern redcedar (*Juniperus virginiana*) (Comer et al. 2003).

Refuge study sites span the range of the Northern Atlantic Coastal Plain Tidal Salt Marsh, occurring on a north-south latitudinal gradient along the Atlantic coastline. Study sites, beginning with the northernmost refuge and continuing south, were Rachel Carson, Parker River, Rhode Island Complex (John H. Chafee and Sachuest Point), Stewart B. McKinney, Wertheim, Edwin B. Forsythe, Bombay Hook, Prime Hook, and Eastern Shore of Virginia Complex (Eastern Shore of Virginia and Fisherman Island) (Figure 1.1). U.S. Geological Survey (USGS) and USFWS personnel selected study areas to represent different marsh conditions and management treatments (Neckles et al. 2008). Within each refuge, salt marshes were divided into marsh study units that were delineated based on marsh management treatment and natural hydrologic features. Marsh units represented a single or combination of marsh management treatment types (e.g. ditched, open marsh water management (OMWM), OMWM/ditched). The disturbance severity of each unit was determined to be “high” or “low” based on local knowledge. Survey points in marsh units were chosen using a stratified random sample, stratified by marsh management type, and the number of survey points within each unit was proportional to marsh unit area. If avian sampling points had been previously established at a refuge then those points were used for logistical and financial reasons.

Avian Community Sampling

Seasonal field technicians conducted three call-broadcast surveys at survey points during the breeding season (May - August) following the Standardized North American Marsh Bird Monitoring Protocols (Conway 2008). Surveys included a five-minute passive listening period followed by audio broadcast calls of focal marsh birds to elicit vocalizations and increase detection rates of secretive and infrequently vocalizing marsh birds (Gibbs and Melvin 1993, Conway and Gibbs 2005). Marsh bird species that were broadcast at each refuge depended on the refuge's geographic location and bird species ranges (Table 1.1). I did not use call-broadcast at Rachel Carson because secretive marsh birds do not inhabit the salt marshes there. Calls were broadcast for 30 seconds followed by 30 seconds of silence for each species. Technicians recorded all bird species detected during both the 5-minute passive period and the call-broadcast period. Locations of individual birds were grouped into three distance categories (0 – 50 m, 50 – 100 m, 100+ m). Survey technicians received marsh bird identification training and were instructed on proper monitoring protocol procedures at an avian training workshop prior to each field season. A marsh bird identification test was given at the end of each workshop to evaluate identification skills and minimize observer bias that may have been incurred during the surveys. Survey condition information was recorded at the start of each call-broadcast survey and included: date, survey start time, travel method (e.g. foot, boat), temperature, sky condition, wind speed, and background noise. Survey start times ranged from 4:43 am to 12:47 pm. Surveys were not conducted when wind speed was greater than 12 mph or during sustained rain or heavy fog.

Marsh Bird Community Integrity Index

I evaluated marsh bird community integrity at each survey point using a revised Marsh Bird Community Integrity Index (BCI) (DeLuca et al. 2004). The index scores marsh bird species attributes along a generalist to specialist gradient and sums the attribute scores to develop a species-specific integrity score (S_{IMBCI}) (Table 1.2). I evaluated three attributes: foraging habitat, nesting substrate, and conservation rank. Generalists were considered to be species that feed in a variety of habitats and are non-marsh nesters, while specialists were those that are marsh obligate feeders and marsh ground nesters. Foraging habitat and nesting substrate preferences were evaluated for each species using life history information from the Birds of North America Online (Cornell Lab of Ornithology and the American Ornithologists' Union 2010). Conservation rank was evaluated to account for regional species conservation status, and scores were assigned using the Priority Bird List of New England/Mid-Atlantic Coast Bird Conservation Region (BCR) 30 (Atlantic Coast Joint Venture 2008a). Priority bird species were identified based on factors such as global and/or continental conservation concerns, the importance of the BCR to a species' global or continental distribution, and population trends and threat levels within the region (Atlantic Coast Joint Venture 2008b). In the index, unranked species were considered generalists and highest concern species were considered specialists. For example, the S_{IMBCI} of Clapper Rail (*Rallus longirostris*) is 11.5. Clapper Rail is a marsh obligate forager (foraging habitat = 4), marsh ground nester (nesting substrate = 4), and ranked high on the Priority Bird List (conservation rank = 3.5).

To calculate BCI for a survey point, the S_{IMBCI} of each species detected at a point was summed, then divided by the number of species detected (S_n) at the point to obtain an average S_{IMBCI}. To account for tidal marsh obligate (TMO) bird species abundance at the survey point I multiplied the average S_{IMBCI} by the expression "$(1 + (\Sigma MaxTMO_c / \Sigma \bar{x} RMaxTMO_c))$". The total of the maximum count of TMO individuals for each species ($MaxTMO_c$) at the point was divided by the total of the average maximum count of TMO individuals for each species ($\bar{x} RMaxTMO_c$) across all refuge survey points located within the same refuge as the focal survey point. I considered seven species tidal marsh obligates: Clapper Rail, Willet (*Tringa semipalmata*), Saltmarsh Sparrow (*Ammodramus caudactus*), Nelson's Sparrow (*A. nelsoni*), unknown Sharp-tailed Sparrow (*A. spp.*), Seaside Sparrow (*A. maritimus*), and Swamp Sparrow (*Melospiza georgiana*). Unknown Sharp-tailed Sparrow refers to sharp-tailed sparrows that could not be identified to the species level.

$$\text{Survey Point BCI} = \frac{[(\Sigma S_{IMBCI} / S_n) * (1 + (\Sigma MaxTMO_c / \Sigma \bar{x} RMaxTMO_c))]}{[(\Sigma RS_{IMBCI} / RS_n) * (1 + (\Sigma \bar{x} RMaxTMO_c / \Sigma \bar{x} RMaxTMO_c))]} * 100$$

The index denominator was calculated in the same manner as the numerator, except all applicable refuge survey points were analyzed in each component. The "survey point-driven" numerator was divided by the "refuge-driven" denominator and multiplied by 100 to obtain the survey point's final BCI score. Dividing the "survey point" numerator by the "refuge-specific" denominator calculated a BCI survey point score that directly related to the overall BCI of the associated refuge. This eliminated possible BCI penalizations that a survey point or refuge might have incurred for not naturally occurring within a TMO species range, when being compared to the BCI of other survey points and refuges within the range. BCI scores of survey points sampled multiple years were averaged to estimate one BCI score for each point.

Species determined to be "edge" species were removed from the BCI score calculations due to the likelihood that the species were in the proximity of the marsh, but not actually utilizing the marsh (U.S. EPA 2002). Detection of edge species was generally limited to a few records per species and species life history information was used to determine if a species could be considered an edge species or not.

Habitat Variables

Habitat variables at the local and landscape scale were measured at each call-broadcast survey point location. At the local scale, technicians estimated the percent cover of plant communities within a 50 m radius around each survey point. Technicians visually assessed the surrounding vegetation and habitat types by using binoculars to scan 360-degrees around the point and by walking the area when necessary. Local plant communities and habitat types were grouped into the following categories: *S. alterniflora* dominated ("low marsh"); perennial turf grasses ("high marsh"); salt marsh terrestrial border; brackish terrestrial border; invasives; pannes, pools, and creeks; open water; and upland (Appendix A). A cover class guide was used to aid in the estimation of the percent cover of the predefined plant communities and habitats. Landscape scale variables were calculated using ArcGIS 9.3 (ESRI 2009). The percent cover of land cover types was estimated in a 250 m radius around each survey point using land cover data from the National Oceanic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program, resolution 30 m (NOAA Coastal Services Center 2005). To facilitate the evaluation of the surrounding landscape associated land cover classes were grouped into 11 overall land cover categories: bare land, developed open space, development, agriculture, grassland, forest, estuarine wetland, palustrine wetland, scrub-shrub, unconsolidated shore, and water (Appendix B).

Interpreting Changes in Bird Community Integrity

I used the range of the BCI scores to define three salt marsh condition categories, "Good", "Caution", and "Concern", in order to interpret changes in bird community integrity as it relates to ecosystem condition (Tierney et al. 2009). To define the thresholds between the categories I evaluated frequency distributions of the percentage of species-specific integrity scores detected at survey points. "Good" BCI scores represented the frequency distribution where the percentages of species integrity scores detected were dominated by tidal marsh obligate species with high integrity scores. "Caution" BCI scores represented the frequency distribution where the percentages of generalist and specialist species, based on species integrity scores, were at or approaching similar frequencies. "Concern" BCI scores were those where the frequency distribution of the percentages of species integrity scores detected were dominated by generalist species with low integrity scores.

Statistical Analyses

I used analysis of variance to evaluate the relationship between BCI and marsh management treatment and disturbance severity (high or low) within refuges (alpha = 0.05) (Zar 1999). I compared the differences between mean BCI of different marsh management treatment types within refuge using Tukey's post-hoc test (Zar 1999). I used multivariate linear regression (Zar 1999) to determine if any relationship(s) existed between BCI, the response variable, and the habitat variables (percent cover of plant community/habitat types and land cover classes). Prior to the regression analysis, I used a correlation analysis to determine which habitat variables were highly correlated with one another. When the percent cover of a plant community/habitat type was significantly correlated with another plant community/habitat type, one of the variables was manually selected to include in the regression analysis. The same process was performed for the land cover variables. I used stepwise linear regression to determine which habitat variables best predicted BCI at the local (50 m) and landscape (250 m) scales. Regression stepping method criteria was alpha = 0.05 as the model entry value and 0.10 as the removal value. I conducted all analyses in PASW Statistics 18.0 (SPSS, Inc. 2009).

RESULTS

Technicians surveyed 184 points across 39 marsh units in salt marshes that represented seven marsh management treatment types. 136 bird species were detected (25 wetland obligates, 62 wetland generalists, and 49 edge species), 2008 - 2009 (Appendices C, D).

Marsh Bird Community Integrity and Refuge Marsh Management

BCI scores ranged from 34.62 to 187.36 with a mean BCI score of 98.18 (± 1.97). E.B. Forsythe had the greatest mean refuge BCI score (123.35 ± 5.60, n = 26) while Rachel Carson had the lowest (77.57 ± 4.28, n = 22) (Table 1.3). The BCI score differed among marsh management types at Rachel Carson ($F_{3,18}$ = 8.951, P = 0.001), Parker River ($F_{2, 26}$ = 4.343, P = 0.024), Bombay Hook ($F_{2, 8}$ = 4.838, P = 0.042), and Prime Hook ($F_{1,17}$ = 12.118, P = 0.003) but not at Rhode Island ($F_{1, 6}$ = 3.338, P = 0.117), S.B. McKinney ($F_{2, 13}$ = 0.764, P = 0.486), or E.B. Forsythe ($F_{2, 23}$ = 0.408, P = 0.670). At Rachel Carson, BCI scores from tidal restricted sites were 1.7 times greater than ditched scores (P = 0.003), 1.4 times greater than reference scores (P = 0.005), and 1.4 times greater than ditch plugged scores (P = 0.031). At Parker River, OMWM/ditched BCI scores were 1.2 times greater than ditched scores (P = 0.047) and 1.2 times greater than reference scores (P = 0.042). At Bombay Hook, reference BCI scores were 1.1 times greater than inactive OMWM scores (P = 0.045). At Prime Hook, BCI scores at ditched sites were 1.3 times greater than scores at OMWM sites (P = 0.003). BCI score also differed by disturbance category (low, high) at Bombay Hook ($F_{1, 9}$ = 9.428, P = 0.013). All other refuge disturbance comparisons of BCI scores were not significant. Analyses could not be performed at refuges with only one marsh management type (i.e. Wertheim and Eastern Shore of VA).

Marsh Bird Community Integrity and Habitat Variables

BCI scores at the local scale were positively associated with high marsh ($\beta = 0.26$, $t = 3.57$, $P = <0.001$) and negatively associated with open water ($\beta = -0.25$, $t = -3.47$, $P = 0.001$) (Table 1.4). Five plant community/habitat type variables (i.e. open water; pannes, pools, and creeks; high marsh; salt marsh terrestrial border; and upland) were included in the stepwise analysis, while three variables (i.e. brackish terrestrial border; low marsh; and invasives) were not included. The non-included variables were significantly correlated ($P = <0.001$) with one or more of the included variables.

BCI scores at the landscape scale were negatively associated with percent cover of forest ($\beta = -0.21$, $t = -2.99$, $P = 0.003$), development ($\beta = -0.29$, $t = -3.58$, $P =< 0.001$), and palustrine wetland ($\beta = -0.20$, $t = -2.84$, $P = 0.005$) (Table 1.5). Seven land cover variables (i.e. agriculture, development, forest, grassland, palustrine wetland, unconsolidated shore, and water) were included in the stepwise analysis, while four variables (i.e. bare land, developed open space, scrub-shrub, and estuarine wetland) were not included. The non-included variables were significantly correlated ($P = <0.001$) with one or more of the included variables.

Monitoring Marsh Bird Community Integrity

The distribution of the percentages of species-specific integrity scores detected shifted with changes in BCI scores (Figure 1.2). “Good” BCI scores were determined to be BCI scores greater or equal to 123.48 (85^{th} percentile), with a mean species integrity score of 7.97 (± 0.13), n = 627. “Caution” scores ranged from 97.96 to 123.48 (50^{th} to 85^{th} percentile) and had a mean species integrity score of 7.35 (± 0.09), n = 1,456. “Caution”

BCI scores displayed a frequency distribution where the mean species integrity score was at, or near, the mean of the species integrity score range ($\bar{x}$ = 7.50, range = 3 – 12). "Concern" scores were lower than 97.96 and had a mean species integrity score of 6.46 (± 0.07), n = 2,026. The cutoff points for the BCI condition categories (i.e. "Good", "Caution", and "Concern") represented a 34% and a 48% decrease in BCI from "Good" to "Caution" and from "Caution" to "Concern", respectively, from the greatest calculated BCI score (187.36).

DISCUSSION

I found that the BCI was able to discriminate between marshes of different management treatments within four refuges. The BCI could not discriminate between marsh management treatment type at three refuges (i.e. Rhode Island, S.B. McKinney, and E.B. Forsythe), which was likely due to insufficient sample size at Rhode Island (reference points n = 7, tidal restricted points n = 1) and S.B. McKinney (ditched points n = 4, OMWM points n = 2, and reference points n = 10). Additionally, the 4 ditched points at S.B. McKinney were distributed among three marsh units, while the OMWM and reference points were each concentrated in one unit, respectively. At E.B. Forsythe the ditched and OMWM/ditched salt marshes may be too structurally similar in terms of the presence and size of ditches and OMWM features to detect a difference in BCI. Comparisons of BCI between the same marsh management treatment types and disturbance severities of different refuges are not fair comparisons. Treatment types of the same name may not necessarily mean the same thing across refuges. For example, OMWM methods vary between regions and New England salt marshes have traditionally experienced different OMWM techniques from Delaware Bay marshes. Additionally, the disturbance severity labels “high” and “low” were applied to marsh units subjectively and not based on quantitative data, likely rendering disturbance comparisons between marsh units inappropriate.

The stepwise regression identified relationships between habitat variables and BCI at the local and landscape scales. Land managers may increase BCI by restoring the vegetation structure in altered salt marshes to increase high marsh habitat and decrease open water areas. In the surrounding landscape refuges may increase BCI by decreasing forest cover and palustrine wetland cover, however this recommendation is contingent on site-specific conditions. The size and shape of the target salt marsh, relative to the proximity of forested and palustrine wetland areas must be considered to determine the true negative impacts these areas have on BCI. Concomitantly, when considering different land management actions the conservation priorities of all potentially affected wildlife must be assessed. Decreasing development will also improve BCI, however this strategy is not feasible for refuges with small areas of marsh habitat directly adjacent to public and private roads and buildings (e.g. Rhode Island and S.B. McKinney). These refuges should concentrate on making improvements to marsh habitats at the local scale. Direct alterations to marsh areas or allowable land-use changes to the landscape to improve BCI should be undertaken if the actions will maintain or restore the biological integrity, diversity, and environmental health of refuge marshes. Not all refuges will require such endeavors and current BCI conditions and refuge purposes and priorities should be examined thoroughly.

The BCI index is meant to assess the entire bird community and is intended to be a reflection of salt marsh integrity, not a determination of the relationship between any one stressor and species (DeLuca et al. 2008). High BCI scores should correspond with high salt marsh integrity levels; therefore, the species integrity scores of obligate tidal marsh birds should reflect the highest species integrity scores used in the index. The BCI scale is able to successfully distinguish between three BCI conditions, “Good”, “Caution”, and “Concern”, based on the frequency distribution of species integrity scores of detected species. “Good” BCI indicates salt marsh function and condition is at such a level that tidal marsh obligate birds are positively supported by the marsh and are able to dominate the marsh bird community. “Caution” BCI indicates the salt marsh may be degrading based on similar percentages of generalist and specialist bird species frequencies. “Concern” BCI indicates salt marsh condition has been degraded and the marsh bird community is being dominated by non-marsh nesting, habitat generalist species. Refuge managers and biologists can use the scale to evaluate avian community composition based on species integrity, and as an early warning system when monitoring temporal and spatial variations in BCI. Software such as Program MONITOR (Gibbs and Ene 2010) can be used to determine what magnitude of change in BCI can be detected given different survey efforts in order to develop BCI monitoring programs. Using the calculated BCI scores and associated CVs, the boundary scores between BCI scale condition categories can be used to set trend levels to determine what power changes can be detected in future integrity monitoring programs.

This research supports using the marsh bird community to evaluate the integrity of Northern Atlantic salt marshes. The BCI is recommended for use within refuges to assign a single monitoring metric to sites to evaluate changes in avian community composition and the ecological condition of the surrounding salt marsh. The index may help support the selection of high-quality sites for purposes such as acquisition and conservation priorities and re-focus management priorities to poor-quality sites (Karr 2006). The BCI may further be integrated into a more extensive salt marsh integrity index to monitor ecosystem condition based on relationships between salt marsh integrity metrics and wildlife response. This tool could provide refuge managers with a comprehensive multi-metric salt marsh management framework to guide critical management decisions.

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Table 1.1 Marsh bird vocalization sequences used in call-broadcast surveys.

Refuge	5 min. passive period	Black Rail	Least Bittern	Sora	Virginia Rail	King Rail	Clapper Rail	American Bittern
Rachel Carson	X	-	-	-	-	-	-	-
Parker River	X	-	X	X	X	-	X	X
Rhode Island	X	-	X	X	X	X	X	-
S.B. McKinney	X	-	X	X	X	X	X	X
Wertheim	X	X	-	-	X	X	X	-
E.B. Forsythe	X	X	-	-	X	X	X	-
Bombay Hook	X	X	X	X	X	X	X	X
Prime Hook	X	X	-	-	X	X	X	-
Eastern Shore VA	X	X	-	-	X	X	X	-

Table 1.2 Bird species attributes (Poole and Gill 1999) and modified scoring criteria used to develop species-specific integrity scores for bird community integrity calculations (DeLuca et al. 2004).

	Score				
	Generalist				Specialist
Species Attribute	1	2	2.5	3	4
Foraging habitat	habitat generalist		marsh facultative		marsh obligate
Nesting habitat	non-marsh nesting		marsh vegetation		marsh ground nesting
Conservation rank	unranked		moderate	high (3.5)	highest

Table 1.3 Mean bird community integrity scores of salt marsh study areas and survey points sampled during 2008 and 2009.

Refuge	N	Refuge Mean BCI Score (±SE)	Marsh Management Type	Disturbance	N	Mean BCI Score (±SE)
Rachel Carson	22	77.57 (4.28)	Ditch plugged	High	4	69.90 (6.58)
			Ditched	High	3	56.33 (5.26)
			Reference	Low	6	66.87 (7.45)
			Tidal Restricted	High	9	95.20 (3.82)
Parker River	29	104.64 (3.82)	Ditched	High	10	97.80 (4.05)
			OMWM/Ditched	High	10	118.56 (3.80)
			Reference	Low	9	96.79 (9.20)
Rhode Island	8	94.06 (4.53)	Reference	Low	7	96.77 (4.20)
			Tidal Restricted	High	1	75.09 (.)
S.B. McKinney	16	82.67 (4.79)	Ditched	High	4	92.70 (7.22)
			OMWM	High	2	75.13 (9.74)
			Reference	Low	10	80.16 (6.76)
Wertheim	32	93.87 (4.74)	Ditched	High	32	93.87 (4.74)
E.B. Forsythe	26	123.35 (5.60)	Ditched	High	12	124.83 (9.60)
			OMWM/Ditched	High	9	127.16 (8.93)
			Reference	Low	5	112.93 (9.48)
Bombay Hook	11	119.26 (2.78)	Ditched	High	4	116.31 (2.98)
			Inactive OMWM	High	3	112.11 (5.10)
			Reference	Low	4	127.56 (3.17)
Prime Hook	19	104.26 (4.43)	Ditched	Low	3	132.27 (9.88)
			OMWM	Low/High	16	99.01 (3.73)
Eastern Shore VA	21	83.05 (5.34)	Reference	Low	21	83.05 (5.34)

Table 1.4 Local scale plant community/habitat type models and regression coefficients for stepwise linear regression equations with bird community integrity score as the dependent variable. P^1 indicates the significance of the beta estimate and P^2 indicates the overall significance of the model.

Model	Plant Community/Habitat Type	R^2	β	t	P^1	F	P^2
1	(Constant)	0.10		15.57	<0.001	17.41	<0.001
	Perennial turf grasses ("high marsh")		0.31	4.17	<0.001		
2	(Constant)	0.16		16.32	<0.001	15.32	<0.001
	Perennial turf grasses ("high marsh")		0.26	3.57	<0.001		
	Open water		-0.25	-3.47	0.001		

Table 1.5 Landscape scale land cover models and regression coefficients for stepwise linear regression equations with bird community integrity score as the dependent variable. P^1 indicates the significance of the beta estimate and P^2 indicates the overall significance of the model.

Model	Land Cover	R^2	β	t	P^1	F	P^2
1	(Constant)	0.05		48.35	<0.001	9.84	0.002
	Forest		-0.23	-3.14	0.002		
2	(Constant)	0.10		46.95	<0.001	10.47	<0.001
	Forest		-0.24	-3.46	0.001		
	Development		-0.23	-3.25	0.001		
3	(Constant)	0.14		45.31	<0.001	9.93	<0.001
	Forest		-0.21	-2.99	0.003		
	Development		-0.25	-3.58	<0.001		
	Palustrine wetland		-0.20	-2.84	0.005		

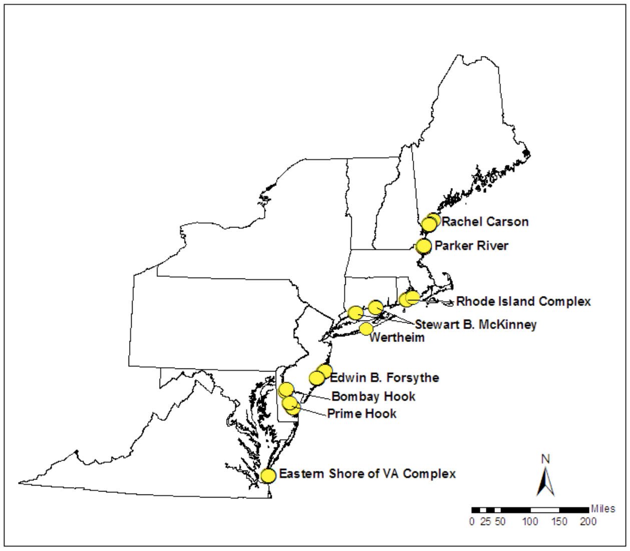
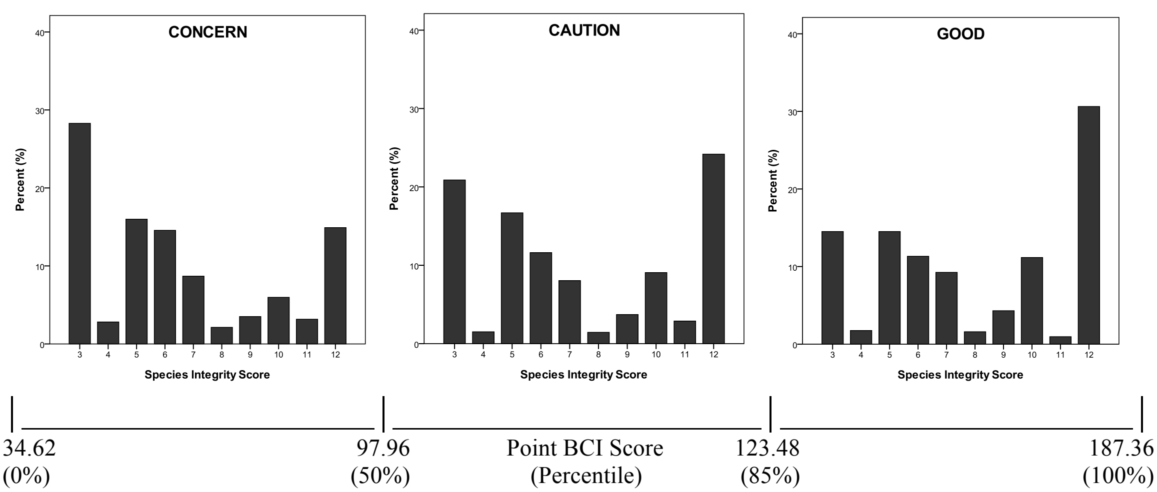


Figure 1.1 Map of the nine National Wildlife Refuges and Refuge Complexes where research was performed.



Species integrity scores represented on the x-axis are based on orginial species integrity scores placed into the following bins, bin value (species integrity scores): 3 (3); 4 (3.5, 4); 5 (4.5, 5); 6 (5.5, 6); 7 (6.5, 7); 8 (7.5, 8); 9 (8.5, 9); 10 (9.5, 10); 11 (10.5, 11); and 12 (11.25, 11.5, 12).

Figure 1.2 Marsh bird community integrity scale with three condition categories based on the frequency distribution of species integrity scores of detected species.

Appendix A. Plant community and habitat type definitions and cover class guide used for local covariate information collection at each survey point (Neckles et al. 2008).

Plant Community/Habitat Type	Common Features
S. alterniflora dominated ("low marsh")	• Regularly flooded by daily tides • Strongly halophytic • Dominated by tall form (75cm+) *S. alterniflora*
Perennial turf grasses ("high marsh")	• Flooded by mean tide or greater • Strongly to moderately halophytic • Dominated by *S. patens*, *D. spicata*, *J. gerardii* • Includes areas of short form *S. alterniflora* as well as solitary forbs such as *L. nashii*, *A. tenuifolius* and *T. maritimum*
Salt marsh terrestrial border	• Infrequently flooded by spring and storm tides • Moderately halophytic • Could include areas of higher elevation on marsh platform (commonly islands or linear patches next to excavated ditches) • Most common: *I. frutescens*; *S. sempervirens*; *P. virgatum*; *A. pungens*
Brackish terrestrial border	• Rarely flooded by tides, but often tidal influenced fresh/brackish • Not halophytic but tolerant of maritime conditions (spray and infrequent pulses) • Could include fresher areas of high water table on marsh plain • Most common: *T. angustifolia*, *S. robustus*, *S. pectinata* • Could include native *P. australis* if properly identified
Invasives	• Invasives such as *P. australis* and *L. salicaria* • Colonization and spread often result of disturbance
Pannes, Pools and Creeks	• Channels, creeks, ditches, pannes and pools
Open Water	• Larger areas of water: bays, rivers, ponds
Upland	• Non-wetland areas of upland that fall into the 100m diameter circle; includes land uses of all types (e.g. natural and developed)

Cover classes:
+: Absent or Less than 1%
1: 1% to 5% cover
2: 6% to 10% cover
3: 11% to 25% cover
4: 26% to 50% cover
5: 51% to 75% cover
6: 76% to 100% cover

Appendix B. Land cover classifications created from the NOAA Coastal Change Analysis Program (C-CAP) land cover classification scheme (NOAA Coastal Services Center 2010).

Land cover	C-CAP land cover class	C-CAP class definition
Bare Land	Barren Land	Contains areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earth material. Generally, vegetation accounts for less than 10 percent of total cover.
Agriculture	Cultivated	Contains areas intensely managed for the production of annual crops. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.
	Pasture/Hay	Contains areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle and not tilled. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.
Forest	Deciduous Forest	Contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
	Evergreen Forest	Contains areas dominated by trees generally greater than 5 meters tall and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
	Mixed Forest	Contains areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover. Both coniferous and broad-leaved evergreens are included in this category.
Developed Open Space	Developed, Open Space	Contains areas with a mixture of some constructed materials, but mostly managed grasses or low-lying vegetation planted in developed areas for recreation, erosion control, or aesthetic purposes. These areas are maintained by human activity such as fertilization and irrigation, are distinguished by enhanced biomass productivity, and can be recognized through vegetative indices based on spectral characteristics. Constructed surfaces account for less than 20 percent of total land cover.
Estuarine Wetland	Estuarine Forested Wetland	Includes tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height,

Land cover	C-CAP land cover class	C-CAP class definition
		and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.
	Estuarine Scrub/Shrub Wetland	Includes tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.
	Estuarine Emergent Wetland	Includes all tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens). Wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and that are present for most of the growing season in most years. Total vegetation cover is greater than 80 percent.
Grassland	Grassland/Herbaceous	Contains areas dominated by grammanoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
Development	Developed, High Intensity	Contains significant land area is covered by concrete, asphalt, and other constructed materials. Vegetation, if present, occupies < 20 percent of the landscape. Constructed materials account for 80 to 100 percent of the total cover. This class includes heavily built-up urban centers and large constructed surfaces in suburban and rural areas with a variety of land uses.
	Developed, Medium Intensity	Contains areas with a mixture of constructed materials and vegetation or other cover. Constructed materials account for 50 to 79 percent of total area. This class commonly includes multi- and single-family housing areas, especially in suburban neighborhoods, but may include all types of land use.
	Developed, Low Intensity	Contains areas with a mixture of constructed materials and substantial amounts of vegetation or other cover. Constructed materials account for 21 to 49 percent of total area. This subclass commonly includes single-family housing areas, especially in rural neighborhoods, but may include all types of land use.
Palustrine Wetland	Palustrine Forested Wetland	Includes tidal and nontidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.
	Palustrine Scrub/Shrub Wetland	Includes tidal and non tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total

Land cover	C-CAP land cover class	C-CAP class definition
		vegetation coverage is greater than 20 percent. Species present could be true shrubs, young trees and shrubs, or trees that are small or stunted due to environmental conditions.
	Palustrine Emergent Wetland (Persistent)	Includes tidal and nontidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation cover is greater than 80 percent. Plants generally remain standing until the next growing season.
Scrub/Shrub	Scrub/Shrub	Contains areas dominated by shrubs less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes tree shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.
Unconsolidated Shore	Unconsolidated Shore	Includes material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Substrates lack vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable.
Water	Open Water	Include areas of open water, generally with less than 25 percent cover of vegetation or soil.

Appendix C. Bird species detected during call-broadcast surveys and corresponding species attribute scores used to calculate species-specific integrity scores (S_{IMBCI}) for bird community integrity calculations.

Guild	Species	Scientific Name	Foraging habitat	Nesting substrate	Conservation rank	S_{IMBCI} score
Cormorants	Double-crested Cormorant	*(Phalacrocorax auritus)*	2.5	2	1	5.5
Corvids	American Crow	*(Corvus brachyrhynchos)*	1	1	1	3
	Fish Crow	*(Corvus ossifragus)*	1	1	1	3
Finches	American Goldfinch	*(Spinus tristis)*	1	1	1	3
Gulls and Terns	Black Skimmer	*(Rynchops niger)*	2.5	1	2.5	6
	Bonaparte's Gull	*(Chroicocephalus philadelphia)*	2.5	1	1	4.5
	Common Tern	*(Sterna hirundo)*	3	4	2.5	9.5
	Forster's Tern	*(Sterna forsteri)*	2.5	1	3.5	7
	Great Black-backed Gull	*(Larus marinus)*	2.5	2	1	5.5
	Herring Gull	*(Larus argentatus)*	2.5	3	1	6.5
	Laughing Gull	*(Larus atricilla)*	1	2.5	1	4.5
	Least Tern	*(Sternula antillarum)*	2.5	1	3.5	7
	Ring-billed Gull	*(Larus delawarensis)*	1	1	1	3
	Royal Tern	*(Thalasseus maximus)*	2.5	1	2.5	6
	Sandwich Tern	*(Thalasseus sandvicensis)*	2.5	1	3.5	7
Hawks and allies	Bald Eagle	*(Haliaeetus leucocephalus)*	1	1	2.5	4.5
	Northern Harrier	*(Circus cyaneus)*	4	4	1	9
	Osprey	*(Pandion haliaetus)*	1	1	1	3
Herons	American Bittern	*(Botaurus lentiginosus)*	4	1	2.5	7.5
	Black-crowned Night-Heron	*(Nycticorax nycticorax)*	2.5	1	2.5	6
	Cattle Egret	*(Bubulcus ibis)*	1	2	1	4
	Glossy Ibis	*(Plegadis falcinellus)*	3	3	3.5	9.5
	Great Blue Heron	*(Ardea herodias)*	2.5	1	1	4.5
	Great Egret	*(Ardea alba)*	2.5	1	1	4.5
	Green Heron	*(Butorides virescens)*	2.5	1	1	4.5
	Least Bittern	*(Ixobrychus exilis)*	4	2.5	2.5	9
	Little Blue Heron	*(Egretta caerulea)*	3	2.5	2.5	8
	Snowy Egret	*(Egretta thula)*	2.5	1	2.5	6
	Tricolored Heron	*(Egretta tricolor)*	4	2.5	2.5	9
	Yellow-crowned Night-Heron	*(Nyctanassa violacea)*	2.5	1	2.5	6
Kingfishers	Belted Kingfisher	*(Megaceryle alcyon)*	2.5	1	1	4.5
Loons	Common Loon	*(Gavia immer)*	4	4	1	9
Mimids	Gray Catbird	*(Dumetella carolinensis)*	1	1	2.5	4.5
New World Blackbirds and allies	Boat-tailed Grackle	*(Quiscalus major)*	1	2.5	1	4.5
	Bobolink	*(Dolichonyx oryzivorus)*	1	1	1	3
	Common Grackle	*(Quiscalus quiscula)*	1	1	1	3
	Eastern Meadowlark	*(Sturnella magna)*	1	1	1	3
	Red-winged Blackbird	*(Agelaius phoeniceus)*	1	2.5	1	4.5
Quails	Northern Bobwhite	*(Colinus virginianus)*	1	1	3.5	5.5
Rails	Black Rail	*(Laterallus jamaicensis)*	4	4	4	12
	Clapper Rail*	*(Rallus longirostris)*	4	4	3.5	11.5
	Sora	*(Porzana carolina)*	4	4	2.5	10.5

Guild	Species	Scientific Name	Foraging habitat	Nesting substrate	Conservation rank	S_{IMBCI} score
	Virginia Rail	*(Rallus limicola)*	4	4	1	9
Shorebirds	American Oystercatcher	*(Haematopus palliatus)*	4	2	4	10
	Black-bellied Plover	*(Pluvialis squatarola)*	2	2	3.5	7.5
	Black-necked Stilt	*(Himantopus mexicanus)*	3	2	1	6
	Dunlin	*(Calidris alpina)*	2.5	1	3.5	7
	Greater Yellowlegs	*(Tringa melanoleuca)*	4	3	3.5	10.5
	Least Sandpiper	*(Calidris minutilla)*	2.5	4	2.5	9
	Lesser Yellowlegs	*(Tringa flavipes)*	2.5	2	2.5	7
	Ruddy Turnstone	*(Arenaria interpres)*	2.5	1	4	7.5
	Semipalmated Plover	*(Charadrius semipalmatus)*	2.5	1	2.5	6
	Semipalmated Sandpiper	*(Calidris pusilla)*	2.5	2	3.5	8
	Short-billed Dowitcher	*(Limnodromus griseus)*	2.5	2	3.5	8
	Spotted Sandpiper	*(Actitis macularius)*	2.5	2	2.5	7
	Whimbrel	*(Numenius phaeopus)*	2.5	1	4	7.5
	Willet*	*(Tringa semipalmata)*	4	4	3.5	11.5
	Wilson's Snipe	*(Gallinago delicata)*	2.5	3	1	6.5
Sparrows	Swamp Sparrow*	*(Melospiza georgiana)*	4	2.5	3.5	10
	Nelson's Sparrow*	*(Ammodramus nelsoni)*	4	4	2.5	10.5
	Saltmarsh Sparrow*	*(Ammodramus caudacutus)*	4	4	4	12
	Savannah Sparrow	*(Passerculus sandwichensis)*	1	1	1	3
	Seaside Sparrow*	*(Ammodramus maritimus)*	4	4	4	12
	Unknown Sharp-tailed Sparrow spp.*	*(Ammodramus nelsoni/caudacutus)*	4	4	3.25	11.25
	Song Sparrow	*(Melospiza melodia)*	1	1	1	3
Starlings	European Starling	*(Sturnus vulgaris)*	1	1	1	3
Swallows	Barn Swallow	*(Hirundo rustica)*	1	1	1	3
	Purple Martin	*(Progne subis)*	1	1	1	3
	Tree Swallow	*(Tachycineta bicolor)*	1	1	1	3
Tyrant Flycatchers	Eastern Kingbird	*(Tyrannus tyrannus)*	2.5	1	3.5	7
	Great Crested Flycatcher	*(Myiarchus crinitus)*	1	1	3.5	5.5
	Willow Flycatcher	*(Empidonax traillii)*	2	1	3.5	6.5
Vireos	White-eyed Vireo	*(Vireo griseus)*	1	1	1	3
Waterfowl	American Black Duck	*(Anas rubripes)*	2.5	2	4	8.5
	Blue-winged Teal	*(Anas discors)*	4	2	1	7
	Canada Goose	*(Branta canadensis)*	2	1	1	4
	Common Eider	*(Somateria mollissima)*	2.5	1	3.5	7
	Gadwall	*(Anas strepera)*	4	2	2.5	8.5
	Hooded Merganser	*(Lophodytes cucullatus)*	2	1	2.5	5.5
	Mallard	*(Anas platyrhynchos)*	1	2.5	3.5	7
	Mute Swan	*(Cygnus olor)*	2.5	2	1	5.5
Wood-warblers	Common Yellowthroat	*(Geothlypis trichas)*	2.5	2.5	1	6
	Yellow Warbler	*(Dendroica petechia)*	1	1	1	3
Woodpeckers	Northern Flicker	*(Colaptes auratus)*	1	1	3.5	5.5
	Yellow-shafted Flicker	*(Colaptes a. auratus)*	1	1	3.5	5.5
Wrens	Marsh Wren	*(Cistothorus palustris)*	4	2.5	3.5	10
	Sedge Wren	*(Cistothorus platensis)*	2.5	2.5	2.5	7.5

*Tidal marsh obligate species

Appendix D. Bird species detected during call-broadcast surveys determined to be "edge" species and not included in bird community integrity calculations.

Guild	Species	Scientific Name
Cardinals and allies	Blue Grosbeak Indigo Bunting Northern Cardinal	*(Passerina caerulea)* *(Passerina cyanea)* *(Cardinalis cardinalis)*
Chickadees and Titmice	Black-capped Chickadee Tufted Titmouse	*(Poecile atricapillus)* *(Baeolophus bicolor)*
Corvids	Blue Jay	*(Cyanocitta cristata)*
Finches	House Finch Purple Finch	*(Carpodacus mexicanus)* *(Carpodacus purpureus)*
Grouse, Quail, and allies	Wild Turkey	*(Meleagris gallopavo)*
Hawks and allies	Cooper's Hawk Red-tailed Hawk Sharp-shinned Hawk Turkey Vulture	*(Accipiter cooperii)* *(Buteo jamaicensis)* *(Accipiter striatus)* *(Cathartes aura)*
Hummingbirds	Ruby-throated Hummingbird	*(Archilochus colubris)*
Mimids	Northern Mockingbird	*(Mimus polyglottos)*
New World Blackbirds and allies	Baltimore Oriole Brown-headed Cowbird	*(Icterus galbula)* *(Molothrus ater)*
Nuthatches	Brown-headed Nuthatch White-breasted Nuthatch	*(Sitta pusilla)* *(Sitta carolinensis)*
Pigeons and Doves	Mourning Dove Rock Pigeon	*(Zenaida macroura)* *(Columba livia)*
Shorebirds	American-Golden Plover Killdeer "Peep"	*(Pluvialis dominica)* *(Charadrius vociferus)* *N/A*
Sparrows	Chipping Sparrow Eastern Towhee Field Sparrow House Sparrow White-throated Sparrow	*(Spizella passerina)* *(Pipilo erythrophthalmus)* *(Spizella pusilla)* *(Passer domesticus)* *(Zonotrichia albicollis)*
Swallows	Northern rough-winged Swallow	*(Stelgidopteryx serripennis)*
Swifts	Chimney Swift	*(Chaetura pelagica)*
Thrushes	American Robin Wood Thrush	*(Turdus migratorius)* *(Hylocichla mustelina)*
Tyrant Flycatchers	Eastern Phoebe Eastern Wood-Pewee	*(Sayornis phoebe)* *(Contopus virens)*
Vireos	Red-eyed Vireo Warbling Vireo	*(Vireo olivaceus)* *(Vireo gilvus)*
Waxwings	Cedar Waxwing	*(Bombycilla cedrorum)*
Wood-warblers	Ovenbird Pine Warbler Prairie Warbler Yellow-breasted Chat	*(Seiurus aurocapilla)* *(Dendroica pinus)* *(Dendroica discolor)* *(Icteria virens)*
Woodpeckers	Downy Woodpecker Red-bellied Woodpecker Red-headed Woodpecker	*(Picoides pubescens)* *(Melanerpes carolinus)* *(Melanerpes erythrocephalus)*
Wrens	Carolina Wren House Wren Winter Wren	*(Thryothorus ludovicianus)* *(Troglodytes aedon)* *(Troglodytes troglodytes)*

Chapter 2

MONITORING SALT MARSH BIRDS USING RAPID VERSUS INTENSIVE ASSESSMENT METRICS

INTRODUCTION

Monitoring program design and implementation provides the foundation for much of our understanding of wildlife population trends and responses to habitat management. Most monitoring programs are fiscally constrained and increased spending accountability has led to a critical examination of how to acquire needed information to improve management decisions and maximize conservation gains (Legg and Nagy 2006, Nichols and Williams 2006, McDonald-Madden et al. 2010). Therefore, defining measurable and realistic monitoring objectives and developing the appropriate sampling design are crucial to successful monitoring programs. Resources must be allocated efficiently to execute and sustain monitoring programs with program objectives, time, personnel effort and experience, and budgetary limitations, among other factors, specifically stated.

The focus of many conservation and monitoring initiatives has shifted from the single-species approach to the ecosystem level (Busch and Trexler 2003). While monitoring at the ecosystem level can lead to additional pressures on program resources, ecosystem monitoring targeted toward management needs can be used to help understand the causes of ecosystem changes and evaluate if and how management actions are achieving objectives (Nichols and Williams 2006). Monitoring plans must be feasible to implement while contending with additional strains on finances, logistics, and survey efforts, and must ultimately be integrated into conservation and management decision-making (Neckles et al. 2008).

Restoration and management of salt marsh ecosystems have recently been designated as high conservation priorities, especially in light of accelerated sea-level rise (IPCC 2007, Rahmstorf 2007). Presently, a salt marsh monitoring plan that assesses salt marsh integrity and assists in guiding management actions is in development for coastal National Wildlife Refuges (Neckles et al. 2008). The plan is being developed under the premise that refuge staff must use a limited resource base to meet monitoring program goals. To contend with minimal resources, monitoring objectives may be achieved by monitoring specific taxa as indicators of ecosystem health and by supplementing intensive assessment metrics with appropriate rapid metrics. When a relationship exists between rapid and intensive metrics, the more efficient rapid metrics can serve as useful monitoring indicators in place of intensive, and inherently more costly, assessment methods. The objectives of this project were to: (1) determine and compare the effects of visit effort on site-occupancy and abundance estimations for tidal marsh obligate bird species; and (2) determine the relationships between Seaside Sparrow abundance, a rapid metric, and intensive reproductive metrics.

METHODS

Study Areas

I conducted this research at Bombay Hook and Prime Hook National Wildlife Refuges, collectively known as the Coastal Delaware National Wildlife Refuge Complex, and at adjacent state and privately owned lands. Bombay Hook National Wildlife Refuge (39° 15' N, 75° 26' W) was established in 1937 as a refuge and breeding ground for migrating birds in the Atlantic Flyway (U.S. Fish and Wildlife Service 2004). The refuge contains 8,082 ha of tidal salt marsh that consists of managed and unaltered areas (Warner 2009). Eleven 2.25 ha plots were established in three marsh areas: a parallel grid ditched area (n = 4), an open marsh water management (OMWM) treated area (n = 3), and an unaltered reference area (n = 4). The OMWM treated marsh was installed in 1981 as a trial area by the Delaware Division of Fish and Wildlife – Mosquito Control and experienced no additional alterations following the initial treatment (Warner 2009). This area may be considered old inactive OMWM as it does not receive the typical maintenance or upkeep as active OMWM systems do.

Prime Hook National Wildlife Refuge (38° 50' N, 75° 13' W) was established in 1963 to protect coastal wetlands that serve as wintering and breeding ground for migratory waterfowl (U.S. Fish and Wildlife Service 2000). Most of the Refuge's tidal salt marsh was ditched in the early 1930s and/or farmed prior to the Refuge's creation (Pepper 2008). Nineteen plots (1.00 - 2.25 ha) were established on and adjacent to Refuge property along a gradient of marsh management: Prime Hook National Wildlife Refuge (n = 16; OMWM), Delaware State Wildlife Area (n = 2; grid ditched), and Delaware Nature Society property (n = 1; grid ditched). For the purposes of this thesis the location of these 19 plots will be referred to as "Prime Hook" from herein. All plots were at least 100 m apart except for two. Research was conducted at Bombay Hook from 2008 – 2009 and at Prime Hook from 2006 – 2009, during the breeding season (May – August).

The salt marshes found at these two refuges were classified as Northern Atlantic Coastal Plain Tidal Salt Marsh (Comer et al. 2003). This system of salt marshes occurs on the bayside of barrier beaches and along the outer mouth of tidal rivers where salinity has not been strongly impacted by freshwater. A typical tidal salt marsh profile can be characterized as a low regularly flooded marsh strongly dominated by smooth cordgrass (*Spartina alterniflora*); a higher irregularly flooded marsh dominated by saltmeadow cordgrass (*S. patens*) and saltgrass (*Distichlis spicata*); low hypersaline pannes characterized by glasswort (*Salicornia* spp.); and a salt scrub ecotone characterized by marsh elder (*Iva frutescens*), groundsel tree (*Baccharis halimifolia*), and switchgrass (*Panicum virgatum*). Slightly higher elevated areas may also support eastern redcedar (*Juniperus virginiana*) (Comer et al. 2003).

Rapid Avian Measures

<u>Relative Abundance Estimates</u>

Seasonal field technicians conducted eight call-broadcast surveys at survey plots during the breeding season (May - August) following the Standardized North American Marsh Bird Monitoring Protocols (Conway 2008). Surveys include a five-minute passive listening period followed by audio broadcast calls of focal marsh birds to elicit vocalizations and increase detection rates of secretive and infrequently vocalizing marsh birds (Gibbs and Melvin 1993, Conway and Gibbs 2005). Calls were broadcast for 30 seconds followed by 30 seconds of silence for each species. Technicians recorded all bird species detected during both the 5-minute passive period and the call-broadcast period. Locations of individual birds were grouped into three distance categories (0 – 50 m, 50 – 100 m, 100+ m). Survey technicians received marsh bird identification training and were instructed on proper monitoring protocol procedures at an avian training workshop prior to each field season. A marsh bird identification test was given at the end of each workshop to evaluate identification skills and minimize observer bias that may have been incurred during the surveys. Survey condition information was recorded at the start of each call-broadcast survey and included: date, survey start time, travel method (e.g. foot, boat), temperature, sky condition, wind speed, and background noise. Survey start times ranged from 6:04 am to 12:47 pm. Surveys were not conducted when wind speed was greater than 12 mph or during sustained rain or heavy fog. Survey dates were grouped into "date bins" that consisted of two-week intervals emphasizing early, middle, and late breeding season survey windows to facilitate analysis (Conway et al. 2008).

I used survey data to calculate relative abundance of four primary tidal marsh obligate species of the Delaware Bay: Clapper Rail (*Rallus longirostris*), Willet (*Tringa semipalmata*), Saltmarsh Sparrow (*Ammodramus caudacutus*), and Seaside Sparrow (*A. maritimus*). Relative abundance was estimated by determining the sum of the maximum number of individuals detected at each survey point, divided by the total number of points. I evaluated changes in species relative abundance (± SD) and coefficient of variation estimates to determine how the number of visits to a sampling location influenced variability in these parameters. Seaside Sparrow relative abundance estimates used in breeding ecology regression analyses represented the maximum number of individuals detected across all eight call-broadcast surveys by plot.

Occupancy Estimation

I used Program PRESENCE ver. 3.0 Beta (MacKenzie and Hines 2002), to estimate occupancy rates of the four tidal marsh obligate species: Clapper Rail, Willet, Saltmarsh Sparrow, and Seaside Sparrow. I evaluated changes in species occupancy ($\Psi \pm$ SE) and 95% confidence interval estimates to determine how the number of visits to a sampling location influenced variability in these parameters. Data from the same surveys were used to compare changes in species relative abundance to changes in species occupancy rates. Occupancy rates were estimated using a likelihood-based method, which does not discriminate against missing surveys (MacKenzie et al. 2002). Call-broadcast data was used to create a detection history for each species at each survey point. For example, if a Clapper Rail was detected at point "X" during the first and second survey in a series of surveys, but not during the third survey, the detection history is 110. A "1" indicates the species was detected during the survey and a "0" indicates the species was not detected. Analysis of such detection histories enables occupancy rates to be calculated when detection probabilities are less than one (MacKenzie et al. 2002). For this analysis I included all points surveyed in 2008 and 2009.

Prior to estimating occupancy, I analyzed which survey covariate(s) influenced the detection probability of each species. Noise most strongly influenced detection probability in all cases; therefore, noise was held constant and used as the detection probability covariate in each visitation occupancy model. I modeled visitation effort by estimating occupancy using data from two call-broadcast survey visits, three visits, four visits, and eight visits. To model the effects of two visits I used data from visit no. 1 and 5, which represented early and mid-season surveys. Model results of three visits were based on visit no. 1, 5, and 8; four visits on no. 1, 3, 6, and 8; and eight visits consisted of all surveys (visit no. 1 through 8). When Program PRESENCE could not analyze detection history data of the pre-chosen visits due to software issues, supplemental survey data from visits that complemented the seasonal timing of the original pre-chosen visits were used in the analysis. Willet occupancy for two visits was analyzed using visit no. 1 and 4. Occupancy for the maximum-visit scenario (the "eight-visit scenario") was analyzed for Saltmarsh Sparrow using the first seven survey visits and for Seaside Sparrow using the first six survey visits.

Intensive Avian Measures

Sparrow Territory Density

Seaside Sparrow territories were mapped on each plot eight times using the mapping method recommended by the International Bird Census Committee (1970). Mapping was conducted between 0600 and 1200 hours during the breeding season (May – August). I estimated the number of sparrow breeding territories for each plot using data from the territory mapping surveys. The territory density (number of territories per hectare of marsh) for each plot was estimated by dividing the mean number of territories by plot size (1.00 – 3.00 ha) (Table 3.2). I used linear regression to compare territory densities to sparrow relative abundance for each plot to determine if there was a relationship between the rapid (call-broadcast surveys) and intensive (territory mapping) sampling techniques (Zar 1999).

Sparrow Nest and Fledgling Density

I searched for Seaside Sparrow nests on each plot and monitored all nests. Plots were searched for nests at least eight times per plot during the breeding season. Nests were marked with a flag to enable nests to be relocated easily for monitoring purposes. The flag was placed approximately 1 m from each nest, with the nest in between the flag and a plot marker flag. Flags were not placed in front of the nest opening, but to the side or behind the nest opening to minimize nest disturbance. Flags were labeled with nest species and nest number and all nest locations were recorded using a handheld GPS unit. Nests were revisited every three to four days to monitor nest status. I recorded clutch size, number of hatchlings, and number of fledglings, as well as the presence or absence of adults and adult defensive behavior. The cause of nest failure (i.e. predation, abandonment, and flooding) was determined to the greatest extent possible. Nests were considered successful if at least one chick fledged.

Located nests were used to determine nest density for each plot. Nest density (number of nests per hectare of marsh) was estimated by dividing the mean number of nests by plot size (1.00 – 3.00 ha) (Table 3.2). Final fledgling counts for each plot were used to calculate fledgling density (number of fledglings per hectare of marsh). I used linear regression to compare nest density and fledgling density to sparrow relative abundance for each plot to determine if there was a relationship between the rapid (call-broadcast surveys) and intensive (nest searching and monitoring) sampling techniques (Zar 1999).

Daily Nest Survival

Nest monitoring records were used to determine daily nest survival for each marsh unit by year (Table 3.2). Plots were pooled into marsh units due to small nest sample sizes on some plots. Daily nest survival rates were estimated in Program R (R Core Development Team 2010) using a logistic-exposure model (Shaffer 2004). Unlike logistic regression models, the logistic-exposure model allows for varying exposure periods from when nests are first detected and requires no assumptions about when a nest was lost. Marsh unit daily nest survival rates were compared to sparrow relative abundance estimates for each plot by year using linear regression to determine if a relationship existed between rapid (call-broadcast surveys) and intensive (nest monitoring and analysis) sampling techniques (Zar 1999).

RESULTS

Sampling Effort

Clapper Rail

Naïve occupancy rates ranged from 0.74 (± 0.08) at 2 visits to 0.89 (± 0.06) at 4 visits (Table 2.1, Figure 2.1). This increase represented a 21% difference in calculated occupancy rates. The occupancy estimate at 8 visits was 0.88 (± 0.04). Clapper Rail relative abundance ranged from 1.53 (± 1.69) at 2 visits to 2.37 (± 1.71) at 8 visits. This increase represented a 56% difference in relative abundance. The coefficient of variation declined from 1.10 to 0.72.

Willet

Naïve occupancy rates ranged from 0.88 (± 0.05) at 4 visits to 0.97 (± 0.02) at 8 visits (Table 2.1, Figure 2.1). This increase represented a 10% difference in calculated occupancy rates. The occupancy estimate at 2 visits was 0.91 (± 0.06). Willet relative abundance ranged from 2.54 (± 2.15) at 3 visits to 4.17 (± 2.63) at 8 visits. This increase represented a 64% difference in relative abundance. The relative abundance estimate at 2 visits was 3.14 (± 2.89). The coefficient of variation declined from 0.92 to 0.63 from 2 to 8 visits.

Saltmarsh Sparrow

Naïve occupancy rates ranged from 0.90 (± 0.16) at 2 visits to 0.96 (± 0.03) at 7 visits (Table 2.1, Figure 2.1). This increase represented a 7% difference in calculated occupancy rates. Saltmarsh Sparrow relative abundance ranged from 1.36 (± 1.47) at 2 visits to 2.48 (± 1.54) at 7 visits, representing a 76% difference in relative abundance. The coefficient of variation declined from 1.08 to 0.62.

Seaside Sparrow

Naïve occupancy rates did not change with number of visits (Table 2.1, Figure 2.1). Seaside Sparrow relative abundance ranged from 7.70 (± 3.42) at 2 visits to 8.93 (± 3.50) at 6 visits. This increase represented a 16% difference in relative abundance. The coefficient of variation declined from 0.48 to 0.39.

Seaside Sparrow Breeding Ecology

Seaside Sparrow relative abundance was significantly correlated with three of the four dependent variables tested. Relative abundance explained a significant proportion of variance in territory density (R^2 = 0.14, β = 0.38, P = <0.001), nest density (R^2 = 0.36, β = 0.60, P = <0.001), and fledgling density (R^2 = 0.24, β = 0.49, P = <0.001). Seaside

Sparrow relative abundance, however, did not explain a significant proportion of variance in daily nest survival rate (R^2 = 0.01, β = 0.08, P = 0.537). (Table 2.2)

DISCUSSION

There was a consistent pattern in the effect of the number of survey visits on the occupancy and relative abundance estimates of each tidal marsh obligate species tested. Overall, occupancy and relative abundance increased as the number of visits increased however there was a greater effect of number of visits on differences between relative abundance estimates than differences between occupancy estimates. Life history features of each species allow for easy detection in presence-absence surveys. Willets and Seaside Sparrows are visible, vocal, territorial species (Lowther et al. 2001, Post and Greenlaw 2009). Saltmarsh Sparrows are non-territorial, however males usually sing from perches and some males continue singing into early August (Greenlaw and Rising 1994). Clapper Rails are usually unseen, but detected by loud advertising and territorial vocalizations (Eddleman and Conway 1998). Call-broadcast surveys have also proven to elicit increased Clapper Rail vocalization (Gibbs and Melvin 1993, Conway and Gibbs 2005). Therefore, if a tidal marsh obligate species individual was present at a site, the individual was likely to be detected on the first visit. As the breeding season progressed and more individuals appeared at a site, the site continued to be detected as "occupied" for the species. However, the consistent occupancy estimation gave no indication of the change in species abundance from visit to visit. Abundance estimates may be a more appropriate monitoring technique for non-rare, vocalizing tidal marsh obligate avian species.

This research supports the importance of monitoring the abundance of non-rare species using a method alternative to site-occupancy estimation. Occupancy has been used to monitor population trends of insects (MacKenzie et al. 2005), reptiles and amphibians (Bailey et al. 2004, Roughton and Seddon 2006, Zylstra et al. 2010), mammals (Sullivan et al. 2002, O'Connell et al. 2006), and birds (Olson et al. 2005, Kroll et al. 2007). These studies have shown that site-occupancy estimation is useful for estimating reliable abundance parameters of rare species and species with low detection rates (MacKenzie et al. 2005). While occupancy may be effective for the study of rare species, presence-absence surveys may be hastily employed to make indirect inferences about abundance trends of non-rare species due to financial and other program constraints (Buckland and Elston 1993, Reunanen et al. 2002), regardless of whether it is appropriate to do so. Empirical evidence suggests that occupancy-abundance relationships are generally positive, however the form of these relationships can depend on factors such as mean occupancy rate and temporal and spatial variation in abundances (Gaston et al. 2000). These factors can confound the power of presence-absence surveys to detect population trends for some species (Rhodes et al. 2006). The sole use of presence-absence data for non-rare species such as tidal marsh obligate birds, could lead to inappropriate conclusions for salt marsh habitat management and fail to detect critical changes in bird species abundances.

The coefficient of variation (CV) for relative abundance estimates steadily decreased as number of visits increased for Clapper Rail, Willet, and Saltmarsh Sparrow, however final CVs were still of high variability (CV of 50-100%) (Gibbs et al. 1998). Seaside Sparrow variability remained intermediate throughout (CV of 25-50%). The variability reflects a mix of natural temporal variations in populations and sampling error related to survey methodology (Link et al. 1994). In a comprehensive analysis of variability estimates based on indices of local plant and animal populations, the mean CV for small birds was 0.57 (Gibbs et al. 1998). Most studies of small bird populations were based on counts of singing individuals, representing only a portion of the population. For high-variability groups like small birds, a power analysis indicated that 20 plots counted three times a year for 10 years could detect a trend change of 25%. Fifty plots counted five times a year for 10 years could detect a change of 10%, and so on. Project CV data can be compared to published reference tables, such as the Gibbs et al. (1998) tables, to aid monitoring program design. Such comparisons would help determine the optimal number of visits and sampling points needed for tidal marsh bird monitoring programs that fall within program budgets.

Based on the Seaside Sparrow breeding ecology results, positive relationships existed between the rapid metric relative abundance and the intensive avian metrics, nest density, fledgling density, and territory density (in decreasing order of correlation). These relationships support the use of Seaside Sparrow relative abundance as an index of Seaside Sparrow productivity and show how a rapid metric can be used to infer intensive metric information. Financial constraints of monitoring programs can be alleviated by training technicians and volunteers in point-count and call-broadcast survey methodology to monitor abundance, and simultaneously, an index of breeding productivity. These survey methods are cost-effective, allowing funds to be freed up that would have otherwise supported costly, time-consuming intensive sampling methods (i.e. territory mapping, nest searching, and nest monitoring and analysis). Furthermore, Seaside Sparrows are highly visible, vocal passerines dependant on salt marshes for all life cycle stages (Post and Greenlaw 2009). They are usually found occupying the lowest, wettest, and muddiest parts of smooth cordgrass-dominated marsh in tidal marshes along the Atlantic and Gulf coasts, and are often considered an indicator of coastal marsh integrity due to these specific habitat requirements (Post and Greenlaw 2009). Warner et al. (2010) found Seaside Sparrows could be used as a bioindicator species of the extent of Hg contamination in tidal marshes along the Delaware Bay. The findings in this study provide additional support for the use of Seaside Sparrows as a wildlife indicator of salt marsh integrity for comprehensive ecosystem monitoring programs.

Land managers must often ensure that monitoring programs can obtain the necessary information to inform management decisions while being conducted on a limited budget with minimal staff. Point-count and call-broadcast surveys can be performed quickly and cheaply by trained volunteers to obtain valuable tidal marsh bird abundance information. Furthermore, abundance estimates of the indicator species Seaside Sparrow can provide details regarding population trends, insight into temporal and spatial variations of basic demographics, and a baseline picture of wildlife response to salt marsh condition.

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Table 2.1 Summary of occupancy (Ψ) and relative abundance estimations for Clapper Rail, Willet, Saltmarsh Sparrow, and Seaside Sparrow.

Species	Number of Visits	Ψ	Std. Error	95% CI Lower Bound	95% CI Upper Bound	Relative Abundance	Std. Deviation	CV
Clapper Rail	2	0.74	0.08	0.55	0.87	1.53	1.69	1.10
	3	0.86	0.07	0.65	0.95	1.70	1.60	0.94
	4	0.89	0.06	0.72	0.96	1.86	1.50	0.81
	8	0.88	0.04	0.77	0.94	2.37	1.71	0.72
Willet	2	0.91	0.06	0.69	0.98	3.14	2.89	0.92
	3	0.96	0.06	0.55	1.00	2.54	2.15	0.85
	4	0.88	0.05	0.76	0.94	3.24	2.25	0.69
	8	0.97	0.02	0.87	0.99	4.17	2.63	0.63
Saltmarsh Sparrow	2	0.90	0.16	0.24	1.00	1.36	1.47	1.08
	3	0.94	0.09	0.44	1.00	2.05	2.06	1.01
	4	0.91	0.06	0.73	0.97	2.20	2.03	0.92
	7	0.96	0.03	0.84	0.99	2.48	1.54	0.62
Seaside Sparrow	2	0.98	0.02	0.88	1.00	7.70	3.42	0.44
	3	0.98	0.02	0.88	1.00	8.53	4.11	0.48
	4	0.98	0.02	0.89	1.00	8.85	4.16	0.47
	6	0.98	0.02	0.87	1.00	8.93	3.50	0.39

Table 2.2 Seaside Sparrow nesting summary table within study plots at Bombay Hook and Prime Hook National Wildlife Refuges, 2006 - 2009.

Refuge	Plot	Plot Area (ha)	Year	Relative Abundance	Territory Density (#territories/ha)	Nest Density (#nests/ha)	Fledgling Density (#fledglings/ha)	Daily nest survival
Bombay Hook	GR1	2.25	2008	16	3.11	4.44	1.78	0.93
			2009	10	1.33	3.11	0.44	0.88
	GR2	2.25	2008	15	2.22	5.33	5.33	0.93
			2009	8	1.33	1.33	0.44	0.88
	GR3	2.25	2008	9	2.44	1.33	0.00	0.93
			2009	12	1.78	3.11	2.22	0.88
	GR4	2.25	2008	8	2.22	1.78	4.44	0.93
			2009	12	2.44	1.33	0.00	0.88
	OM1	2.25	2008	7	3.56	7.11	13.33	0.96
			2009	10	2.44	4.00	5.33	0.94
	OM2	2.25	2008	6	1.78	5.33	5.78	0.96
			2009	6	2.00	2.67	5.33	0.94
	OM3	2.25	2008	12	3.78	10.22	21.33	0.96
			2009	11	3.56	4.00	3.11	0.94
	UN1	2.25	2008	9	1.78	4.89	10.67	0.96
			2009	10	2.67	2.67	4.00	0.95

Refuge	Plot	Plot Area (ha)	Year	Relative Abundance	Territory Density (#territories/ha)	Nest Density (#nests/ha)	Fledgling Density (#fledglings/ha)	Daily nest survival
			2008	7	2.22	3.11	3.56	0.96
	UN2	2.25	2009	10	3.11	3.11	5.33	0.95
			2008	15	3.11	1.78	4.00	0.96
	UN3	2.25	2009	10	2.22	1.78	4.44	0.95
			2008	14	2.67	3.56	6.22	0.96
	UN4	2.25	2009	8	2.22	1.33	2.67	0.95
Prime Hook			2006	4	NA	2.22	4.44	0.85
			2007	8	4.89	1.78	6.22	0.95
			2008	9	1.78	2.22	3.11	0.95
	PH01	2.25	2009	6	1.56	1.78	1.78	0.94
			2006	9	2.67	3.11	6.22	0.97
			2007	11	4.00	3.56	6.67	0.90
			2008	9	1.56	2.22	3.56	0.95
	PH02	2.25	2009	6	2.22	0.00	0.00	0.72
			2006	7	2.67	2.67	8.00	0.97
			2007	10	5.33	2.67	0.00	0.90
			2008	8	2.33	0.67	2.67	0.95
	PH03	1.50	2009	5	2.00	0.00	0.00	0.72
			2006	0	1.78	0.44	0.00	0.01
			2007	3	0.89	0.00	0.00	NA
			2008	10	0.89	0.00	0.00	NA
	PH04	2.25	2009	9	1.56	0.44	1.33	1.00
			2006	8	7.00	3.00	0.00	0.95
			2007	8	8.00	2.00	7.00	0.97
			2008	12	3.50	5.00	6.00	0.97
	PH05	1.00	2009	7	3.50	3.00	8.00	0.96
			2006	9	4.44	5.78	7.11	0.95
			2007	11	5.78	3.56	6.22	0.97
			2008	12	2.44	7.56	12.00	0.97
	PH06	2.25	2009	11	2.89	3.11	3.56	0.96
			2007	0	0.00	0.00	0.00	0.92
			2008	0	0.00	0.00	0.00	0.94
	PH07	2.25	2009	2	0.00	0.00	0.00	0.00
			2007	0	0.00	0.00	0.00	0.92
	PH08	2.25	2008	4	0.67	0.44	0.00	0.94
			2007	7	3.11	2.22	1.33	0.92
			2008	10	2.22	1.33	1.33	0.94
	PH09	2.25	2009	7	2.22	0.44	0.00	0.00
			2007	5	1.33	0.00	0.00	NA
			2008	3	0.33	0.00	0.00	NA
	PH11	1.50	2009	4	1.00	0.00	0.00	1.00
			2007	8	5.78	3.11	1.78	0.90
			2008	9	2.22	2.67	3.56	0.95
	PH12	2.25	2009	15	2.22	1.33	0.00	0.72
			2007	5	2.67	2.22	2.67	0.95
			2008	8	2.67	1.78	2.22	0.95
	PH13	2.25	2009	6	0.89	0.44	0.00	0.94
			2007	4	2.00	0.00	0.00	0.95
			2008	5	1.00	2.00	2.00	0.95
	PH14	2.00	2009	6	1.50	1.50	2.50	0.94
			2007	5	5.00	2.00	0.00	0.95
			2008	10	4.00	6.00	4.00	0.95
	PH15	1.00	2009	8	4.50	4.00	7.00	0.94

Refuge	Plot	Plot Area (ha)	Year	Relative Abundance	Territory Density (#territories/ha)	Nest Density (#nests/ha)	Fledgling Density (#fledglings/ha)	Daily nest survival
			2007	5	4.26	3.19	7.98	0.95
			2008	9	1.86	4.79	7.45	0.95
	PH16	1.88	2009	7	1.60	2.66	2.13	0.94
			2007	13	6.67	3.56	8.00	0.95
			2008	17	3.33	4.89	9.78	0.97
	PH17	2.25	2009	14	2.89	4.89	8.89	0.96
			2007	14	4.44	6.67	13.33	0.95
			2008	17	2.44	7.11	11.56	0.97
	PH18	2.25	2009	19	2.67	6.67	10.22	0.96
			2007	10	10.00	6.00	8.00	0.95
			2008	12	4.50	8.00	7.00	0.95
	PH19	1.00	2009	15	6.00	3.00	4.00	0.94
			2007	10	3.11	1.78	4.44	0.95
			2008	17	2.67	3.56	9.33	0.97
	PH20	2.25	2009	12	2.67	1.78	0.89	0.96

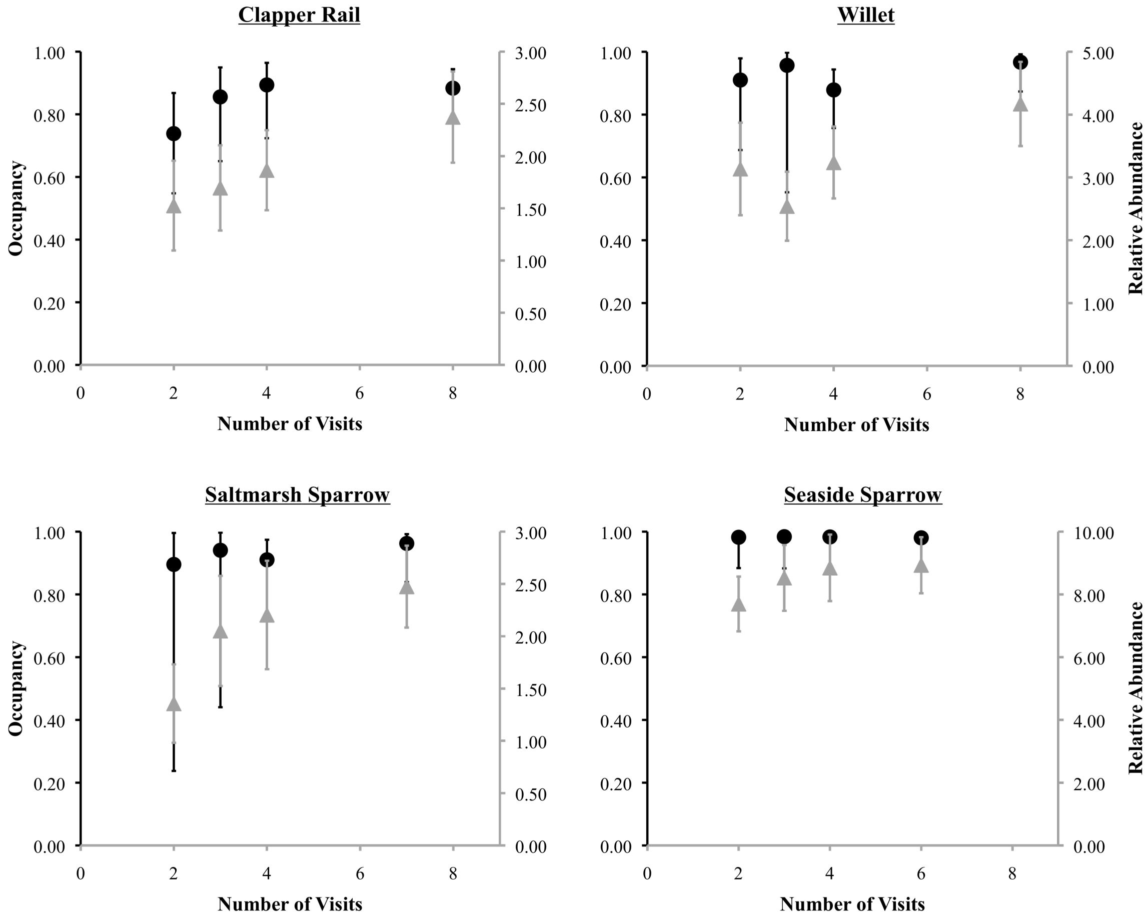

Figure 2.1 Occupancy (●) and relative abundance (▲) estimations with 95% confidence intervals as functions of number of visits for Clapper Rail, Willet, Saltmarsh Sparrow, and Seaside Sparrow.

MANAGEMENT IMPLICATIONS

Avian metrics can be used to monitor salt marsh integrity at national wildlife refuges. Refuges can use the BCI to assign a single monitoring metric to salt marshes to evaluate temporal and spatial changes in avian community composition and as an indicator of the ecological condition of the marsh. The scale can be used as an early warning system to monitoring changes in BCI at low and high quality sites and to re-focus management priorities accordingly, and as a decision-making tool to help support the selection of high-quality sites for acquisition and conservation priority purposes. The BCI may further be integrated into a more extensive salt marsh integrity index to monitor ecosystem condition based on relationships between salt marsh integrity metrics and wildlife response, and to provide additional guidance to refuge managers regarding critical management decisions.

Tidal marsh bird monitoring programs must gather the information necessary to inform management decisions while being executed on a limited budget with minimal staff. Technicians and volunteers can be trained in point-count and call-broadcast survey methodology to alleviate resource constraints and still obtain required data. It is recommended that survey points are visited four times during the breeding season to obtain relative abundance estimates for tidal marsh obligate birds. The sole use of occupancy estimations for these non-rare species is not recommended as such estimations may fail to detect critical changes in species abundances and may lead to inappropriate conclusions for salt marsh habitat management. Furthermore, abundance estimates of the species Seaside Sparrow can be used as an index of breeding productivity to provide insight regarding population trends and temporal and spatial variations of basic demographics. Cost-effective point-count and call-broadcast surveys can be used to infer information otherwise obtained from costly, time-consuming intensive sampling methods (i.e. territory mapping, nest searching, and nest monitoring and analysis). Seaside Sparrow may also be used as an indicator of ecosystem health and provide a baseline picture of wildlife response to salt marsh condition in refuge ecosystem monitoring programs.

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