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Index of Ecological Condition for the Tidal Salt Marsh Ecosystem of Northeastern North America

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INDEX OF ECOLOGICAL CONDITION FOR THE TIDAL SALT MARSH ECOSYSTEM OF

NORTHEASTERN NORTH AMERICA

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INDEX OF ECOLOGICAL CONDITION FOR THE TIDAL SALT MARSH ECOSYSTEM OF NORTHEASTERN NORTH AMERICA

By Josh Parrott

Thesis Advisors: Drs. Brian J. Olsen & Zachary T. Wood

An Abstract of the Thesis Presented in Partial
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We created a metric of ecological condition for use in the northeastern US tidal saltmarsh ecosystem. We used the metric to characterize relative condition of tidal salt marshes across management and protection status, geomorphic setting, and a large geographic extent. We followed a method previously used for freshwater marshes and forests, using an environmental gradient that was defined a priori and is easily interpreted. To define the relative condition of marshes, we characterized the environment, the bird community, and how they interact using data from 2012 – 2014. We found that sites within areas designated as conserved via the USGS GAP project, scored highest and had more tidal saltmarsh-dependent birds, important indicators of quality salt marsh. We found that, although protecting tidal salt marsh from permanent alteration can encourage relatively good environmental conditions, this has not translated into the predicted avian community assemblage that such an environment would suggest, but this varies across sub-ecoregions and geomorphic setting. Also, we found that the avian taxa vary markedly in what environmental conditions drive their average detections; this suggests that several taxa should be included as indicators of the saltmarsh environs to cover the breadth of variation in how landscape and disturbance variables influence them

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CHAPTER 1

INDEX OF ECOLOGICAL CONDITION FOR TIDAL SALT MARSH ECOSYSTEM OF NORTHEASTERN NORTH AMERICA

1. Background

The main goal of the thesis was to describe the relative condition of the tidal saltmarsh ecosystem in northeastern North America and create a measure of said condition that could be applicable as a means of evaluating changes over time, especially considering restoration efforts. We followed a recent approach that combines generalized components of an ecosystem. These metrics are composed of various species' responses to an *a priori* defined and easily interpreted environmental gradient. Since their inception, these methods have evolved and been applied to a variety of ecosystems and taxa, including birds, diatoms, fish, and plants (Howe, Regal et al. 2007, Niemi, Brady et al. 2009, Giese, Howe et al. 2015). Here, we apply these quantitative advances to describe tidal salt marshes within the northeastern US—an imperiled and heavily impacted ecosystem of considerable conservation focus (Adam 2002, Ganju, Defne et al. 2017, Newton, Icely et al. 2020, FitzGerald, Hein et al. 2021). We used bird assemblage data and a suite of environmental datasets that describe ecological and geomorphological processes that impact the probability of marsh degradation or loss to develop a metric that links the avian data to the environmental conditions. We then used this metric to test whether lands protected and managed for biodiversity differed from unprotected lands across the northeastern US.

Indicator taxa can serve as convenient signals of ecosystem condition – a term that we prefer over ecosystem "health" or "integrity" as it does not assume a specific, idealized state – when it is not easily measured directly. Ideally, indicators should track ecosystem change closely, providing early warning signs of declines in ecosystem condition (Noss 1990), and potentially suggest the cause of the change by identifying what aspects or elements of the ecosystem have changed (Herricks and Schaeffer 1985). Such taxa should indicate changes in condition from a wide range of stressors (Herricks and Schaeffer 1985) and be more cost-effective to assess than the underlying ecological processes. Here we test whether birds, long-valued for their ability to indicate both environmental impact (Hutto 1998, Johnson 2008) and ecosystem condition (Howe, Regal et al. 2007, Niemi, Brady et al. 2009, Giese, Howe et al. 2015), can serve as indicators of salt marsh condition. We posit that marshes with highly vegetated intertidal areas and little anthropogenic disturbance generally contain more saltmarsh-specialist bird species such as saltmarsh sparrows (*Ammospiza caudacuta*), seaside sparrows (*A. maritima*), Acadian Nelson's sparrows (*A. nelson subvirgata*), clapper rails (*Rallus crepitans*), and willets (*Tringa semipalmata*). Breeding in these taxa is linked almost exclusively to the salt marsh in this region, and therefore their populations should be strongly dependent upon the overall condition of the saltmarsh ecosystem and the coastal zone.

Tidal salt marshes are important ecosystems that serve as a buffer to storm surge and as habitat that maintains populations of many organisms specific to intertidal marsh conditions. These unique ecosystems are found in the transition zone between terrestrial and marine environments, where saltwater from tidal movements meets the freshwater flows from adjacent upland and riverine systems. The intricate interactions within these salt marshes result in various ecological services that benefit both the environment and biotic communities. For example, they act as natural buffers that help protect coastal areas from the impacts of storms, by decreasing the force of waves that would otherwise hit the coastline directly—reducing the risk of erosion and damage to infrastructure—and absorbing and storing excess water (Costanza, Perez-Maqueo et al. 2008, Luisetti, Turner et al. 2014). Also, by absorbing and dampening the force of storm-related waves, salt marshes help shield beaches, dunes, and estuaries from direct wave action, preserving their ecological functions and the organisms that depend on them. Furthermore, salt marshes serve to filter and purify adjacent estuaries and bays, sequester carbon from the oceans, and support economically important fisheries. Preserving these services is crucial for maintaining the overall health and resilience of coastal ecosystems.

Tidal salt marsh is a uniquely productive ecotone dominated by relatively few halophytic plant species and strongly shaped by local hydrological regimes, stochastic storm events, localized perturbations to vegetation or sediment, and ecological succession. Tidal salt marshes along the Atlantic Coast of the United States from Virginia to Maine feature distinct intertidal zones (Bertness 1991, Bertness 1991) within the normal tidal frame. The high marsh zone, submerged weekly to monthly, exists between the mean daily high tide and the maximum flood height and is dominated by saline-adapted rhizomatous grasses (*Spartina patens, S. alterniflora, Distichilis spicata*) and rushes (*Juncus roemerianus* or *J. geradii*). The low marsh zone is flooded daily and is dominated by *S. alterniflora,* or by *S. cynosuroides* in more brackish areas. Given adequate sediment supply, vegetation in these two intertidal zones can trap sediment and provide stability and growth of the marsh surface over time in the face of sea-level rise (SLR) (Temmerman, Bouma et al. 2005, Blum, Christian et al. 2020, Cahoon, McKee et al. 2020). Conversion from marsh to open water can happen rapidly in either zone, however, wherever the sediment supply is too low to act as a countervailing force to erosion and SLR (Morris, Sundareshwar et al. 2002, Ganju, Defne et al. 2017, Ganju, Defne et al. 2020). Further, horizontal, inland migration of the marsh in the face of SLR can be limited locally by topography and anthropogenic development of the marsh edge (Adam 2002, Newton, Icely et al. 2020). Much of the marshland in our study region is predicted to decrease or disappear entirely in the coming decades due to SLR (Spencer and Harvey 2012, FitzGerald, Hein et al. 2021).

Tidal salt marshes have also been degraded due to anthropogenic impacts. Anthropogenic alteration of coastal ecosystems is multi-faceted with a long legacy (Adam 2002, Newton, Icely et al. 2020) occurring since initial human occupation of the coastline and accelerating dramatically since European colonization. Salt marsh loss has been caused, directly, by removing or otherwise altering the marsh for development or, indirectly, by altering the feedback between vegetation growth and inundation regimes (Bourn and Cottam 1951, Adam 2002, Foley, DeFries et al. 2005, Newton, Icely et al. 2020, Smith, Adamowicz et al. 2022). As most salt marshes along the U.S. Atlantic Coast have been extensively altered for hundreds of years, we assume identification of a hypothetical “pristine” equilibrium condition would be problematic or even impossible. The U.S. Atlantic Coast does, however, possess a large gradient of modern disturbance, including variation in three primary factors known to cause negative effects on salt marsh flora and fauna: wetland loss, upland development, and altered connectivity to tidal flow. Given the mechanistic understanding of these forces on on-going tidal marsh degradation and loss, and the ultimate effects on birds and plants, we can rank tidal salt marshes along a gradient of condition that includes factors that are well studied in the region, such as intertidal wetland loss and landcover change, loss of upland natural buffers, and adjacent development and the associated anthropogenic pressures.

2. Statistical Workflow

Our workflow (Figure 1) consisted of five steps, whereby we 1) defined potential indicator bird taxa at each marsh using counts from avian survey data, 2) defined marsh condition along a composite of four principal components calculated using 16 environmental variables, 3) described the relationship between birds and composite environmental condition, 4) used that relationship to identify a meaningful avian index of ecosystem condition (IEC) across our survey region, and 5) tested whether this metric varied between protected and unprotected lands, among sites with different management foci, and across various geomorphic categories.

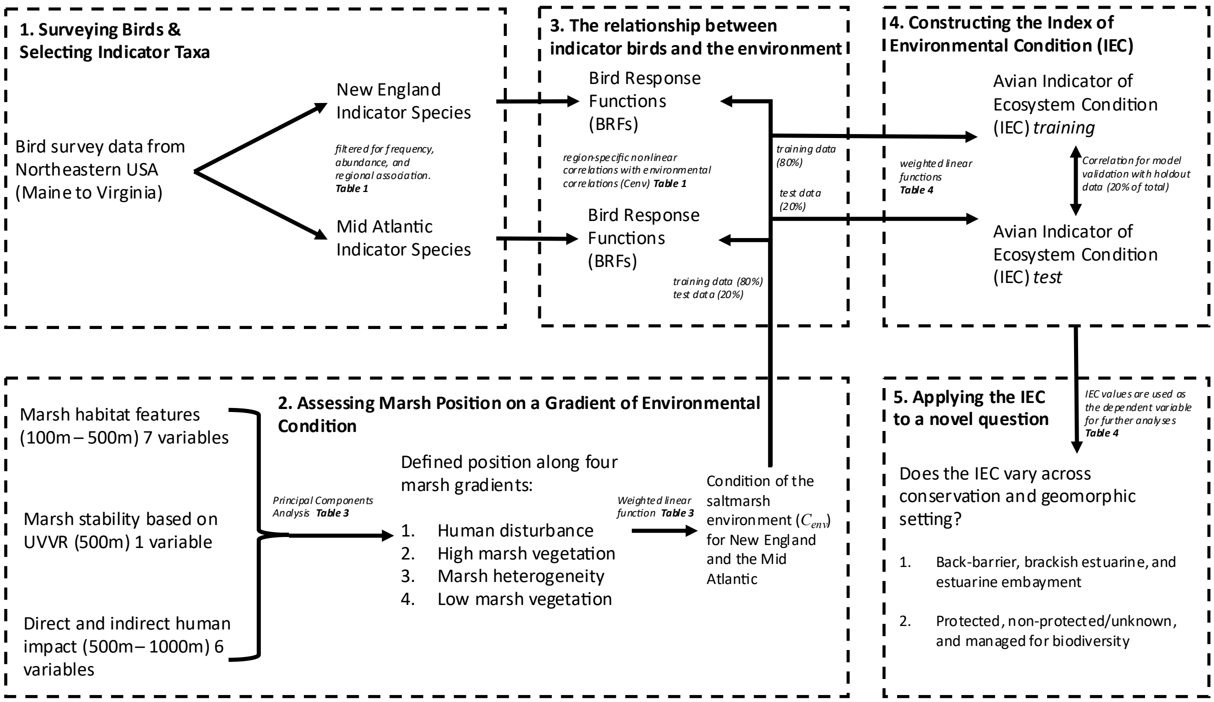

Figure 1: Statistical work flow for creating (1-4), validating (4), and applying (5) a novel metric of tidal salt marsh condition using avian indicator taxa. Our Indicator of Environmental Ccondition (IEC) was developed, validated, and applied using 1260 survey locations, assessed over three years (2012-2014) from Maine to Virginia, USA.

3. Surveying birds and selecting indicator taxa

We conducted bird surveys at 1260 locations, over three years (2012-2014), two to three times per summer (May – August), in salt marshes from Maine to Virginia, USA. Survey sites were selected using a generalized random tessellation stratified (GRTS) design among sites within estuarine emergent marsh patches along the U.S. Atlantic Coast as designated by the National Wetland Inventory (Wilen and Bates 1995). First-stage sampling candidate polygons with state and federally protected areas were added to randomly drawn polygons, and second-stage survey points with historical data (within either randomly selected or manually added sampling polygons) were prioritized over randomly selected survey points whenever they were available. We defined survey dates across eight sub-ecoregions (Conway, Arizona et al. 2006), which are delineated roughly from north to south, to allow for differences in phenology across the latitudinal range of the effort. All survey technicians were trained prior to the start of the season on a standardized protocol and monitored for consistency throughout the survey period. All birds using marsh habitats within 100 m of the survey point were recorded. A detailed description of our site selection and survey protocols can be found in (Wiest, Correll et al. 2016). Surveyed marshes varied in their landscape composition, bird community composition, and in the amount of disturbance in and around the marsh.

We divided our survey region into two broad geographic ecoregions for bird analyses: New England (US states of Maine, New Hampshire, Massachusetts, Rhode Island, and Connecticut; spanning three sub-ecoregions: Coastal Maine, Cape Cod and Casco Bay, and Southern New England) and the Mid-Atlantic ecoregion (US states of New York, New Jersey, Delaware, Maryland, and Virginia; spanning five sub-ecoregions: Long Island, Coastal New Jersey, Delaware Bay, Coastal Delmarva, and the Eastern Chesapeake Bay). The two broad ecoregions differ, on average, in their bird communities, ranges of marsh size, SLR rate, and glacial histories. As such, we conducted all bird analyses independently for each of the two ecoregions, including identifying indicator taxa for each.

We identified potential indicator taxa for each ecoregion based upon their frequency of presence, average count across surveys, and statistical association with the ecoregion (step 1; Table 1). To test for species-ecoregion relationships, we used the “multipatt” function in the “indicspecies” (De Caceres and Legendre 2009) package using the “IndVal” statistic (Dufrene and Legendre 1997, De Caceres and Legendre 2009, De Caceres, Legendre et al. 2010) in Program R across the full survey extent. By controlling the relative frequency of detections across all survey locations and the mean value of all counts, this function tested for an association between mean counts for each taxa and ecoregion. Non-significant results of this test indicate that counts for a particular species do not deviate from a random distribution of the observed detections across the full survey extent. We used a p-value that represents the proportion of randomized permutations of the statistic that is at least as great as the observed count, where alpha = 0.05, and its confidence interval to look for associations between taxa and the two ecoregions. We include a statistic that predicts the affinity for each avian species for a given ecoregion as compared to the other (based on average detections). Additionally, we used the lower confidence interval limit of the estimate of likelihood of occurrence from this function to prune rare species within each ecoregion (based on presence-absence data). The resulting list of potential indicator species for each ecoregion includes those with a greater than 10% chance, on average, of detection at a survey point within the assigned ecoregion, including those that were disproportionately present within one of the two ecoregions (e.g., possessed > 10% occurrence for only one ecoregion) and those that were detected similarly across the two regions (e.g., possessed > 10 % occurrence for both ecoregions). We selected indicators for the condition index from this list of potential indicators in step 4. After removing taxa that did not show a relationship with our environmental variables, the remaining taxa (Table 1) were used to calculate values for sites in each ecoregion. 22 taxa were used in both ecoregions, eight taxa were unique to the New England IEC calculation, and 22 were unique to the Mid-Atlantic.

Table 1. The list of selected indicator taxa for New England (n = 30 taxa; n = 568 sites). Lack of fit (LOF) details the biotic response model fit, R^2 is variance explained, the mean value of estimated peak in average detections (mean), the standard deviation of that mean (SD), H is the scaling factor for the normal distribution, direction of response details if the response curve increases, then decreases within the range of C_{env} values (intermediate), decreases only (negative), or increases only (positive), the range of the response is the change in average detection over the range of the C_{env}, the affinity for the ecoregion as compared to the Mid-Atlantic, and likelihood of detecting that taxa after 6 - 9 visits.

Taxon	LOF	R2	Mean	SD	H	Direction of response	Range of response	Affinity for New England	Likelihood of detection
American black duck	0.571	0.321	18.237	7.449	10.525	positive	0.278	0.559	0.27
American crow	0.511	0.367	5.424	2.693	3.207	intermediate	0.413	0.688	0.713
American goldfinch	0.213	0.614	4.645	2	1.276	intermediate	0.247	0.816	0.54
Barn swallow	1.052	0.272	1.966	4.728	11.164	intermediate	0.72	0.425	0.627
Black-bellied plover	0.773	0.476	9.541	3.016	3.478	positive	0.457	0.552	0.165
Canada goose	1.66	0.182	5.134	3.065	6.807	intermediate	0.668	0.534	0.538
Common grackle	1.615	0.35	2.441	3.695	8.255	intermediate	0.781	0.582	0.632
Common tern	0.861	0.495	20	6.599	38.534	positive	0.715	0.516	0.286
Common yellowthroat	0.48	0.365	5.626	2.692	2.536	intermediate	0.333	0.52	0.759
European starling	2.697	0.386	-10	7.222	82.084	negative	1.641	0.587	0.348
Great blue heron	0.403	0.261	7.016	3.581	1.422	intermediate	0.135	0.427	0.384
Great egret	1.53	0.356	20	8.039	47.661	positive	0.984	0.371	0.476
Greater yellowlegs	0.333	0.571	20	7.812	23.091	positive	0.475	0.587	0.43
Herring gull	0.825	0.365	17.313	10	42.846	positive	0.926	0.523	0.665
House sparrow	0.397	0.789	1.334	2	2.01	negative	0.401	0.789	0.179
Least sandpiper	0.491	0.639	12.273	4.131	5.822	positive	0.477	0.433	0.211
Least tern	1.209	0.259	10.86	3.875	5.62	positive	0.553	0.436	0.198
Lesser yellowlegs	0.459	0.347	20	5.476	15.841	positive	0.216	0.299	0.173
Mallard	1.628	0.235	-9.538	10	27.414	negative	0.532	0.564	0.513
Mourning dove	0.276	0.523	-1.035	3.439	1.885	negative	0.208	0.381	0.203
Nelson's sparrow	1.177	0.625	8.337	2	4.085	positive	0.815	0.977	0.354
Red-winged blackbird	4.611	0.178	-5.487	10	136.681	negative	3.047	0.466	0.829
Saltmarsh sparrow	2.48	0.306	14.807	5.967	29.667	positive	1.343	0.455	0.375
Savannah sparrow	0.319	0.481	19.447	6.469	13.046	positive	0.268	0.856	0.217
Snowy egret	0.908	0.656	20	7.162	61.624	positive	1.225	0.439	0.541
Song sparrow	0.281	0.797	3.833	2.907	10.625	intermediate	1.304	0.642	0.959
Swamp sparrow	0.708	0.178	6.467	2.313	0.601	intermediate	0.102	0.512	0.16

Tree swallow	1.058	0.625	8.638	3.902	13.757	positive	1.285	0.52	0.733
Willet	1.959	0.801	20	6.699	194.746	positive	3.672	0.401	0.516
Yellow warbler	0.182	0.278	4.656	3.233	1.982	intermediate	0.182	0.619	0.621

Table 1 (cont.). The list of selected indicator taxa for the Mid Atlantic (n = 44 taxa; n = 692 sites). Lack of fit (LOF) details the biotic response model fit, R^2 is variance explained, the mean value of estimated peak in average detections (mean), the standard deviation of that mean (SD), H is the scaling factor for the normal distribution, direction of response details if the response curve increases, then decreases within the range of C_{env} values (intermediate), decreases only (negative), or increases only (positive), the range of the response is the change in average detection over the range of the C_{env}, the affinity for the ecoregion as compared to the Mid-Atlantic, and likelihood of detecting that taxa after 6 - 9 visits.

Taxon	LOF	R2	Mean	SD	H	Direction of response	Range of response	Affinity for the Mid-Atlantic	Likelihood of detection
American crow	0.275	0.748	3.796	2.094	1.262	intermediate	0.237	0.312	0.323
American oystercatcher	1.002	0.687	20	5.918	48.362	positive	0.771	0.793	0.237
Barn swallow	1.743	0.556	3.745	3.598	17.296	intermediate	1.494	0.575	0.849
Black skimmer	0.61	0.346	7.043	2	0.916	intermediate	0.182	0.993	0.223
Boat-tailed grackle	0.64	0.653	6.726	2.158	3.431	intermediate	0.629	0.997	0.541
Canada goose	0.774	0.697	-0.683	5.112	12.265	negative	0.841	0.466	0.47
Clapper rail	1.218	0.825	7.576	2.417	16.309	intermediate	2.672	0.936	0.768
Common grackle	0.613	0.9	1.783	2.631	7.757	negative	1.167	0.418	0.453
Common tern	2.58	0.281	20	7.303	35.13	positive	0.706	0.484	0.268
Common yellowthroat	0.575	0.778	2.617	3.437	7.802	intermediate	0.815	0.48	0.701
Eastern kingbird	0.419	0.395	5.223	2.004	0.92	intermediate	0.177	0.606	0.291
European starling	0.431	0.896	2.465	2.053	4.615	intermediate	0.896	0.413	0.244
Fish crow	0.377	0.262	5.612	2.36	1.158	intermediate	0.184	0.808	0.38
Forster’s tern	1.463	0.608	7.987	2.463	6.664	intermediate	1.074	0.994	0.51
Great black-backed gull	0.48	0.343	10.5	5.583	3.981	positive	0.235	0.529	0.38
Great blue heron	0.412	0.357	5.958	2.238	1.367	intermediate	0.237	0.573	0.516
Glossy ibis	0.412	0.679	7.044	2.436	2.934	intermediate	0.473	0.726	0.395
Grey catbird	0.128	0.874	3.194	2.06	0.81	intermediate	0.156	0.529	0.243
Great egret	0.83	0.698	20	8.369	84.029	positive	1.731	0.629	0.808
Greater yellowlegs	0.24	0.384	6.51	2.35	0.781	intermediate	0.13	0.413	0.302
Herring gull	0.707	0.529	8.462	4.398	8.211	positive	0.628	0.477	0.606
Killdeer	0.197	0.565	2.099	2.999	0.803	intermediate	0.103	0.52	0.136
Laughing gull	2.628	0.722	6.995	2.3	20.244	intermediate	3.477	0.857	0.702

Least sandpiper	0.716	0.339	11.111	5.328	4.966	positive	0.322	0.567	0.277
Least tern	0.49	0.247	6.878	3.088	1.463	intermediate	0.173	0.564	0.257
Lesser yellowlegs	0.365	0.349	6.325	2	0.559	intermediate	0.111	0.701	0.171
Mallard	0.412	0.737	-10	7.906	29.921	negative	0.617	0.436	0.397
Mourning dove	0.263	0.68	3.98	2.207	1.042	intermediate	0.184	0.619	0.331
Northern cardinal	0.233	0.642	4.044	2	0.526	intermediate	0.104	0.61	0.223
Northern mockingbird	0.193	0.701	2.773	2	0.701	intermediate	0.14	0.632	0.199
Osprey	0.876	0.18	7.496	5.524	9.073	intermediate	0.394	0.559	0.677
Purple martin	0.61	0.501	4.584	2.116	1.303	intermediate	0.236	0.907	0.264
Red-winged blackbird	1.574	0.763	2.478	5.051	84.906	intermediate	4.494	0.534	0.951
Saltmarsh sparrow	2.045	0.422	9.4	3.655	8.277	positive	0.87	0.545	0.449
Short-billed dowitcher	0.746	0.552	10.295	3.346	3.325	positive	0.391	0.857	0.191
Semipalmated plover	0.447	0.128	20	9.441	5.315	positive	0.104	0.893	0.158
Semipalmated sandpiper	1.26	0.297	6.632	2.313	2.655	intermediate	0.45	0.867	0.258
Seaside sparrow	2.07	0.826	9.185	2.778	28.827	positive	4.122	0.92	0.655
Snowy egret	1.108	0.61	8.093	2.934	6.18	positive	0.822	0.561	0.691
Song sparrow	0.619	0.827	1.096	3.628	8.749	negative	0.915	0.358	0.534
Virginia rail	0.459	0.295	5.831	2.012	0.682	intermediate	0.133	0.686	0.177
Willow flycatcher	0.319	0.851	-10	5.714	44.97	negative	0.672	0.632	0.226
Willet	0.889	0.894	8.505	2.828	20.684	positive	2.886	0.599	0.77
Yellow warbler	0.36	0.88	-0.205	3.371	6.124	negative	0.716	0.381	0.383

Selected indicator taxa varied markedly between ecoregions both in the average number of detections for each taxon and how many taxa qualified as indicators using our criteria (New England = 30 and the Mid-Atlantic = 44 taxa). We surveyed 1260 tidal saltmarsh sites 6 - 9 times (mean = 8.3) over the three years of our study (Figure 2). A total of 64 bird species were documented in at least 10% (126) of the survey points and were retained for these analyses. Among these taxa, a total of 238,639 detections were documented: 80,090 in New England and 158,549 in the Mid-Atlantic.

In this paper, we use the term "condition" to describe the relative state of the ecosystem, though various authors have referred to ecosystem state alternatively as its health (Schaeffer, Herricks et al. 1988, Rapport 1995, Wicklum and Davies 1995) or integrity (Wicklum and Davies 1995) The term "health" may be a useful metaphor for communicating results to the public (Schaeffer, Herricks et al. 1988) and can underscore that ecosystem resilience, or lack thereof, in the face of environmental stressors is analogous to organismal homeostasis, or its failure, in the face of illness (Rapport 1995). However, "health" assumes a single, preferred, organismal homeostatic condition, while an ecosystem may have multiple equilibria, different stakeholders who hold different preferences among ecological states, or an ecosystem may not exhibit any equilibrium state at all. We eschew the use of "integrity" for similar reasons, where its use infers deviation from a single, preferred equilibrium state. Instead, we use the term "condition", which we define as a snapshot of ecological state at a given time, and we consider ecological condition as a relative measure along a gradient between defined endpoints, which may or may not represent equilibrium states.

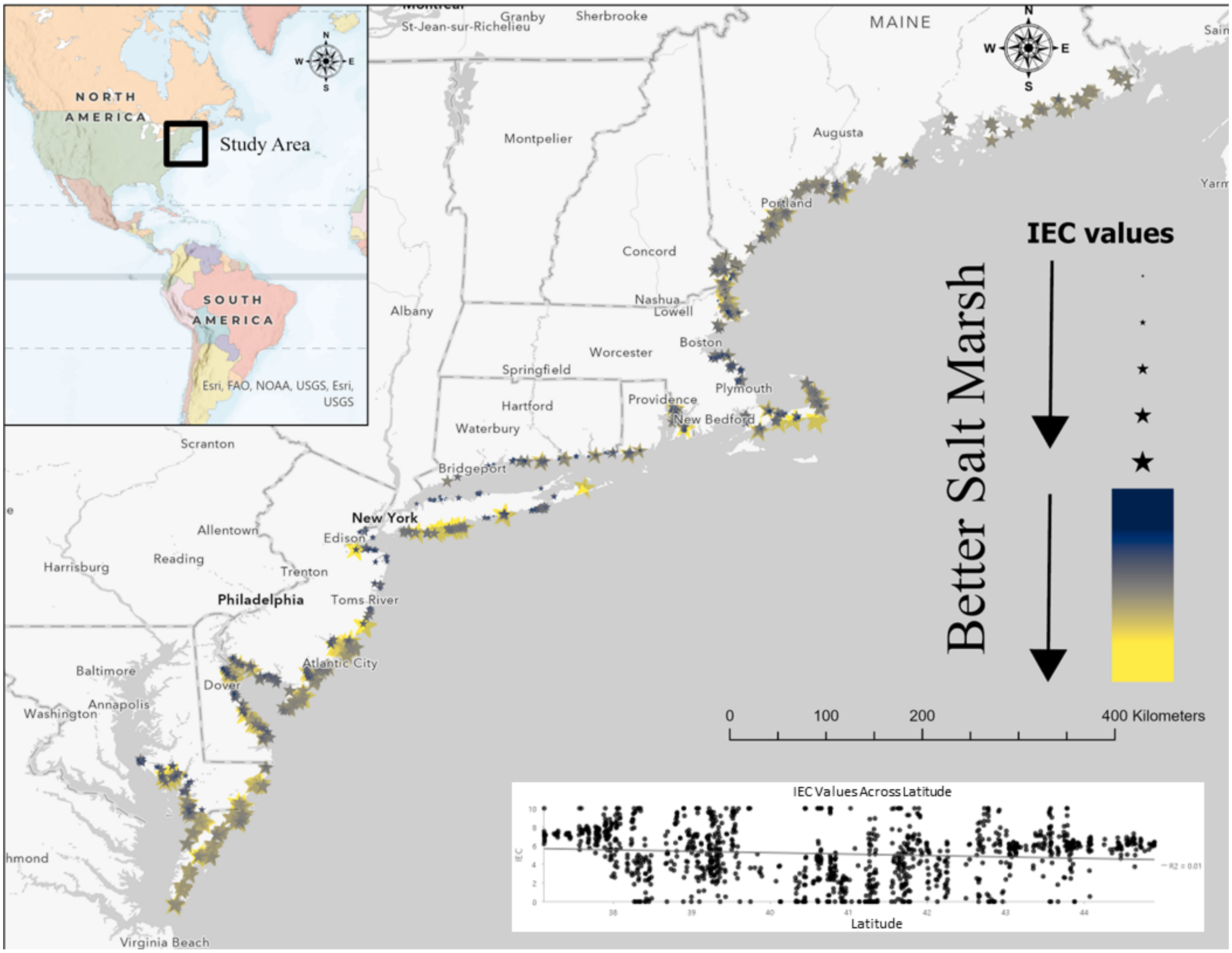

Figure 2. The Indicator of Ecosystem Condition (IEC) for each survey location across the New England and the Mid Atlantic ecoregions of the U.S. Atlantic coast. IEC values vary by size and color. The range of residuals from a regression between the IEC and the underlying marsh environmental condition (C_{env}) is similar across the geographic range.

4. Assessing the Marsh Environment

We used a set of published environmental spatial datasets to represent tidal salt marsh variation across our survey area and to describe marsh environmental condition around each survey point (step 2; Table 2). We used remotely sensed categories of plant and water coverage to estimate this within 100 or 500 m of our survey location, including high marsh vegetation (Correll, Hantson et al. 2019), low marsh vegetation (Holmquist, Schile-Beers et al. 2021), mudflat, pools / pannes, streams, terrestrial border and brackish vegetation, and upland vegetation (Correll, Hantson et al. 2019). Landcover data were calculated as either percent cover, absolute area covered, or both. We also combined land cover variables into a previously validated index of marsh geological stability, the unvegetated to vegetated marsh ratio (UVVR) (Ganju, Defne and Fagherazzi; Ganju et al.) and transformed this ratio into a binomial (stable / unstable) variable, defining a UVVR value of 0.1 or less as unstable based on past experiments and models (Ganju, Defne et al. 2020). The resulting variable details the percent of intertidal area that is unstable within 500 m of our survey locations.

Six additional variables were included to capture both direct and indirect measures of human impact to the marsh, including the extent of hardened development (structures impervious to water infiltration and non-hardened development (open spaces and agriculture), human population density, upland habitat loss, intertidal wetland loss, and marsh connectivity (McGarigal et al.). We extracted these six variables from published spatial datasets as proportions of buffer spaces of 500- or 1,000-m radii from survey sites and logit transformed the results. Where necessary, variables were $\log_{10}$ or square-root transformed to increase linearity across covariates. Data sources, buffer radii, data transformation, and literature support for all variables are listed in Table 2. All variables used to define the saltmarsh environment had correlations (Pearson's r) of less than 0.7, after transformation.

Table 2. Environmental variables represent 100, 500 and 1,000 m radii from bird survey locations. Tidal salt marsh as represented here is a collection of intertidal features including vegetated areas such as high/low marsh vegetation and a shrubby border (upland and terrestrial border) that normally fringes the landward boundary of the tidal frame and is rarely flooded, save extreme storm events or unfortunate alignment of factors such as heavy storm surge amplified by spring high tides. Non-vegetated features such as tidal waterways, pools, pannes and mudflats exist within the intertidal range and comprise the remaining habitat mosaic within 100 m of the survey site. Disturbance in the form of development and habitat loss are included to represent the human footprint across our survey area.

Environmental variables	**Sampling radius**	**Data resolution**	**NE Mean/Range**	**MA Mean/Range**	**Transformation**	**Description**	**Data source citation**
Upland %	100 m	3 m	3.77 (0 - 94.56)	1.49 (0 - 89.17)	logit	Extra-tidal vegetation above normal maximum flood height.	Correll et al. (2019)
Terrestrial border %	100 m	3 m	6.20 (0 - 95)	9.58 (0 - 95)	logit	Shrubby and brackish intertidal vegetation.	Correll et al. (2019)
Mudflat %	100 m	3 m	2.76 (0 - 62.35)	1.33 (0 - 72.57)	logit	Intertidal muddy areas devoid of vegetation.	Correll et al. (2019)
Pool/Panne %	100 m	3 m	1.51 (0 - 30.69)	1.36 (0 - 28.37)	logit	Depressed, bare, or water-filled areas the of high marsh zone.	Correll et al. (2019)
Streams %	100 m	3 m	3.7 (0 - 55.46)	11.75 (0 - 87.13)	logit	Free-flowing intertidal water bodies.	Correll et al. (2019)
High Marsh %	100 m	3 m	39.2 (0 - 92.41)	34.54 (0 - 92.49)	logit	High marsh vegetation, flooded weekly to monthly.	Correll et al. (2019)
Low Marsh %	100 m	30 m	30.13 (0 - 95)	25.29 (0 - 95)	logit	Proportion of area with > 95% probability of low marsh vegetation.	Holmquist and Windham-Myers (2022)
Unstable Marsh %	500 m	15 m	12.39 (0 - 93.17)	17.86 (0 - 93.12)	logit	The percentage deemed unstable due to a UVVR > 0.1.	Correll et al. (2019)
Low Marsh Area (m2)	500 m	30 m	661 (0 - 2,188)	805 (0 - 2,440)	sqrt	Total area of vegetated low marsh with a greater than 95% probability.	Holmquist and Windham-Myers (2022)
High Marsh Area (m2)	500 m	3 m	888 (3 - 2,272)	1,117 (0 - 2,410)	sqrt	Total area of vegetated high marsh.	Correll et al. (2019)
Impervious Surface Dev %	500 m	30 m	16.56 (0 - 58.85)	14.87 (0 - 84.04)	logit	Proportion of area that is hardened surfaces.	McGarigal, K., et al. (2018)
Non-Hardened Dev %	500 m	30 m	10.44 (0 - 69.02)	5.02 (0 - 60.54)	logit	Proportion of area that is non-natural open spaces.	McGarigal et al. (2018)
Wetland Loss %	1 km	30 m	34.61 (0 - 92.64)	32.18 (0 - 90.51)	logit	The intensity of impact caused by all forms of development.	McGarigal et al. (2018)
Habitat Loss %	1 km	30 m	17.15 (0 - 78.42)	16.29 (0 - 77)	logit	An index that details indirect habitat (upland) loss.	McGarigal et al. (2018)
Connectivity %	1 km	30 m	7.29 (0.27 - 27.37)	16.05 (0.44 - 47.50)	logit	The ecological distance, weighted by development type.	McGarigal et al. (2018)
Human Population Density	1 km	30 m	218 (0 - 2,606)	173 (0 - 3,781)	log	Average persons per square kilometer for the year 2010.	CIESIN, Columbia University (2016)

We developed a composite variable describing the condition of the environment (C_{env}) for salt marshes across the northeastern US—a linear combination of the first four principal components (PCs) created using our 16 environmental variables (Table 2). The first four principal components from our Principal Components Analysis (PCA) explained 65.57% of the total variance in our 16 initial variables. These four components were used to define the C_{env} at each bird survey location (Figure 3).

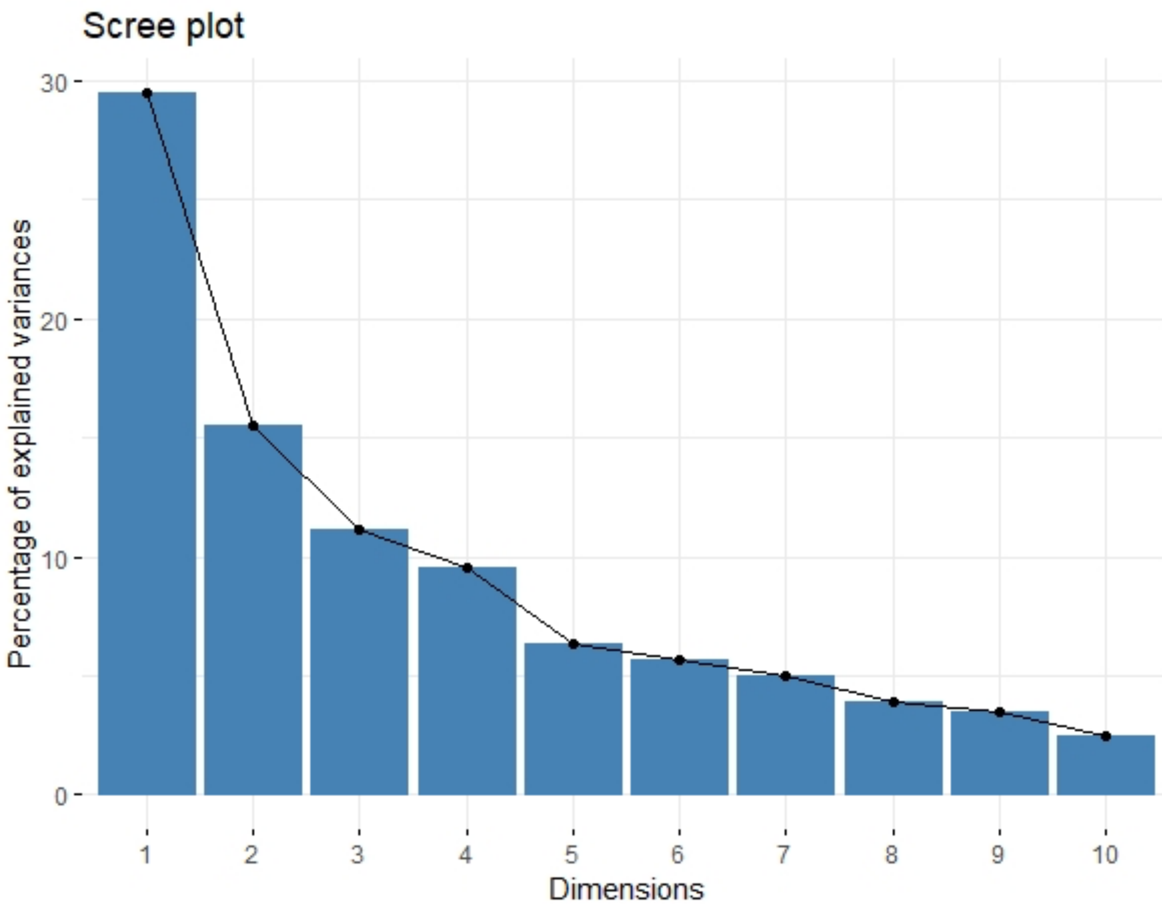

Figure 3 The first four principal components from our PCA of the 16 marsh and landscape variables explained 65.57% of the total variance and were used to make the C_{env}.

Individual variable weights from the PCA suggest that these four components describe 1) disturbance and habitat loss, 2) high marsh vegetation cover, 3) marsh elevation gradient, and 4) low marsh vegetation cover (Table 3). All four of the components used to construct the C_{env} were either positively correlated with, or we reversed their coordinates so that they were correlated positively with, high marsh vegetation, either as percent cover at the survey-site level (within 100 m of the survey location) or at the marsh level (within

500 m). We did this so that the composite metric of the highest values would represent conditions that are most likely to support the habitat component known to be positively associated with saltmarsh stability and nesting locations for marsh dependent birds.

Table 3. Contribution and correlation (r) of 16 environmental variables with each principal component used to create the C_{env}.

Environmental Variables	PC1 Contribution (r)	PC2 Contribution (r)	PC3 Contribution (r)	PC4 Contribution (r)
Upland % 100m	1.757 (-0.284)	4.042 (-0.314)	12.089 (-0.465)	0.010 (-0.012)
Terrestrial border % 100m	0.368 (-0.130)	2.036 (-0.223)	23.992 (-0.655)	3.763 (0.238)
Mudflat % 100m	0.131 (-0.077)	2.435 (-0.244)	11.354 (0.451)	0.375 (0.075)
Pool/Panne % 100m	1.476 (0.260)	1.154 (0.168)	4.327 (0.278)	0.660 (-0.100)
Streams % 100m	4.723 (0.465)	10.898 (-0.515)	9.188 (0.406)	4.698 (-0.265)
High Marsh % 100m	0.002 (-0.010)	31.006 (0.869)	4.573 (0.286)	0.059 (-0.030)
Low Marsh % 100m	0.112 (-0.072)	5.759 (-0.375)	5.549 (0.315)	36.096 (0.736)
Unstable Marsh % 500m	3.755 (0.415)	14.525 (-0.595)	14.485 (0.509)	4.321 (0.255)
Low Marsh Area (m2) 500m	2.062 (0.307)	0.073 (-0.042)	1.864 (0.183)	44.350 (0.815)
High Marsh Area (m2) 500m	2.000 (0.303)	26.561 (0.805)	2.274 (0.202)	0.898 (0.116)
Impervious Surface Dev % 500m	12.513 (-0.757)	0.278 (0.082)	3.065 (0.234)	0.013 (0.014)
Non-Hardened Dev % 500m	7.943 (-0.603)	0.246 (-0.077)	0.123 (0.047)	2.238 (0.183)
Wetland Loss % 1km	12.746 (-0.764)	0.256 (-0.079)	4.411 (0.281)	0.839 (0.112)
Habitat Loss % 1km	19.273 (-0.940)	0.003 (-0.008)	1.186 (0.146)	0.002 (0.006)
Connectivity % 1km	15.240 (0.836)	0.395 (0.098)	0.335 (-0.077)	0.000 (0.001)
Human Population Density	15.900 (-0.854)	0.335 (0.090)	1.185 (0.146)	1.678 (0.159)

PC1 values were heavily influenced by the amount of inter- and extra-tidal landscape change, hardened and non-hardened development, population density within 1 km of the survey location, and the loss of ecological connectivity, suggesting that it is strongly driven by human disturbance. We firstly multiplied PC1 values by -1, so that they would be positively correlated with less disturbance and more intertidal vegetation. Positive avian associations with this gradient would thus indicate species' sensitivity to impacts from anthropomorphic disturbance to both the surrounding marsh area and adjacent landscape. High PC1 values indicate relatively undisturbed upland with natural buffers and more intertidal vegetation cover. This component was relatively unrelated to changes in wetland composition within 100 m of the survey locations, with all contribution values less than 5.0 % and correlation coefficients less than 0.50. (Table 3) Hereafter, we refer to this PC as the human footprint gradient as it best describes variation in disturbance and habitat loss due to anthropogenic activities.

PC2 was also flipped on its axis so that positive values could be interpreted as more high marsh vegetation and less percent cover of non-vegetated habitat features, such as streams, and mudflats and the percent cover of unstable marsh calculated using average binomial stable / unstable based on the UVVR threshold. The component is also negatively correlated with upland vegetation and terrestrial border / brackish vegetation. Positive association with this gradient would indicate affinity for percent composition of high marsh at the survey-site level and total area of high marsh at 500 m and the relative absence of non-marsh intertidal features. Hereafter, we refer to this component as the high marsh vegetation gradient as its highest values are found in marshes with the highest extent and percentage cover of high marsh vegetation.

PC3 was positively correlated with most marsh cover types within 100m of the survey site: streams, mudflats, pools / pannes, high marsh vegetation, and low marsh vegetation. It is negatively correlated, however, with terrestrial border / brackish vegetation, and upland vegetation. Positive association with this gradient would suggest the indicator taxa has an affinity for most cover types within salt marshes, including non-vegetated areas, and thus is found in marshes with relatively diverse intertidal marsh coverage types save terrestrial border / brackish and upland habitats. This component was only weakly associated with all variables at the scale of 500 m or greater (contributions all less than 5.0 %) except for the marsh stability index, which is itself a composite of the other heavily weighted smaller scale landscape cover variables. Hereafter, we refer to this component as the marsh elevation gradient as the highest values exist for landcover types within the intertidal zone as opposed to the upland landscape.

PC4 was multiplied by -1 so that positive values indicate a higher percent cover of low marsh vegetation within 100 m of the survey point and more low marsh vegetation cover within 500 m. Changes along this gradient reflect the amount and proportion of low marsh vegetation. Higher values indicate both higher-than-average percent composition of low marsh vegetation and more low marsh vegetation vs unvegetated marsh. Strong positive association with this gradient would indicate affinity for a higher proportion and total area of low marsh vegetation cover. Hereafter, we refer to this component as the low marsh vegetation gradient as it best describes the extent and percentage cover of low marsh vegetation.

The C_{env} serves as the environmental gradient that defines the range of saltmarsh habitat and disturbance conditions as measured here; it is a composite, weighted variable, created from the four PCs detailed above. The PCs were weighted by how much they contributed to the total variation that each explains, then added together, then scaled between 0 - 10. The C_{env} is strongly influenced by the first two PCs, in both ecoregions, as they together account for 68.5% of the C_{env}. The C_{env} is, therefore, highly negatively correlated with disturbance and positively correlated with high marsh and low marsh vegetation.

5. Biotic Response Functions

To determine which of our previously identified candidate indicator species were most informative in indicating the gradients described by our composite C_{env} metric, we parameterized biotic response functions (Figure 1, Step 3) that describe the relationship between each candidate species within each ecoregion and the C_{env} gradient (Table 1). The fitted functions are modified normal distributions as detailed in equation 1.

$$D_i(C_{env}) = \frac{1}{\sigma\sqrt{2\pi}} e^{\left(-\frac{(Cenv-\mu)^2}{2\sigma^2}\right)} h \quad \text{(eq. 1)}$$

The equation, modified from Geise et al. (2015), estimates the rate of detection of a given species across the range of C_{env} values ($D_i\ (C_{env})$); with μ and σ as the mean and standard deviation of the normal distribution, and h as a scaling factor so that the area under the curve is not constrained to one. We binned sites into similar C_{env} values to find the best fit curve and ease convergence (Giese, Howe et al. 2015). Each of the bins represents 150 - 234 (New England) and 168 - 261 (Mid-Atlantic) surveys spread across three consecutive breeding seasons, with variation in total surveys due to variation in number of sites for each bin and the total number of surveys across seasons. Average detections are computed for each bin and used to estimate the biotic response functions. Positive responses (Figure 4) describe birds that are more common in marshes with higher C_{env} values. A function with mean values greater than 10, suggests that further increase in detections could occur for a species given C_{env} values better than what we have measured across our survey area. Such areas would, hypothetically, have more intertidal vegetation with less disturbance than measured here. Mean function values below 0 indicate that one would expect higher counts for that taxon across a suite of environmental conditions that are negatively correlated with the marsh conditions captured by the C_{env}. Such conditions could include natural upland ecosystems, brackish and freshwater wetlands, or even more heavily disturbed and developed areas than we included here. Note that there are more ways to be negatively than positively associated with the C_{env} gradient, for example, negative conditions could include brackish wetlands, natural upland, or more anthropogenic disturbance than we measured. In contrast, conditions higher than 10 suggest more intertidal marsh vegetation and less anthropogenic disturbance than we measured. After calculating BRFs for each indicator avian species, and the composite C_{env}, we performed similar analyses with each indicator for the separate PCs, as a post-hoc analysis to explain what individual components may be driving the avian response to the C_{env} (Table 1, Appendix A). Bird taxa vary in what PCs, and their contributing variables, drive the species responses to the composite C_{env}.

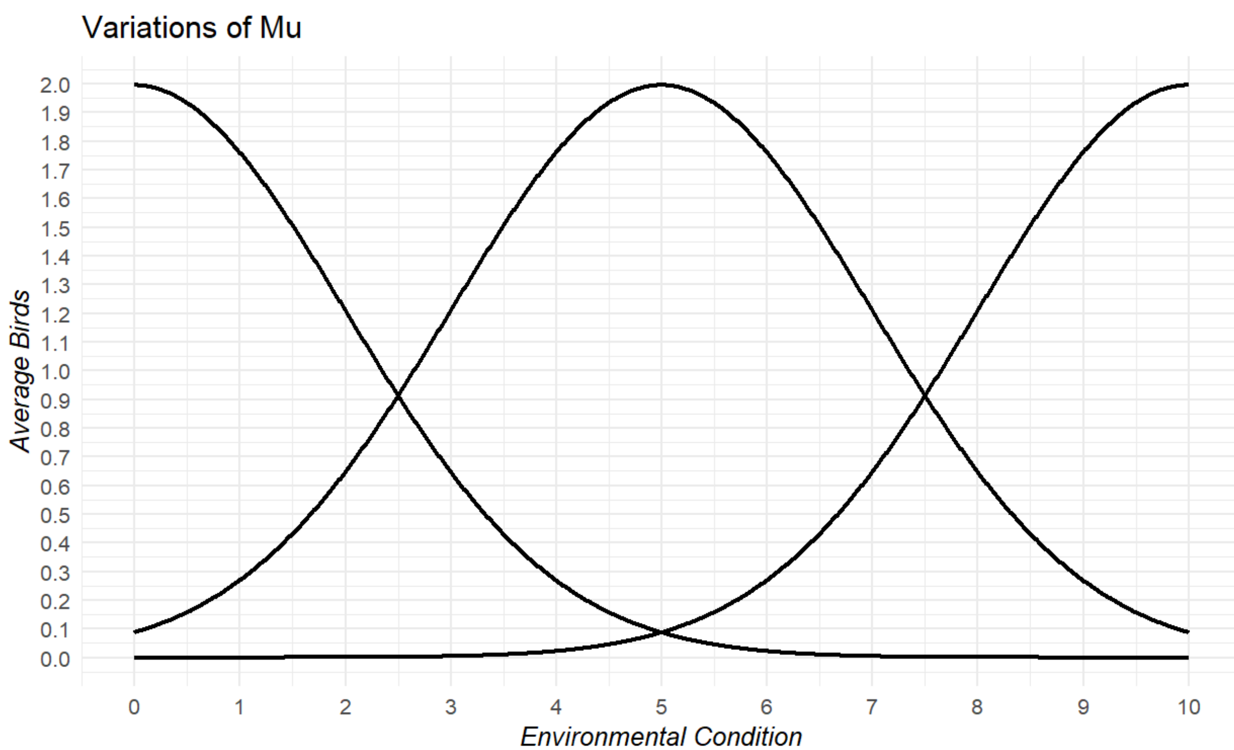

Figure 4. Examples of negative response (left curve), an intermediate response (middle curve), and a positive response (right curve), all having the same scaling parameter (h). These curves correspond with low, middle, and higher μ values, which indicate where along the environmental condition gradient (C_{env}) the average number of bird detections peaks.

6. Constructing the Indicator of Environmental Condition (IEC) metric

The functions that describe the non-linear relationship between average detections of each avian indicator taxa and the C_{env} (Table 1), represent assumed biotic responses to the saltmarsh environment (step 3 in Figure 1) and were used to calculate an overall index of environmental condition (IEC; step 4). So, the IEC metric represents relative marsh condition, ranked 0 – 10, as determined by avian assemblages and their collective response to the environment as we have defined it here. We calculated an IEC function for each ecoregion separately using a unique suite of informative avian taxa. We used only those candidate indicator taxa with functions that predicted an increase or decrease in average detections of more than 0.10 birds over the full range of the C_{env} and that also had a model fit of $R^2 > 0.10$. Ecoregion-specific IEC functions were then calculated from an algorithm that fits the indicator responses to the C_{env} composite measure using an automated routine that minimizes lack-of-fit for non-linear relationships (Gay 1990, Giese, Howe et al. 2015).

$$\sum_{j=1}^{N} \left(\frac{D_{i_j} - D_i\left(C_{env,j}\right)}{D_i\left(C_{env,j}\right)} \right)^2 \quad \text{(eq. 2)}$$

Where N is the total number of bins (20), D_i is the average detection of indicator *i* in C_{env} value bin *j*, given μ, σ, and h from equation 1. These parameters are varied iteratively until values minimize equation 2.

Importantly avian contributions to the IEC metric occurred through biotic responses as influenced through various components of the C_{env}, and the differences in component contributions varied markedly across indicators (Table 1, Appendix A). Because of this variation across indicator taxa and component influence, the IEC should be interpreted as the response to the saltmarsh environment of the composite saltmarsh avian community. No single avian indicator taxon can capture the dimensional breadth of the saltmarsh ecosystem, as measured here across the northeastern US. For example, when calculating biotic responses for each component separately, clapper rails responded most convincingly to the human disturbance gradient (PC1), with an estimated increase of 2.97 detections from the most disturbed to the least disturbed marsh sites ($R^2 = 0.93$; mean = 9.95 ± 3.90). Clapper rails also exhibited a peak in average detections around the mean of the marsh elevation gradient (PC3: $R^2 = 0.59$; mean = 5.84 ± 1.99) and the low marsh gradient (PC4: $R^2 = 0.60$; mean = 3.47 ± 2.72), and were negatively associated with the high marsh vegetation gradient (PC2: $R^2 = 0.38$; mean = -4.62 ± 10 with a decrease estimated at 1.72 birds/site on average across the range of PC2 values). The responses, in general, combine to suggest an affinity for heterogeneous intertidal landscape that is undisturbed by adjacent development and habitat loss. Importantly, though rails suggest higher values of the C_{env} (more undisturbed and vegetated intertidal area), the highest detections occurred in different marshes than was the case for some other species that may have contributed similarly to the IEC because of the individualized response of each species to the underlying marsh characteristics. Overall, what individual indicator taxa are "indicating" is a combination of influences, measured and unmeasured, as estimated here using their response to a composite of environmental gradients. Each of the indicator taxa contributes unique information to the metric, and the metric, in turn, is therefore able to capture multiple mechanistic pathways to marshes with high bird counts in a way that no single species would be able to.

Indicator taxa retained in the IEC indicated high, intermediate, or low salt marsh condition values as defined by the mean C_{env} values each is predicted to peak at (μ, given σ). For example, many saltmarsh-dependent species, piscivorous species (e.g., great egrets (*Ardea alba*), snowy egrets (*Egretta thula*), common terns (*Sterna hirundo*)), and shorebirds (e.g., least sandpipers (*Calidris minutilla*), black-bellied plover (*Pluvialis squatarola*), American oystercatcher (*Haematopus palliatus*)) showed a strong positive response with counts mostly increasing with greater C_{env} values in one or more ecoregions. Conversely, European starlings (*Sturnus vulgaris*) had a negative response in the New England ecoregion, but an intermediate, hump-shaped response, with a predicted peak in average abundance at C_{env} 2.47 +/- 2.05, in the Mid-Atlantic.

Overall, there is a weak latitudinal trend in IEC values (Figure 2), generally increasing as one travels south across our survey region, presumably driven by variation in development and intertidal vegetation cover and reflected in the C_{env}'s influence on the number of avian detections, though substantial variation occurs within each ecoregion, and across sub-ecoregions.

7. Evaluation of the IEC

We evaluated the IEC values using 20% of our survey data which we had previously set aside prior to constructing the IEC. We then correlated these IEC values with the C_{env} values of their associated survey locations to test whether the relationship shown between the IEC and C_{env} in the initial data set was maintained among the withheld validation set for each ecoregion. This step mimics the process one would take for novel data collected elsewhere in either ecoregion, or at another time, for use in evaluating changes in marsh conditions over time or across restoration efforts. We used the biotic response function tables for each ecoregion that had been initially calculated using 80% of the data to determine the IEC values for the remaining 20% of our survey sites in each geographic ecoregion (step 4).

We evaluated the fit between the C_{env} and the IEC with Pearson's product-moment correlation coefficients. We found a significant Pearson's product-moment correlation between the IEC metric and the C_{env} of the test data sets, indicating both consistency in the biotic responses to the C_{env} and suggesting that the index could work similarly on novel data within the range of birds and marsh conditions captured by our validation data set: New England: $r = 0.45$ (95% CI = 0.26 – 0.61); $t = 4.62$, df = 113, p-value < 0.0001 and the Mid-Atlantic: $r = 0.60$ (95% CI = 0.49 – 0.70); $t = 9.23$, df = 138, p-value < 0.0001. The relationship between the C_{env} and IEC validation datasets for both ecoregions resemble the same for the reconstituted datasets: New England: $r = 0.45$ (95% CI = 0.38 – 0.51); $t = 11.87$, df = 566, p-value < 0.0001 and the Mid-Atlantic: $r = 0.64$ (95% CI = 0.59 – 0.68); $t = 21.91$, df = 690, p-value < 0.0001.

Saltmarsh-dependent birds were found more often in survey sites with higher-than-average IEC scores, which we expected due to known bird dependencies on intertidal features positively correlated with the C_{env}. A notable threshold around the mean condition in the New England ecoregion was apparent, suggesting an increase in the rate of detections of dependent birds. We tested for this breakpoint using piecewise regression, which tests for a change in the linear trend over different regions of the IEC values and estimates where this change occurs (Figure 5). A significant increase in slope occurs around an IEC value of 5.87 (SD = 0.20), with an increase of 1.71 (SD = 0.13) detections of tidal-marsh dependent species for every increase of 1 IEC value after the break point: $p < 0.0001$; $R^2 = 0.47$. These results suggest a five-fold increase in slope across IEC values greater than 5.87 relative to those less than the threshold. Practitioners should be aware that the IEC may have a non-linear relationship with marsh condition and should not assume that an increase of 1.0 for lower IEC values is equivalent to a similar increase among marshes with higher IEC values. In the Mid-Atlantic, the fit between IEC values and dependent species is linear (Figure 6), with more variance explained using this method: $R^2 = 0.52$ vs 0.47.

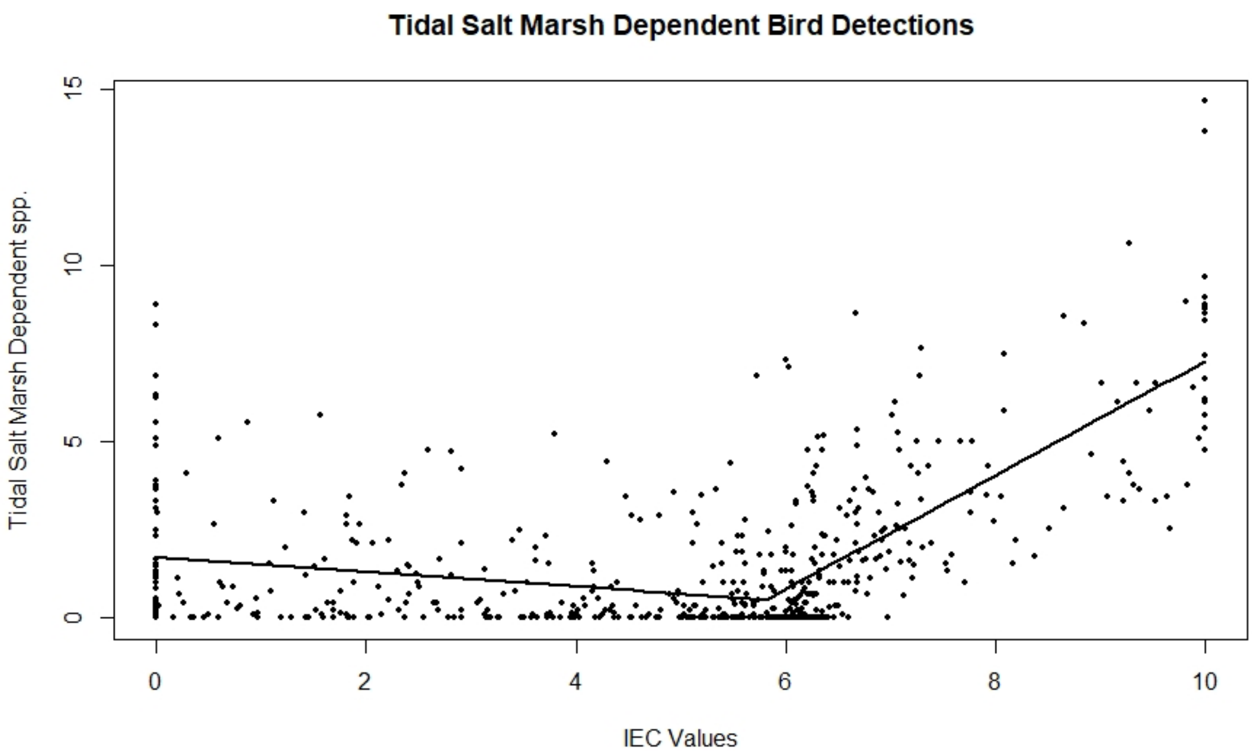

Figure 5. Results from a piecewise regression for the New England ecoregion with average detection of tidal salt marsh-dependent taxa ~ IEC values. A significant breakpoint was estimated at around the mean IEC value for both ecoregions, suggesting that marsh conditions that are higher than average contain far more dependent taxa.

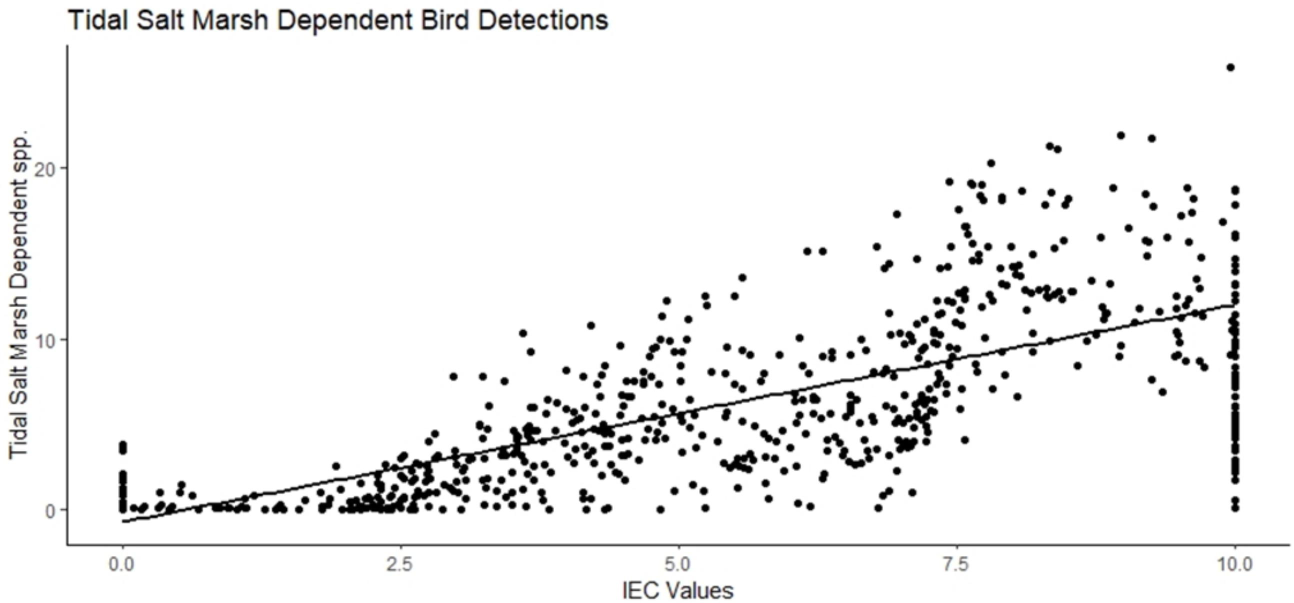

Figure 6. Results from a regression for the Mid-Atlantic ecoregion with average detection of tidal salt marsh-dependent taxa ~ IEC values. A significant breakpoint was estimated at around the mean IEC value for both ecoregions, suggesting that marsh conditions that are higher than average contain far more dependent taxa.

8. Applying the IEC

We tested whether metric values varied between marshes with different conservation status, geomorphic settings, and across sub-ecoregions. We used a linear regression with IEC values as the dependent variable, conservation status, sub-ecoregion, and geomorphic setting as fixed effects; and included interactions between conservation status and sub-ecoregion (Eq. 3, Figure 1, step 5).

Eq. 3: IEC ~ Conservation + Conservation x Sub-ecoregion + Sub-ecoregion + Geomorphic setting

We used USGS Gap Analysis project codes (Scott, Davis et al. 1993) to classify sites according to their protection status and management intention (conservation). We combined GAP status 1 and 2, to create a new category ("biodiversity") to describe conserved lands which are protected and have management plans to actively foster biodiversity. We also included Gap status 3 ("protected"), where lands are protected from development but allow for some resource extraction or ATV recreation, etc. Lastly, we included GAP 4 ("none"), which are areas that are unprotected and unmanaged or of unknown conservation status.

We included the sub-ecoregion, as detailed above, to account for differences in the impact of conservation status across regions. We also included the geomorphic setting—whether the site is in a back-barrier lagoon, or an estuarine embayment—as a predictor, because this factor can influence tidal saltmarsh bird densities (Wiest, Correll et al. 2019), the vegetation mosaic (Mahoney and Bishop 2018), tidal prism, and wave energy attenuation (Dalrymple, Zaitlin et al. 1992).

The effects of conservation status, sub-ecoregion, and geomorphic setting explained 21% of the variation in IEC values: F: 14.07, df = 24 and 1235, p-value: < 0.0001. Sites within marshland classified as back-barrier lagoons, and those protected and managed for biodiversity generally scored the highest (Figure 5; Table 4); though, the magnitude of differences between categories varied across sub-ecoregions. A significant interaction between conservation status and sub-ecoregion was also found.

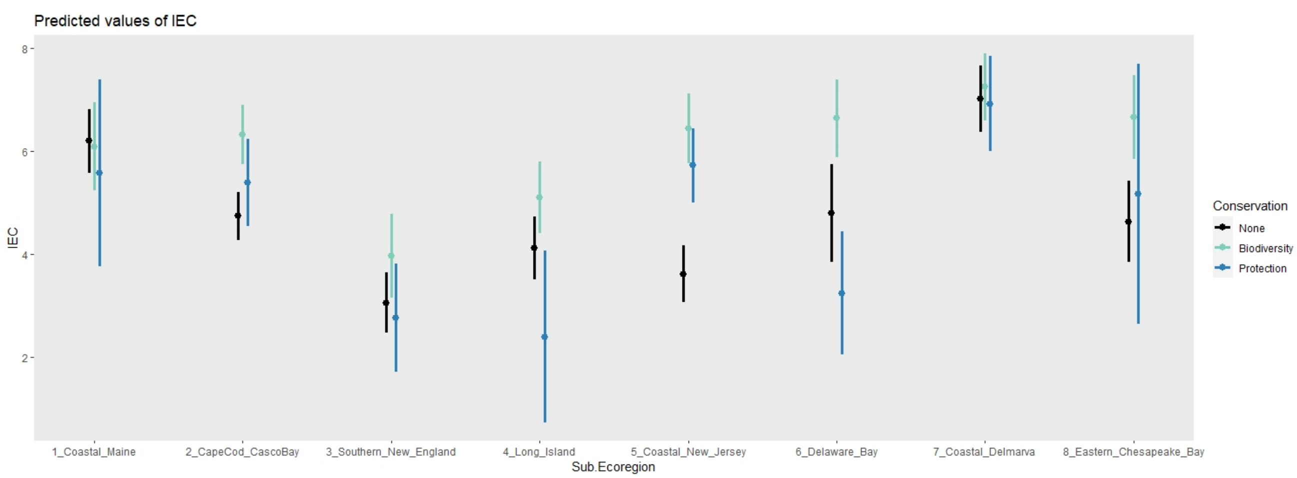

Figure 7. Estimates derived from the linear regression across sub-ecoregions after accounting for geomorphic setting. IEC values varied markedly across conservation designations, but this varied across sub-ecoregions (displayed north to south).

Table 4. Results of linear model with conservation status, sub-ecoregion, geomorphic setting and interaction between conservation and sub-ecoregion as predictors of IEC values

Independent variables	Df	Sum sq	Mean sq	F value	Pr (>F)
Conservation	2	541	270.5	41.82	P < 0.0001
Sub Ecoregion	7	1255	179.32	179.32	P < 0.0001
Geo setting	1	21	20.64	20.64	0.07
Conservation x Sub Ecoregion	14	367	26.23	26.23	P < 0.0001
Residuals	1235	7988	6.47	6.47	

1.7 Conclusions

We developed a metric to study saltmarsh ecological conditions across the northeastern Atlantic coast of the US following previously published methods for freshwater wetlands and forests. The metric (IEC) is calculated from an index of response functions derived from how birds respond to a composite variable representing tidal saltmarsh environments. The resulting IEC values were significantly higher at sites within areas protected and managed for biodiversity (USGS GAP status 1 and 2), evidence that conservation efforts had a positive effect on tidal salt marsh, however this varied across sub-ecoregions. Also, saltmarsh-dependent bird species were strong, positive contributors to the IEC, suggesting their value in determining marsh condition along the four environmental gradients, but for reasons that appeared to vary by species and across ecoregions. Further, we found that the variety of responses to individual components of the C_{env} composite suggest many indicator taxa should be utilized due to the plethora of environmental combinations driving biotic responses.

The practical value of this approach is twofold in that it is both easy to reproduce using standardized bird surveys and is interpretable through known ecological interactions between birds, anthropogenic stressors, and habitat features of the tidal salt marsh. Here, we used birds as indicators due to the broad geographic scope of our data, the known interactions between saltmarsh birds and their environment, and the ease with which sites can be surveyed. To use the IEC metric detailed here, one needs only to reproduce the standardized bird surveys and calculate the metric using the included biotic response functions in Table 1 and novel bird data (Figure 1, step 4).

In both ecoregions, higher than average IEC values predict both above average environmental conditions and saltmarsh-dependent birds. Taxa that indicate good environmental conditions include those with a wide array of ecological niches supported by salt marshes: aerial insectivores, diving terns, long-legged piscivorous waders, charadriiform shorebirds, and saltmarsh-specialist breeders, each presumably responding to conditions relating to the unique aspects of their ecology. As such, the higher bird abundance is in general, and the more niches that are likely captured by those birds, the higher the general condition of the ecosystem as indicated by the IEC. Negative indicators include taxa that were positively correlated with development and habitat loss such as the American crow (*Corvus brachyrhynchos*), American goldfinch (*Spinus tristis*), common grackle (*Quiscalus quiscula*), and European starling. In contrast, most of the selected indicator taxa were negatively associated with the development and habitat loss that the human disturbance gradient represents, in both ecoregions, predicting nonlinear increases of average detections in undisturbed areas.

High IEC values indicate more vegetated intertidal marsh and less impact due to human disturbance and habitat loss. The best tidal saltmarsh sites as indicated by IEC values suggest intertidal marsh vegetation stretching for hundreds of meters. The platform would be fringed by thick stands of taller *S. alterniflora* along tidally inundated waterways that cut into the marsh. At the site level, thick mats of grass would occupy half the area, interspersed within areas of taller grass (*S. alterniflora*), potentially with patches of shrubs breaking the horizon and fringing the inland-upland transition zone. Variation in the cover of streams, ditches and pools predict numbers of aerial and stalking piscivores that use such features, as well as clapper rails. The site may experience a large intertidal range indicative of our more northerly locations, and at low tide such a marsh could be more than half mudflat, at which point one should be able to spot foraging birds exploiting bare areas or the newly exposed base of grasses growing in the (expanded) low marsh zone. Variance in predicted stability of the marsh at these sites depends on the variance in the amount of unvegetated intertidal area, a tradeoff between foraging sites for birds that exploit bare areas and the predicted stability of the marsh platform over decades. Development and other disturbance to intertidal wetlands within one km would be minimal.

Along with the ease of recreating the metric, results of analyses using the metric provides evidence of its viability to rank salt marshes along the Atlantic coast of the northeastern US. Highly ranked marshland coincides with conditions presumably created or preserved through conservation efforts as documented by GAP status, showing sensitivity for such an evaluation.

Table 1. List of the indicator taxa for New England and biotic response functions for PCs one and two.

Taxon	LOF-1	R2-1	Mean-1	SD-1	H-1	direction-1	range-1	LOF-2	R2-2	Mean-2	SD-2	H-2	direction-2	range-2
American black duck	0.314	0.447	20.000	9.204	9.618	positive	0.192	0.417	0.145	16.400	10.000	5.056	positive	0.112
American crow	0.263	0.471	5.153	3.111	3.578	intermediate	0.342	0.253	-0.018	5.483	10.000	10.054	intermediate	0.056
American goldfinch	0.133	0.534	5.259	3.039	1.802	intermediate	0.184	0.357	0.252	4.314	3.371	2.133	intermediate	0.192
Barn swallow	0.665	0.525	1.376	4.964	11.714	negative	0.733	0.928	0.036	5.202	5.728	10.785	intermediate	0.254
Black-bellied plover	0.655	0.507	9.914	4.043	3.343	positive	0.314	0.829	0.169	20.000	9.843	11.334	positive	0.216
Canada goose	1.443	0.115	1.354	6.748	16.109	negative	0.533	1.893	-0.041	3.612	10.000	21.323	intermediate	0.157
Common grackle	1.127	0.662	-10.000	8.412	63.815	negative	1.314	0.271	0.548	4.459	3.824	7.090	intermediate	0.481
Common tern	1.247	0.326	20.000	8.016	22.373	positive	0.462	0.422	0.131	14.555	10.000	6.693	positive	0.148
Common yellowthroat	0.126	0.723	6.817	3.815	3.628	intermediate	0.302	0.387	0.396	6.980	3.291	3.105	intermediate	0.337
European starling	2.356	0.557	-10.000	7.856	59.462	negative	1.225	1.267	0.003	4.878	4.392	6.118	intermediate	0.274
Great blue heron	0.205	0.342	7.484	4.526	1.759	intermediate	0.115	0.286	-0.031	8.279	10.000	3.339	positive	0.039
Great egret	0.688	0.129	8.246	6.475	7.606	positive	0.260	0.580	0.254	14.636	10.000	14.757	positive	0.327
Greater yellowlegs	0.294	0.352	7.528	4.518	2.613	intermediate	0.173	0.354	0.384	19.954	10.000	12.604	positive	0.238
Herring gull	1.302	0.067	9.838	10.000	22.496	positive	0.344	0.935	0.045	4.126	7.269	14.906	intermediate	0.228
House sparrow	0.563	0.770	1.431	2.251	1.867	negative	0.331	0.808	0.308	2.933	3.143	1.619	intermediate	0.189
Least sandpiper	0.484	0.540	12.421	5.240	4.419	positive	0.282	0.715	0.230	8.425	3.512	1.634	positive	0.175
Least tern	1.691	0.204	9.533	4.198	3.813	positive	0.335	1.111	-0.096	6.331	10.000	4.732	intermediate	0.034
Lesser yellowlegs	0.217	0.671	20.000	5.339	15.009	positive	0.193	0.609	0.212	20.000	6.673	5.648	positive	0.106
Mallard	0.745	0.709	-6.860	6.541	27.777	negative	0.916	0.882	0.114	3.651	5.299	5.537	intermediate	0.214
Mourning dove	0.149	0.780	-10.000	6.748	9.322	negative	0.177	0.231	0.317	-4.003	6.937	2.597	negative	0.107
Nelson's sparrow	0.702	0.847	7.607	2.279	4.070	intermediate	0.710	0.970	0.865	9.651	2.328	6.464	positive	1.107
Red-winged blackbird	2.671	0.615	-9.358	10.000	207.883	negative	4.079	2.332	0.388	15.196	10.000	119.143	positive	2.655
Saltmarsh sparrow	1.270	0.039	10.860	9.436	10.780	positive	0.219	0.893	0.641	11.412	4.306	8.744	positive	0.744
Savannah sparrow	0.279	0.571	11.303	4.244	2.198	positive	0.191	0.280	0.453	8.761	3.088	0.913	positive	0.116
Snowy egret	1.061	0.370	20.000	8.702	37.160	positive	0.759	0.709	0.230	13.968	10.000	13.550	positive	0.296
Song sparrow	0.236	0.790	2.019	4.986	18.609	intermediate	1.076	0.251	0.631	5.478	3.269	11.298	intermediate	1.040
Swamp sparrow	0.603	0.385	6.365	2.048	0.640	intermediate	0.124	0.476	0.327	10.040	3.422	1.386	positive	0.159
Tree swallow	0.815	0.589	5.876	2.798	7.311	intermediate	0.928	1.153	0.729	16.696	6.361	55.332	positive	1.883
Willet	2.085	0.688	14.608	5.887	52.539	positive	2.457	1.933	0.593	20.000	7.819	95.560	positive	1.967

Yellow warbler	0.231	0.029	2.173	10.000	5.582	intermediate	0.059	0.353	0.186	6.079	3.104	1.930	intermediate	0.212

Table 1 (cont.) List of the indicator taxa for the id-Atlantic and biotic response functions for PCs three and four.

Taxon	LOF-3	R2-3	Mean-3	SD-3	H-3	direction-3	range-3	LOF-4	R2-4	Mean-4	SD-4	H-4	direction-4	range-4
American black duck	0.622	-0.078	2.491	10.000	3.161	intermediate	0.031	0.347	0.033	1.347	5.612	1.800	negative	0.089
American crow	0.495	0.153	6.011	4.820	5.143	intermediate	0.230	0.260	0.233	3.977	3.501	3.732	intermediate	0.328
American goldfinch	0.293	0.146	3.122	5.284	3.094	intermediate	0.133	0.335	0.353	-10.000	9.933	13.544	negative	0.256
Barn swallow	1.142	0.199	13.859	10.000	26.042	positive	0.567	0.982	0.108	3.951	3.801	7.259	intermediate	0.547
Black-bellied plover	0.626	0.075	5.648	3.411	1.501	intermediate	0.131	1.100	0.092	7.357	5.385	2.892	intermediate	0.130
Canada goose	1.482	0.459	20.000	8.937	68.121	positive	1.377	1.280	0.351	4.822	2.408	6.007	intermediate	0.897
Common grackle	1.776	0.202	15.808	10.000	29.341	positive	0.653	0.434	0.524	5.769	3.377	6.780	intermediate	0.615
Common tern	0.984	-0.004	12.047	10.000	6.151	positive	0.122	0.812	0.214	5.047	2.327	1.438	intermediate	0.223
Common yellowthroat	0.234	0.595	2.876	3.380	3.680	intermediate	0.387	0.131	0.731	-10.000	9.163	22.055	negative	0.441
European starling	1.366	0.261	18.795	10.000	31.397	positive	0.637	1.967	0.017	3.611	3.877	5.438	intermediate	0.416
Great blue heron	0.189	0.518	10.122	4.776	2.471	positive	0.185	0.182	0.363	6.755	4.150	1.700	intermediate	0.120
Great egret	1.877	0.429	20.000	7.992	44.366	positive	0.916	0.638	0.657	14.056	5.961	24.241	positive	1.186
Greater yellowlegs	0.309	0.253	17.438	10.000	9.644	positive	0.208	0.253	0.269	9.460	6.266	4.327	positive	0.187
Herring gull	0.732	0.674	20.000	8.945	64.781	positive	1.309	1.019	0.531	7.130	3.898	11.042	intermediate	0.918
House sparrow	0.739	0.018	13.803	10.000	4.682	positive	0.102	0.677	-0.055	4.456	2.979	1.077	intermediate	0.119
Least sandpiper	0.528	0.137	15.548	9.094	5.476	positive	0.144	0.534	-0.010	10.982	10.000	4.163	positive	0.074
Least tern	1.169	-0.149	0.726	10.000	5.262	negative	0.073	0.876	0.127	4.814	2.096	1.233	intermediate	0.224
Lesser yellowlegs	0.355	-0.058	4.804	2.204	0.227	intermediate	0.039	0.318	-0.078	2.534	3.847	0.342	intermediate	0.030
Mallard	0.858	0.467	20.000	8.921	30.963	positive	0.627	0.309	-0.001	4.787	9.681	8.702	intermediate	0.048
Mourning dove	0.262	-0.040	12.119	10.000	1.836	positive	0.036	0.114	0.038	3.126	4.663	0.669	intermediate	0.038
Nelson's sparrow	1.190	0.321	5.793	2.067	2.452	intermediate	0.464	1.126	0.112	15.055	10.000	17.620	positive	0.392
Red-winged blackbird	2.723	-0.162	3.423	10.000	78.741	intermediate	0.611	2.926	0.002	2.844	10.000	77.734	intermediate	0.700
Saltmarsh sparrow	0.836	0.239	17.571	10.000	18.927	positive	0.406	1.665	0.104	3.503	2.849	3.027	intermediate	0.392
Savannah sparrow	0.340	0.014	2.974	4.210	0.964	intermediate	0.069	0.286	-0.009	14.038	10.000	3.041	positive	0.067
Snowy egret	1.357	0.263	17.691	10.000	21.444	positive	0.458	0.848	0.398	20.000	9.666	36.961	positive	0.714
Song sparrow	0.430	0.121	6.739	8.163	25.625	intermediate	0.362	0.115	0.410	-0.142	10.000	32.960	negative	0.529
Swamp sparrow	0.703	0.144	-10.000	9.125	7.635	negative	0.153	0.695	-0.062	-4.019	10.000	2.870	negative	0.063
Tree swallow	1.639	0.026	7.885	9.432	21.339	intermediate	0.266	1.438	0.076	11.895	10.000	29.554	positive	0.577

Willet	2.894	-0.037	9.381	10.000	27.610	positive	0.392	1.920	0.320	6.413	3.510	11.691	intermediate	1.079
Yellow warbler	0.204	0.016	7.036	9.939	5.400	intermediate	0.048	0.148	0.307	-5.181	10.000	7.930	negative	0.177

Table 2. List of the indicator taxa for the Mid-Atlantic and biotic response functions for PCs one and two.

Taxon	LOF-1	R2-1	Mean-1	SD-1	H-1	direction-1	range-1	LOF-2	R2-2	Mean-2	SD-2	H-2	direction-2	range-2
American crow	0.367	0.729	3.650	2.675	1.517	intermediate	0.213	0.291	0.486	3.829	2.756	1.301	intermediate	0.173
American oystercatcher	0.882	0.599	14.938	4.984	12.400	positive	0.596	0.814	0.403	3.126	2.871	2.641	intermediate	0.346
Barn swallow	1.095	0.649	3.657	4.013	19.169	intermediate	1.359	0.644	0.537	5.175	3.482	14.486	intermediate	1.109
Black skimmer	0.428	0.545	7.695	2.212	1.038	intermediate	0.187	0.617	0.416	-10.000	8.021	15.094	negative	0.312
Boat-tailed grackle	0.568	0.644	6.180	2.478	3.868	intermediate	0.595	0.432	0.688	9.046	4.379	6.902	positive	0.554
Canada goose	0.974	0.528	2.521	4.145	6.720	intermediate	0.520	0.445	0.412	4.170	3.515	4.556	intermediate	0.386
Clapper rail	0.668	0.928	9.950	3.899	30.188	positive	2.969	1.687	0.389	-4.617	10.000	77.849	negative	1.725
Common grackle	0.434	0.912	0.758	3.566	9.360	negative	1.011	0.710	0.535	4.501	2.454	3.662	intermediate	0.547
Common tern	0.991	0.304	20.000	9.203	19.091	positive	0.381	1.710	0.115	3.874	2.692	2.769	intermediate	0.380
Common yellowthroat	0.551	0.762	2.674	3.662	8.505	intermediate	0.801	0.210	0.619	5.914	3.618	5.906	intermediate	0.480
Eastern kingbird	0.408	0.191	6.098	3.655	1.363	intermediate	0.112	0.151	0.397	5.252	3.037	1.087	intermediate	0.111
European starling	0.565	0.891	2.662	2.180	4.150	intermediate	0.757	1.126	0.450	5.038	2.000	2.236	intermediate	0.427
Fish crow	0.325	0.382	5.000	3.033	1.471	intermediate	0.144	0.376	0.127	5.887	3.406	1.450	intermediate	0.132
Forster’s tern	0.831	0.906	20.000	6.164	117.136	positive	1.994	1.526	0.641	-10.000	8.013	88.107	negative	1.819
Great black-backed gull	0.950	0.442	20.000	6.791	29.792	positive	0.569	1.318	0.184	2.164	3.542	3.637	intermediate	0.374
Great blue heron	0.509	0.321	7.014	3.402	2.051	intermediate	0.212	0.431	0.532	-10.000	9.159	17.974	negative	0.359
Glossy ibis	0.632	0.685	6.523	2.190	2.992	intermediate	0.539	0.979	0.060	5.764	3.776	4.051	intermediate	0.294
Grey catbird	0.259	0.685	2.677	2.898	1.137	intermediate	0.150	0.244	0.344	4.941	2.458	0.658	intermediate	0.094
Great egret	0.744	0.684	8.123	4.231	13.781	positive	1.093	0.595	0.008	2.841	10.000	27.330	intermediate	0.246
Greater yellowlegs	0.307	0.321	7.489	3.433	1.116	intermediate	0.118	0.216	0.136	-1.368	10.000	3.190	negative	0.059
Herring gull	0.663	0.653	9.970	5.337	11.084	positive	0.684	0.891	0.274	-5.010	10.000	26.579	negative	0.592
Killdeer	0.270	0.452	1.677	4.051	0.949	negative	0.082	0.323	0.212	4.605	2.042	0.427	intermediate	0.081
Laughing gull	2.613	0.830	20.000	7.805	234.466	positive	4.825	6.541	0.494	-10.000	9.039	253.910	negative	5.108
Least sandpiper	0.668	0.375	8.647	4.236	3.161	positive	0.261	0.721	0.043	0.244	8.925	6.172	negative	0.124
Least tern	0.715	0.255	7.626	3.573	1.779	intermediate	0.178	0.298	0.546	2.603	3.415	1.951	intermediate	0.206
Lesser yellowlegs	0.429	0.305	6.722	2.506	0.698	intermediate	0.108	0.845	-0.220	11.238	10.000	2.699	positive	0.050
Mallard	0.481	0.619	0.441	5.080	5.099	negative	0.332	0.446	0.493	4.418	2.483	1.957	intermediate	0.289

Mourning dove	0.163	0.799	4.081	2.344	1.106	intermediate	0.180	0.397	0.088	6.476	4.814	1.490	intermediate	0.074
Northern cardinal	0.118	0.777	3.836	2.294	0.639	intermediate	0.108	0.049	0.526	4.746	3.273	0.567	intermediate	0.050
Northern mockingbird	0.131	0.790	1.986	2.665	0.891	intermediate	0.132	0.121	0.396	4.368	2.659	0.478	intermediate	0.064
Osprey	0.818	0.387	5.299	3.168	6.016	intermediate	0.570	0.574	0.443	16.425	10.000	26.372	positive	0.583
Purple martin	0.233	0.789	4.302	2.154	1.391	intermediate	0.250	0.630	0.170	7.894	3.975	1.909	intermediate	0.165
Red-wing blackbird	1.139	0.848	2.941	4.656	80.105	intermediate	4.688	1.004	0.676	6.641	4.759	67.913	intermediate	3.543
Saltmarsh sparrow	1.030	0.625	6.566	2.032	3.965	intermediate	0.774	1.745	0.096	13.240	10.000	17.807	positive	0.378
Short-billed dowitcher	0.902	0.404	16.815	6.426	12.037	positive	0.401	1.398	-0.008	-6.723	10.000	11.027	negative	0.242
Semipalmated plover	0.376	0.408	20.000	8.895	5.447	positive	0.110	0.495	0.527	-10.000	7.382	11.600	negative	0.234
Semipalmated sandpiper	0.808	0.375	7.031	2.937	3.102	intermediate	0.397	0.837	0.268	-6.672	10.000	17.004	negative	0.374
Seaside sparrow	0.818	0.938	9.363	3.228	29.251	positive	3.561	7.600	0.221	19.589	10.000	147.139	positive	2.845
Snowy egret	1.041	0.575	7.600	3.215	6.509	intermediate	0.758	0.818	-0.003	5.643	7.332	11.487	intermediate	0.160
Song sparrow	0.487	0.908	0.243	4.409	10.043	negative	0.830	0.466	0.316	4.378	3.658	4.594	intermediate	0.347
Virginia rail	0.276	0.595	6.980	2.253	0.921	intermediate	0.162	0.458	0.466	5.170	2.000	0.836	intermediate	0.161
Willow flycatcher	0.186	0.945	-10.000	5.676	38.903	negative	0.574	0.236	0.411	6.658	2.592	0.793	intermediate	0.118
Willet	1.098	0.868	9.915	4.193	30.588	positive	2.733	1.451	-0.095	6.221	10.000	46.720	intermediate	0.328
Yellow warbler	0.341	0.874	1.982	2.934	3.027	intermediate	0.402	0.299	0.351	3.840	3.767	2.113	intermediate	0.165

Table 2 (cont.) List of the indicator taxa for the Mid-Atlantic and biotic response functions for PCs three and four.

Taxon	LOF-3	R2-3	Mean-3	SD-3	H-3	direction-3	range-3	LOF-4	R2-4	Mean-4	SD-4	H-4	direction-4	range-4
American crow	0.221	0.006	8.973	10.000	3.498	positive	0.046	0.408	0.191	-7.852	10.000	6.070	negative	0.129
American oystercatcher	1.100	0.586	20.000	6.352	47.120	positive	0.836	1.364	0.543	7.222	2.627	5.116	intermediate	0.759
Barn swallow	1.382	0.034	1.425	10.000	39.814	negative	0.489	1.654	-0.034	7.460	10.000	40.787	intermediate	0.395
Black skimmer	0.330	0.691	20.000	6.745	18.629	positive	0.354	0.705	-0.087	0.792	10.000	3.250	negative	0.045
Boat-tailed grackle	0.601	0.460	7.152	3.829	5.208	intermediate	0.448	0.857	0.438	3.668	2.346	3.475	intermediate	0.575
Canada goose	0.809	-0.095	4.357	10.000	10.959	intermediate	0.064	0.719	0.207	13.183	10.000	17.760	positive	0.376
Clapper rail	1.797	0.592	5.842	2.700	14.935	intermediate	1.994	1.372	0.595	3.467	2.720	14.999	intermediate	2.077
Common grackle	1.268	-0.080	4.877	10.000	11.210	intermediate	0.055	0.683	0.206	2.473	4.786	5.485	intermediate	0.324
Common tern	1.595	0.613	20.000	7.013	39.930	positive	0.783	0.902	0.810	7.339	2.636	5.767	intermediate	0.854
Common yellowthroat	0.585	0.789	0.991	4.256	10.547	negative	0.883	0.521	0.406	-8.189	10.000	27.410	negative	0.573
Eastern kingbird	0.475	0.268	-10.000	9.330	11.068	negative	0.219	0.358	0.460	-10.000	6.718	12.827	negative	0.242
European starling	1.613	-0.077	6.735	10.000	8.155	intermediate	0.066	1.516	-0.096	5.748	10.000	8.346	intermediate	0.051
Fish crow	0.433	0.265	19.374	10.000	9.882	positive	0.194	0.156	0.709	-9.731	7.393	11.233	negative	0.238
Forster's tern	1.108	0.758	20.000	7.040	99.406	positive	1.954	1.029	0.392	-10.000	9.967	40.993	negative	0.773
Great black-backed gull	1.881	0.106	20.000	8.536	23.438	positive	0.481	1.263	0.290	20.000	9.011	30.125	positive	0.607
Great blue heron	0.625	0.090	17.941	10.000	10.819	positive	0.229	0.460	0.359	-10.000	8.345	13.336	negative	0.275
Glossy ibis	1.029	-0.119	4.499	10.000	9.710	intermediate	0.054	1.934	0.209	16.398	10.000	24.108	positive	0.533
Grey catbird	0.170	0.575	-10.000	8.407	8.267	negative	0.170	0.165	0.459	1.672	2.772	0.670	negative	0.095
Great egret	1.408	0.596	20.000	9.738	78.428	positive	1.506	0.986	0.418	13.724	10.000	45.714	positive	0.990
Greater yellowlegs	0.292	0.038	11.795	10.000	3.143	positive	0.061	0.417	-0.141	7.893	10.000	2.954	intermediate	0.032
Herring gull	1.936	0.588	20.000	7.981	64.910	positive	1.340	0.801	0.122	9.322	10.000	18.506	positive	0.260
Killdeer	0.424	-0.096	-1.366	10.000	1.804	negative	0.034	0.249	-0.080	7.440	10.000	1.466	intermediate	0.014
Laughing gull	2.824	0.810	20.000	7.501	302.995	positive	6.166	2.853	0.597	-1.053	4.998	45.352	negative	3.227
Least sandpiper	0.942	-0.020	9.932	10.000	6.543	positive	0.102	1.270	0.501	20.000	8.996	29.740	positive	0.600
Least tern	0.879	0.490	20.000	6.596	27.803	positive	0.516	0.522	-0.028	0.619	10.000	3.956	negative	0.056
Lesser yellowlegs	0.518	-0.019	5.729	3.109	0.741	intermediate	0.078	0.890	-0.040	-8.108	10.000	4.302	negative	0.090
Mallard	0.567	-0.072	1.433	10.000	6.223	negative	0.076	0.663	0.355	18.935	10.000	19.570	positive	0.394
Mourning dove	0.218	0.440	1.442	4.798	1.862	negative	0.123	0.201	0.359	0.728	4.466	1.447	negative	0.114
Northern cardinal	0.130	0.520	-10.000	8.155	6.691	negative	0.138	0.167	0.445	1.508	2.498	0.489	negative	0.078
Northern mockingbird	0.220	0.074	2.419	4.769	0.830	intermediate	0.050	0.219	0.234	2.302	2.394	0.400	intermediate	0.066
Osprey	1.048	0.498	20.000	9.346	47.184	positive	0.932	0.822	0.601	6.208	3.321	8.420	intermediate	0.835

Purple martin	0.448	0.132	2.698	4.598	2.109	intermediate	0.131	1.114	0.020	-10.000	8.875	10.614	negative	0.215
Red-wing blackbird	1.910	0.584	1.398	6.188	101.222	negative	4.043	1.170	0.093	6.394	10.000	139.311	intermediate	1.027
Saltmarsh sparrow	1.326	0.723	-10.000	6.761	98.978	negative	1.883	1.748	0.864	20.000	6.051	267.424	positive	4.425
Short-billed dowitcher	0.707	0.845	20.000	5.143	103.335	positive	1.206	1.161	0.001	9.300	5.810	5.208	positive	0.258
Semipalmated plover	0.555	0.236	20.000	8.200	7.466	positive	0.154	0.283	-0.015	1.704	6.785	1.254	negative	0.039
Semipalmated sandpiper	2.383	0.128	18.159	10.000	20.376	positive	0.426	1.497	-0.047	11.707	10.000	12.350	positive	0.237
Seaside sparrow	1.928	0.632	2.456	4.130	29.326	intermediate	2.299	4.170	-0.134	5.936	10.000	57.370	intermediate	0.370
Snowy egret	0.731	0.675	20.000	8.181	58.877	positive	1.216	1.856	-0.105	4.357	10.000	16.140	intermediate	0.095
Song sparrow	1.291	0.133	-6.628	10.000	22.330	negative	0.492	0.553	0.714	20.000	8.808	54.969	positive	1.118
Virginia rail	0.593	0.485	1.308	3.626	2.002	negative	0.208	1.361	0.073	-10.000	9.632	8.262	negative	0.160
Willow flycatcher	0.553	-0.067	1.569	10.000	2.776	negative	0.033	0.394	0.132	5.156	3.369	1.129	intermediate	0.092
Willet	2.195	0.356	15.193	10.000	75.294	positive	1.678	1.789	0.202	10.308	10.000	60.169	positive	0.988
Yellow warbler	0.484	0.257	-9.831	10.000	14.318	negative	0.272	0.374	0.150	4.171	3.787	2.009	intermediate	0.147

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BIOGRAPHY OF THE AUTHOR

Joshua Parrott was born October third, 1981, in Chillicothe Illinois, and raised in Hopewell Illinois among a typical farming community along the Illinois river valley. He graduated from Midland High School, a school consolidated across four small communities, with a graduating class of 42 in 2001. He joined the US Marine Corps right out of high school, deployed twice to Iraq during operation “Iraqi Freedom”, left active duty in 2006, started attending Illinois Central Community college the same year, then was involuntarily recalled to active duty, deploying again to Iraq 2007 – 2008. He graduated from ICC with an associate degree in general education in 2010. He started attending Southern Illinois University in 2011 and graduated with a bachelor’s degree in wildlife ecology and conservation in 2015. After this, he worked towards a master’s degree in ecology, specializing in wetland ecology and amphibian disease ecology. These efforts were ultimately thwarted by a lack of funding due to political infighting in the Illinois senate, with several years of funding sources frozen due to the deadlocked budget. He moved to Maine in 2018, following his partner, who he married in 2020. He resumed his scholastic career in 2020, working towards a degree in ecology. He has worked in construction, as a cook, a janitor, an arborist, a hydraulic mechanic, a security forces sergeant, a military police augmentee, an invasive plant surveyor, a bird surveyor, an amphibian disease ecologist, and a tidal salt marsh ecologist.