Estimating spatially explicit occupancy and density for Saltmarsh and Nelson's sparrows

FINAL REPORT

Submitted:

27 January 2023

In partial fulfillment of:

Award ID: F20AC11346

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Recommended citation –
Shriver, G., S. Roberts, and Z. Ladin. 2023. Estimating spatially explicit occupancy and density for Saltmarsh and Nelson's sparrows. Final Report: USFWS Award # F20AC11346. Hadley, MA. 52 pp.

Introduction

Sea-level rise effects on tidal marshes pose an imminent threat to the specialist breeding birds dependent on these ecosystems to complete the annual cycle (Klingbeil et al. 2018, 2021). A suite of tidal marsh specialist species is among the greatest conservation priorities in North America (Correll et al. 2017, Rosenberg et al. 2019, Panjabi et al. 2020), including Saltmarsh (*Ammospiza caudacuta*) and Nelson's (*A. nelsoni*) sparrows. Saltmarsh and Nelson's sparrows are primarily restricted to salt marshes and hybridize where they co-occur from southern Maine to northern Massachusetts (Gjerdrum et al. 2005, Shriver et al. 2005, 2018, Greenberg et al. 2006b, 2006a, Greenlaw et al. 2020). Annual population trends for these taxa are negative with the Saltmarsh and Nelson's sparrows declining by 9% and 4%, respectively (Correll et al. 2017). Due to increasing threats to their habitat, limited geographic range, relatively low population estimates, and severe population declines, the Saltmarsh Sparrow is considered a Species of Greatest Conservation Need in all states from Maine to Virginia and is currently a candidate for listing under the Endangered Species Act with a high probability of extinction before 2050 (Field et al. 2017, Roberts et al. 2017). Therefore, identifying marshes with relatively high occupancy and abundance across the Saltmarsh Sparrow's breeding range can provide valuable information for conservation.

High-resolution, spatially-explicit occupancy and abundance predictions for the Saltmarsh Sparrow (*Ammospiza caudacutus*) do not currently exist but could aid in site prioritization for conservation and management actions. To address this need, the USFWS Delaware Bay Coastal program and the Atlantic Coast Joint Venture partnered with the University of Delaware to use existing Saltmarsh Habitat and Avian Research Program (SHARP) survey data to develop models to generate spatially explicit occupancy and density maps. We started this effort in the Delaware Bay region and then expanded to include the entire Saltmarsh

Sparrow breeding range (Virginia to Maine). We included Saltmarsh Sparrow, the Acadian Nelson's Sparrow (*A. nelsoni subvirgata*), and where they are sympatric (southern Maine to northern Massachusetts), we added a third taxa; sharp-tailed sparrow (individuals that could be not identified as either Saltmarsh or Nelson's sparrow).

The purpose of this project was to use the existing SHARP tidal marsh bird survey data from Virginia to Maine to estimate and predict the occupancy and density for the Saltmarsh and Nelson's sparrows using a fine-scale raster-based vegetation data layer (Correll et al. 2017). Specifically, we used the existing SHARP tidal marsh bird survey data to; 1) estimate Saltmarsh and Nelson's sparrow occupancy and density across suitable habitat in USFWS Region 5 and 2) predict sparrow occupancy and density using these established relationships. We present this information in a spatial data format usable by the conservation community.

Objectives

1. Estimate region-specific focal species occupancy.
2. Estimate region-specific focal species density.
3. Provide spatial data and maps that can be used to identify priority tidal marsh sites for our focal species in the Northeast, particularly the Saltmarsh Sparrow.

Methods

We used tidal marsh bird survey data collected from 2011-2014 to predict Saltmarsh and Nelson's sparrow occupancy and density along the Atlantic coast from the Eastern Chesapeake Bay to Northern Coastal Maine (Figure 1). The study area was divided into nine regions (Figure 1) based on eight pre-established regions created by SHARP: Northern Coastal Maine, Rockland to Cape Ann, Salem to Cape Cod, Southern New England, Long Island, Coastal New Jersey, Delaware Bay, Coastal Delmarva, and Eastern Chesapeake Bay (Wiest et al. 2016). We added one region to the previously defined regions by redefining the two northern-most SHARP regions (originally named "Coastal Maine" and "Cape Cod to Casco Bay") to create a region that encompassed the known hybrid zone for Saltmarsh and Nelson's sparrows (Rockland to Cape Ann; Hodgman et al. 2002, Shriver et al. 2005, Walsh et al. 2011, 2017).

Within each region, points were randomly located using a two-stage cluster sampling design with generalized random-tessellation stratified sampling within each stage (Stevens and Olsen 1999, 2004, Wiest et al. 2016). The number of point count survey locations varied among regions, with the greatest number from Rockland to Cape Ann (n = 590 points) and the fewest in Northern Coastal Maine (n = 134; Table 1). We used the North American Marsh Bird Monitoring Protocol (Conway 2011) to conduct bird surveys at each point where observers recorded all species detected by sight and sound within a 5-minute passive period followed by a region-specific sequence of 30-second marsh bird broadcasts. For all analyses herein, we used the 5-minute passive period to estimate the occupancy and abundance of the three taxa. Trained observers visited as many count locations as possible each year (Table 1), visiting each location at least twice during the breeding season (May – Aug). We defined a 'survey' as a unique location visited at least twice within a year. During each visit to a point the 5-minute passive survey was conducted, where observers recorded the number of individuals detected within 100-m of the observer (i.e., point center). Further detail on each original SHARP region, study design, and field protocols can be found in Wiest et al. 2016 and at www.tidalmarshbirds.org.

We used a spatially explicit tidal marsh vegetation data layer (Correll et al. 2019) to first model how the distribution of vegetation community types regionally influenced the occupancy and abundance of Saltmarsh, Nelson's, and unidentified sharp-tailed sparrows and then predicted these parameters within each region. We used seven vegetation classes (high marsh, low marsh, mudflat, pool/pan, stream, upland, and *Phragmites australis*) in the 3-m resolution tidal marsh vegetation layer (Correll et al. 2019) as independent variables in our regional models (Table 2). To utilize the tidal marsh vegetation layer, we first buffered each point count location with a 100-m radius buffer and then extracted the proportion of each vegetation class within the buffer. Next, we used the vegetation community proportions within each 100-m radius buffer as covariate values in the occupancy and abundance models.

We used the functions "occu" and "pcount" in the *unmarked* package (Fiske and Chandler 2011) in program R (version 4.1.1) to model sparrow occupancy and abundance respectively using the point count survey data from 2011-2014. We 'stacked' years such that the same points visited in multiple years were treated as independent samples in the analysis. This provided occupancy and abundance estimates that represent the 'average' of those parameters from 2011 – 2014. We converted the abundance estimate from 'unmarked' to a density estimate by dividing the abundance estimate by the area sampled (100-m radius circle). We estimated occupancy and density independently for each of the nine regions (Figure 1) using a global model including all vegetation covariates in all models and 'visit' in the detection side of the equation;

Occupancy ~ β_0 + *high marsh* + *low marsh* + *mudflat* + *pool/pan* + *stream* + *upland* + *phragmites*

Abundance ~ β_0 + *high marsh* + *low marsh* + *mudflat* + *pool/pan* + *stream* + *upland* + *phragmites*

Detection ~ *Visit*

Our approach provided regionally specific estimates of the influence of each vegetation community type on occupancy and density that were then used to predict these parameters within each region. Because the ranges for our focal taxa varied throughout the Northeast, we estimated occupancy and density for each taxa in the regions where they occur. Specifically, we estimated Saltmarsh Sparrow occupancy and density alone in seven regions (Salem to Cape Cod, Southern New England, Long Island, Coastal New Jersey, Delaware Bay, Coastal Delmarva, and Eastern Chesapeake Bay; Figure 1); we estimated Nelson's Sparrow occupancy and density alone in one region (Northern Coastal Maine; Figure 1); and in the hybrid zone we estimated Saltmarsh Sparrow, Nelson's Sparrow, and 'sharp-tailed sparrow', individuals that were unidentifiable as either Saltmarsh or Nelson's sparrow and recorded as 'sharp-tailed sparrow' (i.e. potential hybrid individuals) in one region (Rockland to Cape Ann; Figure 1).

Within each region, we used the 'predict' function in the *unmarked* package (Fiske and Chandler 2011) on the occupancy and density model objects to predict sparrow occupancy and density across regional rasters. To provide a biologically meaningful scale for our prediction maps, based roughly on home range sizes for these taxa (Shriver et al. 2010), we created a 200 x 200 m cell vegetation raster layer from the original 3 x 3 m vegetation raster layer. We first overlaid a 200 x 200 m grid onto the 3 x 3 m vegetation raster layer and calculated the proportion of each vegetation community type with the 200 m grid. Next, we used the 200 m grid within each region with the corresponding region-specific model object to predict sparrow occupancy and density within each grid cell, within each region. We then generated region specific predicted occupancy and density maps for sparrows across the nine regions. We used a relative range of occupancy and density values within a region to indicate where specific 'sparrow hot spots' may be located within a region. We determined the direction and significance of the relationships among the vegetation predictor variables and the occupancy and abundance for each taxa based on the beta coefficients and if the 95% CI overlapped zero.

We assessed the accuracy of the estimated occupancy and density predictions for each region by conducting a multi-step validation process involving training 80% of the data and fitting a model with the remaining 20%. We first split the input model data into two datasets: one that included all data from unique survey locations with a Saltmarsh or Nelson's sparrow detection across all years and one that included all data from unique survey locations that did not have a Saltmarsh or Nelson's sparrow detection across all years. We then created two more datasets from these: one that included the data from a random selection of 80% of the unique survey locations in each of those two datasets and one that included the remaining 20% of each of the two datasets. With each of these two datasets we re-ran the occupancy and density models, which were then used to created new predicted occupancy and density values for each 200 x 200 m raster cell. We then fit a linear regression with the predicted values from each dataset and calculated mean squared error (MSE) and R^2 values to assess model fit. Prior to assessing model fit using MSE and R^2 values we removed outlier predicted density estimates > 10 sparrows per hectare as these are anomalous and unrealistic values generated in the hierarchical modeling process that can disproportionately affect the MSE and R^2. This resulted in the removal of < 0.2% of estimates for all regions except of Northern Coastal Maine and Delaware Bay, which had 14.5% and 1.2% of density estimates respectively removed. Mean square error values approaching zero indicate increasing model fit, we therefore set a MSE < 0.10 in determining how our models fit the data (Zar 1999).

Results

Our models were based on 7,740 surveys conducted at 2,940 unique locations in Northeastern salt marshes from 2011 – 2014. The number of locations surveyed ranged from

1,641 locations in 2011 to 2,406 locations in 2014 (Table 1). Long Island had the fewest surveys conducted (n = 459) and Rockland to Cape Ann had the greatest number of surveys conducted from 2011 – 2014 (n = 1,542; Table 1). The influence of different vegetation community types on sparrow (hereafter, 'sparrow' refers to all three taxa) occupancy and density varied among regions (Tables 3 and 4). Saltmarsh Sparrow occupancy was positively associated with the high marsh vegetation community in six regions and negatively associated in Long Island (Table 3). Saltmarsh Sparrow density was positively associated with the high marsh vegetation community in six regions and negatively associated in the Salem to Cape Cod region and Long Island region (Table 4). Nelson's Sparrow occupancy was positively associated with the high marsh vegetation community in the hybrid region (Table 3) and Nelson's Sparrow density was positively associated with the high marsh vegetation community in both the Northern Coastal Maine region and the hybrid region (Table 4). Generally, Saltmarsh Sparrow occupancy and density was negatively related to mudflat and upland cover (Tables 3 and 4) except in the Coastal New Jersey region where all the vegetation covariates showed positive relationships with Saltmarsh Sparrow occupancy and density (Tables 3 and 4). The variation we observed among regions in the relationships between sparrow occupancy and density and the vegetation covariates strengthened using our region-specific approach to developing spatially explicit maps (Figures 3 – 32).

Nelson's Sparrow occupancy and density in Northern Coastal Maine (Figure 2), north of the hybrid zone, indicated a relatively wide-spread distribution with relatively low-density estimates (Figures 3 & 4). In the Rockland to Cape Ann region (hybrid region; Figure 5) Nelson's Sparrow occupancy (Figure 6), Saltmarsh Sparrow occupancy (Figure 7), and Sharp-tailed Sparrow occupancy (Figure 8) were similar with each other. Density predictions for these three taxa were also similar (Figures 9 - 11) and indicated a wide distribution of relatively low-density estimates. In the Salem to Cape Cod region (Figure 12), south of the hybrid zone, Saltmarsh Sparrow occupancy (Figure 13) and density (Figure 14) were patchily distributed. The Southern New England region covered salt marshes from southern CT to southern MA (Figure 15) where Saltmarsh Sparrow occupancy (Figure 16) was relatively high but with low predicted density (Figure 17). The Long Island region (Figure 18) had greater predicted Saltmarsh Sparrow occupancy on the southern portion of the island (Figure 19) than in salt marshes along Long Island Sound (Figure 19). Predicted Saltmarsh Sparrow density on Long Island was relatively low with a few clear areas with high predicted densities (Figure 20). Coastal New Jersey salt marshes (Figure 21) supported relatively high Saltmarsh Sparrow occupancy (Figure 22) and density (Figure 23) with salt marshes associated with Edwin B. Forsythe National Wildlife Refuge and Tuckahoe State Wildlife Management Area supporting high predicted Saltmarsh Sparrow densities (Figure 23). Delaware Bay salt marshes (Figure 24) showed a Saltmarsh Sparrow occupancy pattern that was greater closer to the mouth of the Delaware River (Figure 25) than in upper Delaware Bay. Saltmarsh Sparrow predicted density in Delaware Bay (Figure 26) was greatest along the Murderkill River with 3 - 5 areas supporting relatively high Saltmarsh Sparrow densities (Figure 26). The Coastal Delmarva region (Figure 27) supported relatively high Saltmarsh Sparrow predicted occupancy (Figure 28) and densities (Figure 29). The Eastern Chesapeake Bay region (Figure 30) had relatively low Saltmarsh Sparrow predicted occupancy (Figure 31) with a few areas (Blackwater NWR, Fishing BAY WMA, and Saxis WMA) with relatively high predicted densities (Figure 32).

The results of the validation process indicated a range of accuracy of the predictive modeling process in this study, which varied by region and demographic metric. Across all regions, occupancy MSE values were < 0.10 and R^2 values ranged from 0.109 to 0.868 (Table 5).

Density MSE values were < 0.70 for all regions except for Northern Coastal Maine, which had a MSE of 2.30 (Table 5). Density R^2 values ranged from 0.037 to 0.814 (Table 5).

Discussion

The 'sparrow hotspot maps' we have generated here can be used to identify areas with high probability of sparrow occupancy and high density within the Northeast. Each regional 'sparrow hotspot map' is based on the specific relationships among the taxa and the distribution of the vegetation community types within that region. This regionally specific approach attempts to capture variation in sparrow / vegetation community associations to provide more local and accurate occupancy and density predictions. Our approach to predicting these parameters was also scaled (200 x 200 m grid cells) to our sampling areas (200 m diameter point counts) as well as to the biologically relevant estimated home range sizes for these taxa. These results have not only identified relative areas of importance within each region, but they have also elucidated similarities among the three taxa (Saltmarsh Sparrow, Nelson's Sparrow, and putative hybrids) in the area of sympatry or hybrid zone. Our 'hot spot' maps are very similar for the three taxa in the hybrid zone indicating that these taxa are likely responding to the distribution of the vegetation communities we used in our analyses in similar ways. Therefore, an action designed to benefit Saltmarsh Sparrow in the hybrid zone will likely benefit all sharp-tailed sparrows.

Occupancy and abundance models that we have employed here have become a valuable tool for estimating wildlife-habitat relationships and for predicting species distributions (MacKenzie et al. 2018). Since their inception, occupancy and abundance models have been an essential wildlife conservation and management tool (MacKenzie et al. 2002, Mackenzie and Royle 2005) and the use and application of these analytical approaches continues to expand. Using occupancy modeling approaches to develop spatially explicit maps of rare, threatened, and endangered species–habitat relationships is critical because the recovery of these taxa is dependent on habitat protection, management, and restoration (Guisan et al. 2013). Spatially explicit species distribution models inform and support management recommendations and actions found in state wildlife action plans and are integral to any adaptive management framework (Fontaine 2011). Ultimately, accurate information on the distribution of taxa underpins every aspect of biodiversity conservation, including conservation of rare and / or declining species, predicting potential species invasions, identification of 'hotspots', and increasing our understanding of species-habitat relationships (Franklin 2010, Sofaer et al. 2019). Unfortunately, increases in species distribution modeling appearing in the peer reviewed literature over the past few decades have not always led to examples of these models in conservation management situations (Guisan et al. 2013). The existing support and partnership among the ACJV, USFWS Delaware Bays Program, the University of Delaware, and SHARP seeks to avoid this situation by making the data layers from these analyses understandable and readily available to the conservation community. We think these 'sparrow hotspot maps' can be used locally and regionally to aid in the identification of areas for restoration, areas to be used as reference conditions to assess nearby restoration actions, to set measurable objectives for specific restoration or management actions, and as a means to identify private land owners that may be interested in partnering for salt marsh conservation.

We do suggest that these 'hotspot maps' be used with caution, thoughtfulness, and as a relative guide and not a specific population estimate or assessment of current conditions. The avian and vegetation data used in these analyses were coincident (2011 – 2014 for birds and 2014 for vegetation), but occurred 10 – 15 years prior to the analyses presented here. The predicted occupancy and density maps provided herein may accurately reflect the conditions that occurred in 2011 – 2014, but those conditions have likely changed and therefore, the results of these models may not accurately reflect current situations. Presently, there is an opportunity to update the vegetation data layer (Correll et al. 2019) using contemporary imagery and avian data (2019 – 2022) collected by SHARP to compare with these results. An update of the tidal marsh vegetation layer would also provide an opportunity to specifically estimate changes in tidal marsh vegetation communities over the past decade. We intentionally kept our modeling effort simple, which can increase the likelihood that the results of these analyses are interpretable and useful (Sofaer et al. 2019), but including only vegetation community types does not account for other factors that could influence sparrow occupancy and density. Finally, areas that were predicted to have a very low probability of occupancy or density actually will likely not support sparrows at all, but the models predicted low levels of occupancy or density based on the vegetation occurrence within those grid cells.

We recommend using the results of these analyses as an initial, broad scale tool to aid in making decisions about where to prioritize salt marsh restoration and management to benefit Saltmarsh Sparrows and potentially, other salt marsh obligate taxa. Once potential sites are identified using these results and other sources of information (ACJV prioritization tool), we strongly recommend conducting site level surveys for breeding sparrows prior to developing any type of restoration plan or design. We recommend using the SHARP rapid demographic protocol to 1) determine if sparrows are present, 2) estimate occupancy and abundance, and 3) provide an index of productivity (Sanchez Jr. 2023).

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Table 1. Number of point count locations (2011-2014) surveyed and included in these analyses across the study area in the Northeast, USA.

Region #	Region	# of locations 2011	# of locations 2012	# of locations 2013	# of locations 2014	Total # of surveys conducted
Region 1	Northern Coastal Maine	107	128	108	116	459
Hybrid	Rockland to Cape Ann	318	346	381	497	1542
Region 2	Salem to Cape Cod	148	148	171	174	641
Region 3	Southern New England	201	227	196	285	909
Region 4	Long Island	89	146	139	179	553
Region 5	Coastal New Jersey	226	296	289	309	1120
Region 6	Delaware Bay	140	209	213	413	975
Region 7	Coastal Delmarva	241	221	171	241	874
Region 8	Eastern Chesapeake Bay	171	182	122	192	667
	TOTAL locations surveyed in each year	1641	1903	1790	2406	7740

Table 2. Vegetation community cover types and definitions included as covariates in models used to predict Saltmarsh and Nelson's sparrow occupancy and abundance in the Northeast.

Cover Type	Definition	Dominant Species
High Marsh	Areas of vegetated marsh flooded by mean or higher tides	*Spartina patens*, *Distichlis spicata*, *Juncus gerardii*, short-form *S. alterniflora* (1-35 cm), *Juncus roemerianus, Schoenoplectus pungens*, *Bolboschoenus robustus*, *Limonium carolinianum*, *Symphyotrichum tenuifolium*
Low Marsh	Areas of vegetated marsh regularly flooded by daily tides	Tall-form *Spartina alterniflora* (50+ cm), *Spartina cynosuroides*
Salt pools/pannes	Depressed, bare areas with sparse vegetation cover and extremely high soil salinities. Generally, pools retain water between high tides while pannes do not.	NA
Phragmites australis	Areas of vegetated marsh dominated by non-native invasive species; often disturbed areas	*Phragmites australis*
Mudflat	Exposed muddy areas free of vegetation	NA
Streams	Channels and streams	NA
Upland	Non-wetland terrestrial cover	Various

Table 3. Occupancy model covariate beta coefficients, SEs, and 95% CIs for Saltmarsh Sparrow (SALS), Nelson's Sparrow (NESP), and unidentified 'sharp-tailed sparrow' (STSP) by region.

Region #	Region Name	Variable	Estimate	SE	Lower 95% CI	Upper 95% CI	Species code	Significance
Region 1	Northern Coastal Maine	Upland	-8.03	2.15	-12.23	-3.82	NESP	Significant
		Low marsh	-6.89	3.17	-13.11	-0.67	NESP	Significant
		Mudflat	-5.73	1.93	-9.51	-1.95	NESP	Significant
		Pool pan	-3.97	2.45	-8.78	0.84	NESP	Non-significant
		Stream	-3.27	2.02	-7.22	0.69	NESP	Non-significant
		High marsh	2.91	1.99	-1.00	6.82	NESP	Non-significant
		Phragmites	19.23	17.82	-15.69	54.15	NESP	Non-significant
Hybrid	Rockland to Cape Ann	Upland	-0.55	2.45	-5.35	4.25	NESP	Non-significant
		Stream	0.44	2.28	-4.03	4.90	NESP	Non-significant
		Mudflat	3.50	2.32	-1.05	8.06	NESP	Non-significant
		Low marsh	4.11	2.16	-0.13	8.35	NESP	Non-significant
		High marsh	5.47	2.19	1.18	9.75	NESP	Significant
		Phragmites	6.66	5.08	-3.30	16.63	NESP	Non-significant
		Pool pan	9.92	2.58	4.87	14.98	NESP	Significant
Hybrid	Rockland to Cape Ann	Upland	-4.06	1.72	-7.44	-0.69	SALS	Significant
		Mudflat	-1.41	1.82	-4.98	2.17	SALS	Non-significant
		Stream	0.34	1.57	-2.75	3.42	SALS	Non-significant
		Phragmites	1.06	5.17	-9.07	11.20	SALS	Non-significant
		Low marsh	2.91	1.43	0.10	5.72	SALS	Significant
		High marsh	3.72	1.39	1.00	6.44	SALS	Significant
		Pool pan	6.24	2.03	2.26	10.22	SALS	Significant
Hybrid	Rockland to Cape Ann	Phragmites	-5.53	6.42	-18.11	7.06	STSP	Non-significant
		Upland	-4.88	1.71	-8.23	-1.53	STSP	Significant
		Mudflat	-4.26	2.18	-8.54	0.01	STSP	Non-significant
		Stream	-0.07	1.56	-3.12	2.99	STSP	Non-significant
		Low marsh	2.39	1.35	-0.25	5.03	STSP	Non-significant
		High marsh	2.58	1.26	0.11	5.05	STSP	Significant
		Pool pan	3.49	2.07	-0.57	7.54	STSP	Non-significant
Region 2	Salem to Cape Cod	Mudflat	-18.87	5.93	-30.50	-7.24	SALS	Significant
		Stream	-10.80	3.55	-17.75	-3.85	SALS	Significant
		Phragmites	-4.02	2.06	-8.05	0.01	SALS	Non-significant
		Upland	-2.87	0.99	-4.82	-0.93	SALS	Significant
		Pool pan	-2.01	4.99	-11.79	7.76	SALS	Non-significant
		Low marsh	-0.50	1.04	-2.53	1.54	SALS	Non-significant
		High marsh	1.82	0.70	0.45	3.18	SALS	Significant
Region 3		Pool pan	-21.16	8.76	-38.33	-3.99	SALS	Significant

Region #	Region Name	Variable	Estimate	SE	Lower 95% CI	Upper 95% CI	Species code	Significance
	Southern New England	Mudflat	-5.43	1.34	-8.06	-2.80	SALS	Significant
		Upland	-1.84	0.45	-2.72	-0.96	SALS	Significant
		Stream	-0.90	0.51	-1.90	0.10	SALS	Non-significant
		High marsh	1.53	0.44	0.68	2.39	SALS	Significant
		Low marsh	2.05	1.10	-0.10	4.21	SALS	Non-significant
		Phragmites	4.14	1.41	1.39	6.90	SALS	Significant
Region 4	Long Island	Mudflat	-10.22	3.12	-16.33	-4.10	SALS	Significant
		Upland	-4.56	0.86	-6.24	-2.88	SALS	Significant
		Pool pan	-3.34	3.57	-10.34	3.65	SALS	Non-significant
		Stream	-2.70	0.55	-3.77	-1.62	SALS	Significant
		Phragmites	-2.51	0.97	-4.41	-0.61	SALS	Significant
		Low marsh	-2.12	1.57	-5.20	0.95	SALS	Non-significant
		High marsh	-0.92	0.45	-1.81	-0.03	SALS	Significant
Region 5	Coastal New Jersey	Upland	12.76	3.68	5.56	19.97	SALS	Significant
		Stream	14.80	2.94	9.04	20.57	SALS	Significant
		Phragmites	15.33	3.68	8.12	22.53	SALS	Significant
		Low marsh	16.04	3.04	10.09	21.99	SALS	Significant
		Pool pan	16.09	3.46	9.31	22.88	SALS	Significant
		Mudflat	18.11	3.12	11.99	24.22	SALS	Significant
		High marsh	18.66	2.94	12.89	24.43	SALS	Significant
Region 6	Delaware Bay	Upland	-18.20	5.34	-28.68	-7.72	SALS	Significant
		Mudflat	-10.20	5.35	-20.69	0.29	SALS	Non-significant
		Phragmites	-1.22	1.69	-4.52	2.09	SALS	Non-significant
		Pool pan	-0.72	2.97	-6.55	5.11	SALS	Non-significant
		Stream	0.31	0.99	-1.64	2.25	SALS	Non-significant
		Low marsh	0.91	0.93	-0.91	2.73	SALS	Non-significant
		High marsh	2.79	0.87	1.08	4.50	SALS	Significant
Region 7	Coastal Delmarva	Upland	-5.33	3.34	-11.89	1.22	SALS	Non-significant
		Phragmites	0.42	4.98	-9.34	10.17	SALS	Non-significant
		Low marsh	1.61	2.39	-3.07	6.28	SALS	Non-significant
		Stream	2.84	2.32	-1.71	7.40	SALS	Non-significant
		Pool pan	3.38	7.78	-11.87	18.62	SALS	Non-significant
		High marsh	3.55	2.31	-0.97	8.07	SALS	Non-significant
		Mudflat	6.24	3.24	-0.12	12.59	SALS	Non-significant
Region 8	Eastern Chesapeake Bay	Upland	-93.18	51.33	-193.79	7.43	SALS	Non-significant
		Mudflat	-17.89	13.58	-44.51	8.74	SALS	Non-significant
		Pool pan	-3.33	3.28	-9.75	3.09	SALS	Non-significant
		Phragmites	-3.25	1.62	-6.42	-0.08	SALS	Significant
		Stream	1.38	0.82	-0.23	2.98	SALS	Non-significant

Region #	Region Name	Variable	Estimate	SE	Lower 95% CI	Upper 95% CI	Species code	Significance
		High marsh	1.94	0.75	0.47	3.41	SALS	Significant
		Low marsh	2.33	0.87	0.63	4.02	SALS	Significant

Table 4. Density model covariate beta coefficients, SEs, and 95% CIs for Saltmarsh Sparrow (SALS), Nelson's Sparrow (NESP), and unidentified 'sharp-tailed sparrow' (STSP) by region.

Region #	Region Name	Variable	Estimate	SE	Lower 95% CI	Upper 95% CI	Species code	Significance
Region 1	Northern Coastal Maine	Upland	-2.85	0.66	-4.13	-1.56	NESP	Significant
		Mudflat	-2.24	0.74	-3.69	-0.78	NESP	Significant
		Low marsh	-0.25	0.88	-1.97	1.46	NESP	Non-significant
		Pool pan	0.04	0.89	-1.69	1.78	NESP	Non-significant
		Stream	0.32	0.62	-0.89	1.52	NESP	Non-significant
		High marsh	1.82	0.53	0.78	2.85	NESP	Significant
		Phragmites	3.02	3.17	-3.19	9.22	NESP	Non-significant
Hybrid	Rockland to Cape Ann	Upland	-1.97	1.79	-5.47	1.53	NESP	Non-significant
		Stream	-0.88	1.62	-4.05	2.29	NESP	Non-significant
		Low marsh	2.14	1.55	-0.90	5.18	NESP	Non-significant
		Mudflat	2.79	1.63	-0.40	5.98	NESP	Non-significant
		High marsh	3.21	1.57	0.14	6.28	NESP	Significant
		Phragmites	4.11	2.78	-1.34	9.56	NESP	Non-significant
		Pool pan	6.70	1.61	3.55	9.85	NESP	Significant
Hybrid	Rockland to Cape Ann	Upland	2.63	2.47	-2.21	7.46	SALS	Non-significant
		Mudflat	2.63	2.36	-2.00	7.26	SALS	Non-significant
		Stream	4.74	2.21	0.42	9.07	SALS	Significant
		Phragmites	5.89	3.38	-0.74	12.52	SALS	Non-significant
		High marsh	7.83	2.20	3.52	12.15	SALS	Significant
		Low marsh	7.99	2.18	3.72	12.25	SALS	Significant
		Pool pan	8.85	2.24	4.47	13.24	SALS	Significant
Hybrid	Rockland to Cape Ann	Phragmites	-4.93	4.82	-14.38	4.52	STSP	Non-significant
		Upland	-3.07	3.03	-9.01	2.88	STSP	Non-significant
		Mudflat	-2.56	2.85	-8.14	3.02	STSP	Non-significant
		Stream	1.24	2.59	-3.83	6.32	STSP	Non-significant
		High marsh	3.75	2.58	-1.32	8.81	STSP	Non-significant
		Pool pan	3.89	2.65	-1.30	9.09	STSP	Non-significant
		Low marsh	4.70	2.56	-0.32	9.71	STSP	Non-significant
Region 2	Salem to Cape Cod	Mudflat	-13.79	3.13	-19.93	-7.65	SALS	Significant
		Stream	-9.94	1.77	-13.42	-6.47	SALS	Significant
		Phragmites	-7.29	1.50	-10.23	-4.35	SALS	Significant
		Upland	-6.82	0.81	-8.41	-5.24	SALS	Significant
		Pool pan	-3.75	2.87	-9.37	1.87	SALS	Non-significant
		Low marsh	-2.38	0.55	-3.47	-1.30	SALS	Significant
		High marsh	-2.20	0.41	-2.99	-1.40	SALS	Significant

Region #	Region Name	Variable	Estimate	SE	Lower 95% CI	Upper 95% CI	Species code	Significance
Region 3	Southern New England	Pool pan	-4.49	3.74	-11.82	2.84	SALS	Non-significant
		Mudflat	-2.22	0.82	-3.83	-0.61	SALS	Significant
		Upland	0.84	0.45	-0.04	1.72	SALS	Non-significant
		Stream	1.81	0.41	1.00	2.61	SALS	Significant
		Low marsh	2.98	0.50	2.00	3.97	SALS	Significant
		Phragmites	3.41	0.51	2.41	4.41	SALS	Significant
		High marsh	4.16	0.36	3.44	4.87	SALS	Significant
Region 4	Long Island	Mudflat	-9.18	1.75	-12.60	-5.76	SALS	Significant
		Pool pan	-8.49	2.22	-12.84	-4.14	SALS	Significant
		Upland	-5.80	0.51	-6.80	-4.80	SALS	Significant
		Phragmites	-3.29	0.60	-4.47	-2.10	SALS	Significant
		Low marsh	-2.84	0.84	-4.49	-1.20	SALS	Significant
		Stream	-2.20	0.23	-2.65	-1.74	SALS	Significant
		High marsh	-0.88	0.15	-1.17	-0.59	SALS	Significant
Region 5	Coastal New Jersey	Upland	8.00	2.77	2.56	13.44	SALS	Significant
		Stream	12.61	1.88	8.93	16.29	SALS	Significant
		Phragmites	13.22	2.25	8.82	17.62	SALS	Significant
		Low marsh	13.69	1.92	9.93	17.45	SALS	Significant
		High marsh	15.10	1.86	11.45	18.75	SALS	Significant
		Mudflat	15.16	1.92	11.40	18.92	SALS	Significant
		Pool pan	15.35	2.10	11.23	19.46	SALS	Significant
Region 6	Delaware Bay	Upland	-19.11	4.25	-27.44	-10.78	SALS	Significant
		Mudflat	-7.98	3.44	-14.72	-1.24	SALS	Significant
		Pool pan	-1.01	1.77	-4.49	2.46	SALS	Non-significant
		Phragmites	-0.17	0.94	-2.00	1.66	SALS	Non-significant
		Stream	0.15	0.63	-1.08	1.39	SALS	Non-significant
		Low marsh	0.31	0.59	-0.85	1.47	SALS	Non-significant
		High marsh	2.10	0.52	1.09	3.12	SALS	Significant
Region 7	Coastal Delmarva	Upland	-8.63	3.09	-14.68	-2.58	SALS	Significant
		Pool pan	-2.60	5.95	-14.26	9.07	SALS	Non-significant
		Phragmites	-0.57	3.78	-7.99	6.85	SALS	Non-significant
		Low marsh	0.89	1.98	-3.00	4.78	SALS	Non-significant
		Stream	2.87	1.94	-0.93	6.66	SALS	Non-significant
		Mudflat	3.42	2.23	-0.95	7.80	SALS	Non-significant
		High marsh	3.56	1.92	-0.21	7.33	SALS	Non-significant
Region 8	Eastern Chesapeake Bay	Upland	-126.01	47.43	-218.97	-33.06	SALS	Significant
		Mudflat	-25.82	14.84	-54.91	3.27	SALS	Non-significant
		Pool pan	-8.77	2.91	-14.46	-3.07	SALS	Significant

Region #	Region Name	Variable	Estimate	SE	Lower 95% CI	Upper 95% CI	Species code	Significance
		Phragmites	-7.20	1.43	-10.00	-4.40	SALS	Significant
		Stream	-0.72	0.51	-1.72	0.28	SALS	Non-significant
		Low marsh	0.40	0.48	-0.53	1.33	SALS	Non-significant
		High marsh	1.49	0.45	0.60	2.38	SALS	Significant

Table 5. Occupancy and density model validation for Saltmarsh Sparrow (SALS), Nelson's Sparrow (NESP), and 'unidentified sharp-tailed sparrow' (STSP).

Region #	Region Name	Species code	Occupancy MSE*	Occupancy R^2	Density MSE*	Density R^2
Region 1	Northern Coastal Maine	NESP	0.095	0.490	2.298	0.037
Hybrid	Rockland to Cape Ann	NESP	0.002	0.828	0.015	0.543
Hybrid	Rockland to Cape Ann	SALS	0.002	0.868	0.023	0.443
Hybrid	Rockland to Cape Ann	STSP	0.001	0.630	0.017	0.625
Region 2	Salem to Cape Cod	SALS	0.015	0.109	0.001	0.814
Region 3	Southern New England	SALS	0.003	0.840	0.022	0.483
Region 4	Long Island	SALS	0.015	0.417	0.080	0.481
Region 5	Coastal New Jersey	SALS	0.008	0.790	0.011	0.737
Region 6	Delaware Bay	SALS	0.037	0.476	0.673	0.232
Region 7	Coastal Delmarva	SALS	0.013	0.299	0.022	0.256
Region 8	Eastern Chesapeake Bay	SALS	0.007	0.709	0.214	0.527

*Mean squared error

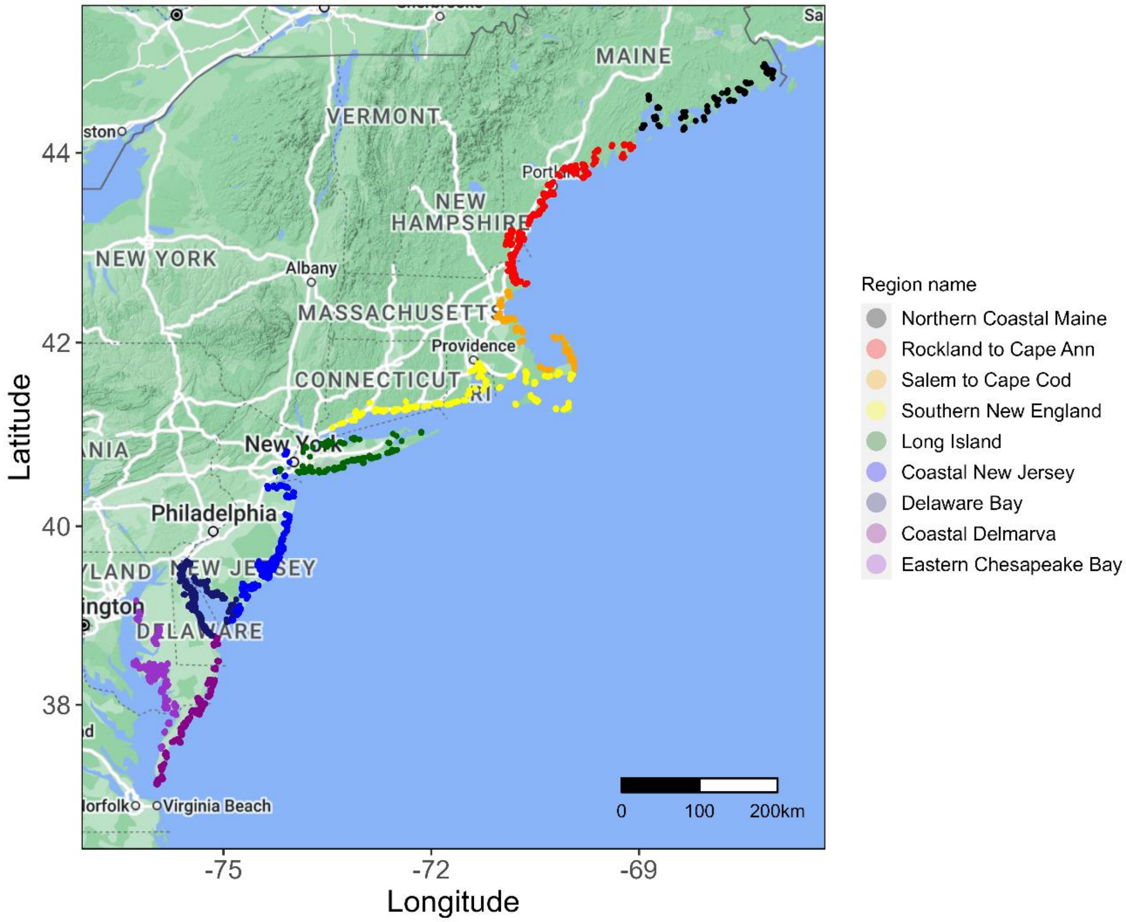

Figure 1. Study area and point count locations surveyed from 2011-2014 along the Atlantic Coast, from Virginia to Maine.

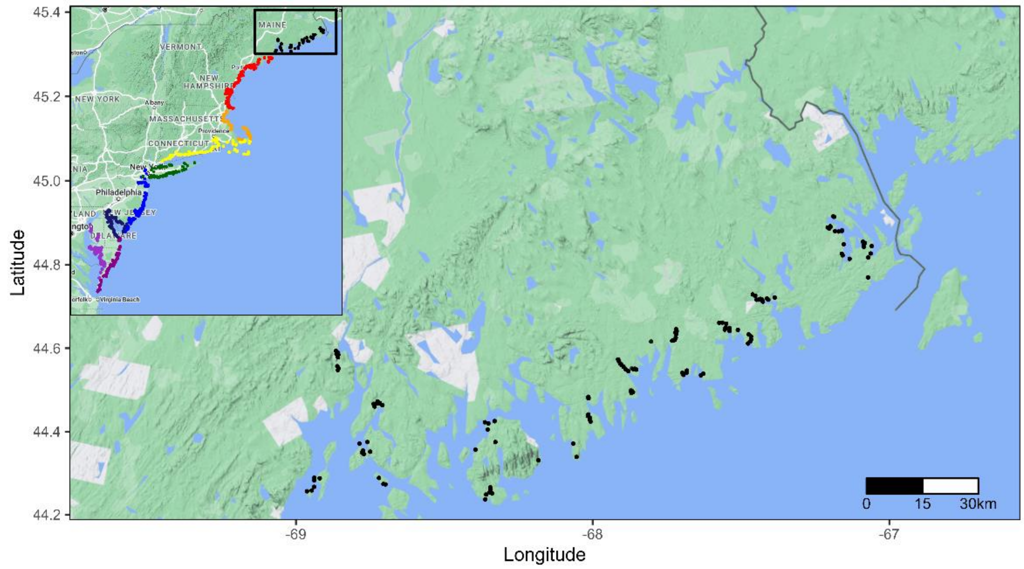

Figure 2. Study area and point count locations surveyed from 2011-2014 in Northern Coastal Maine.

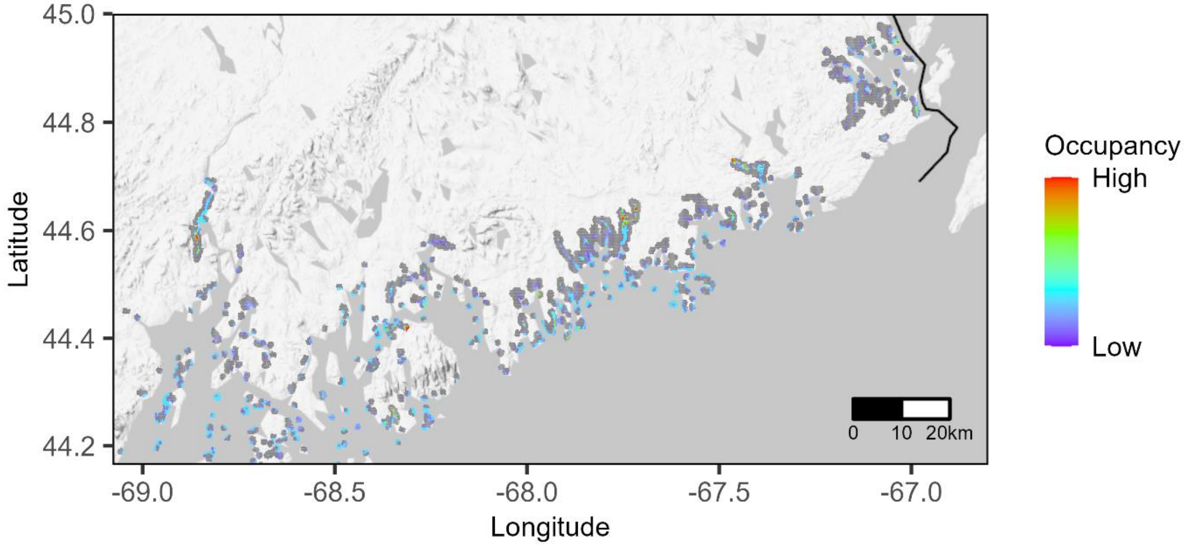

Figure 3. Predicted Nelson's Sparrow occupancy in Northern Coastal Maine based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

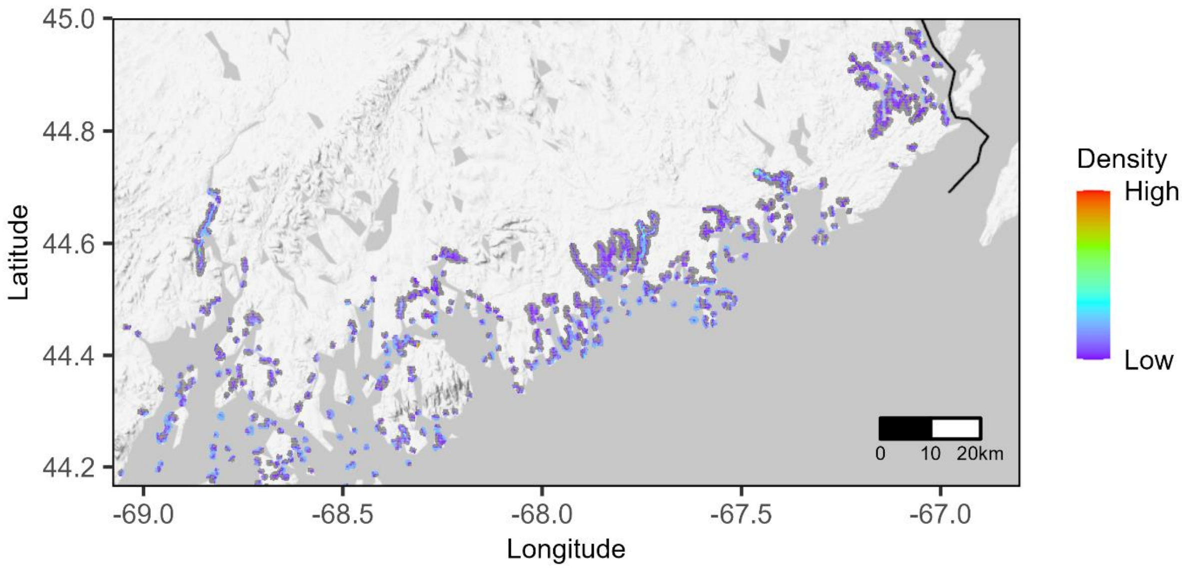

Figure 4. Predicted Nelson's Sparrow density in Northern Coastal Maine based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

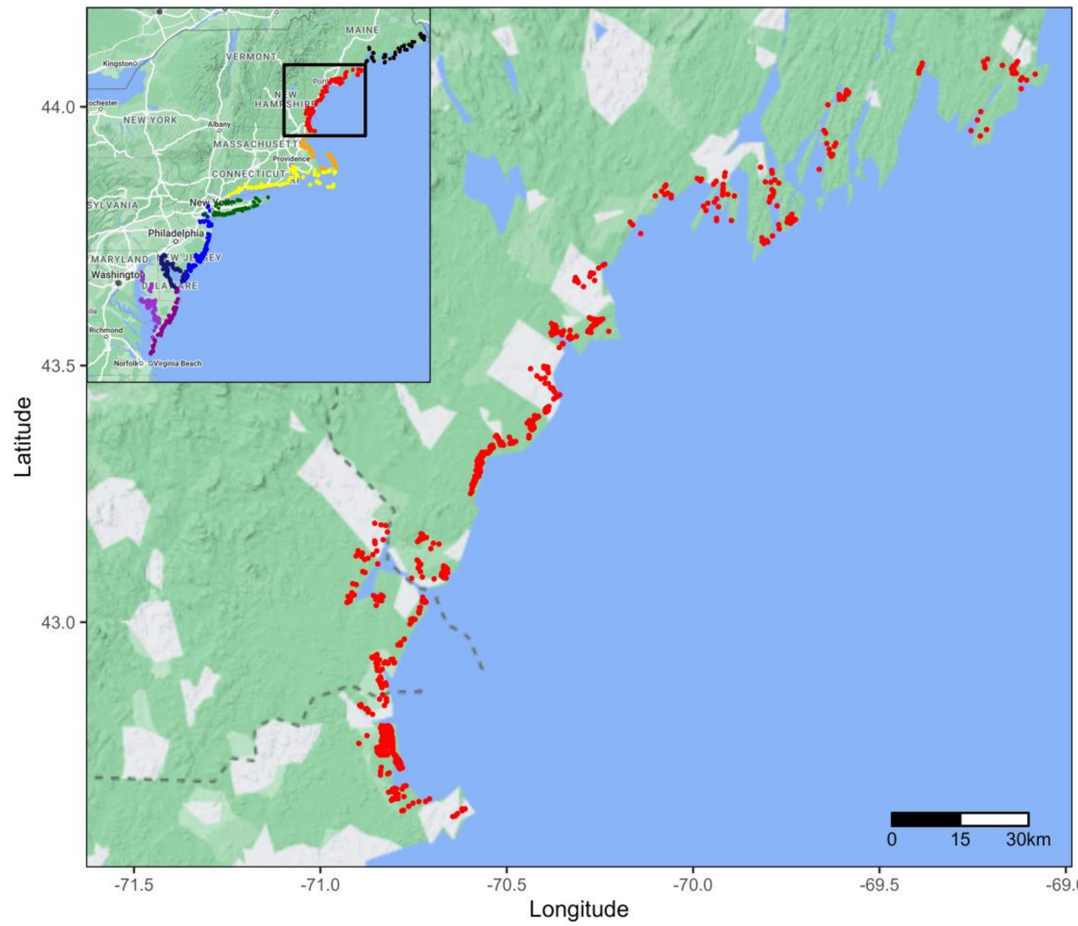

Figure 5. Study area and point count locations surveyed from 2011-2014 from Rockland to Cape Ann.

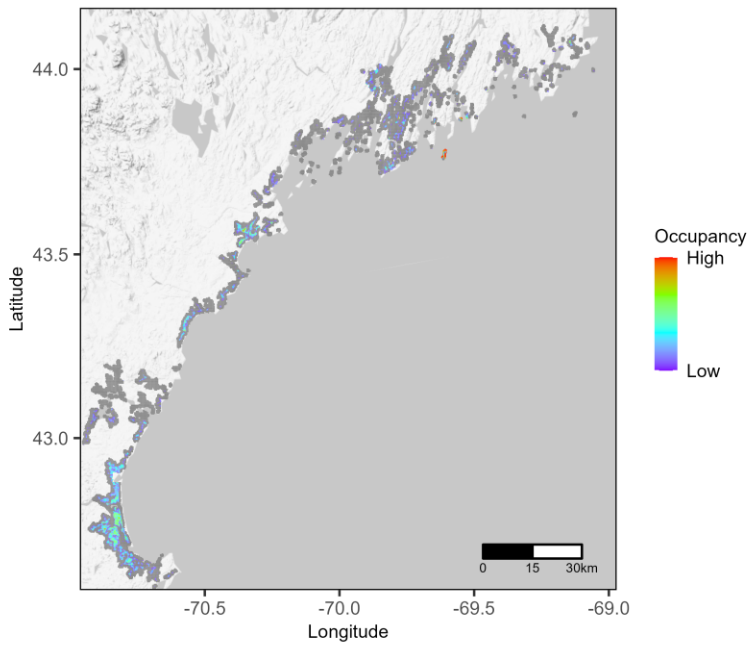

Figure 6. Predicted Nelson's Sparrow occupancy from Rockland to Cape Ann based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

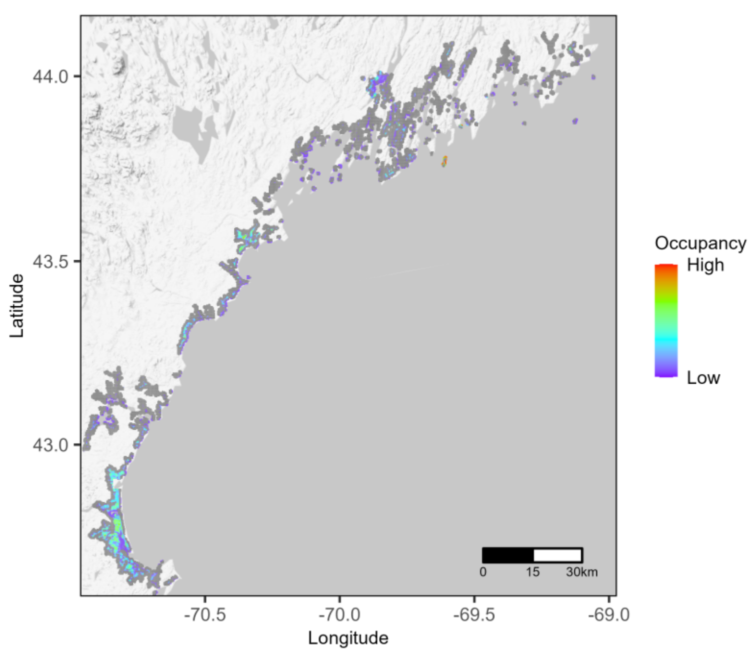

Figure 7. Predicted Saltmarsh Sparrow occupancy from Rockland to Cape Ann based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

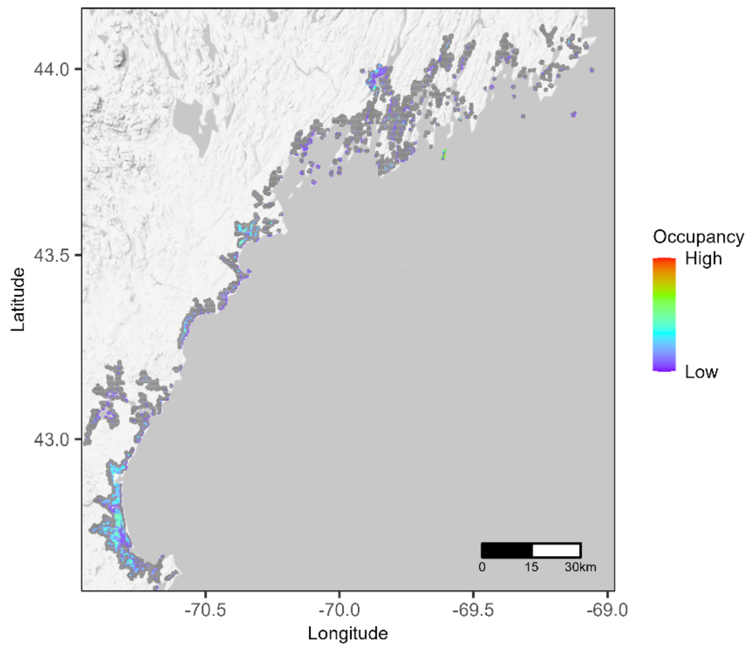

Figure 8. Predicted Sharp-tailed Sparrow occupancy from Rockland to Cape Ann based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

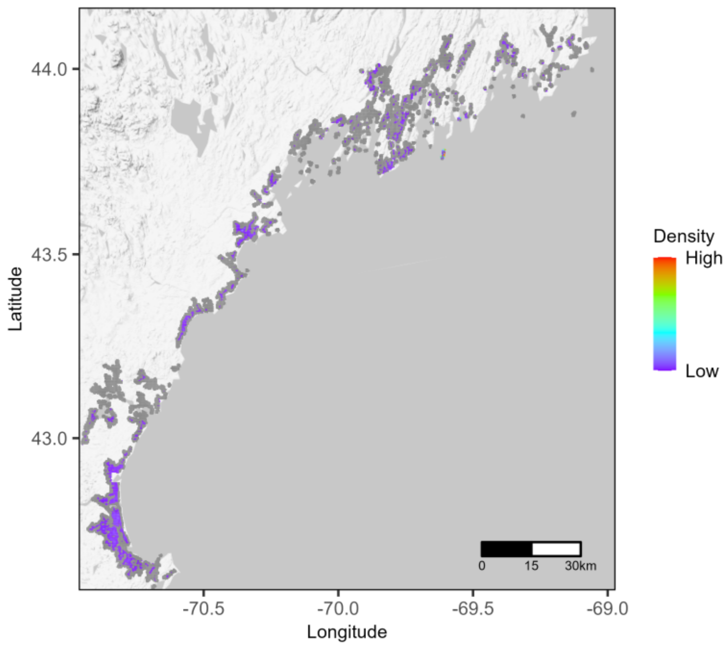

Figure 9. Predicted Nelson's Sparrow density from Rockland to Cape Ann based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

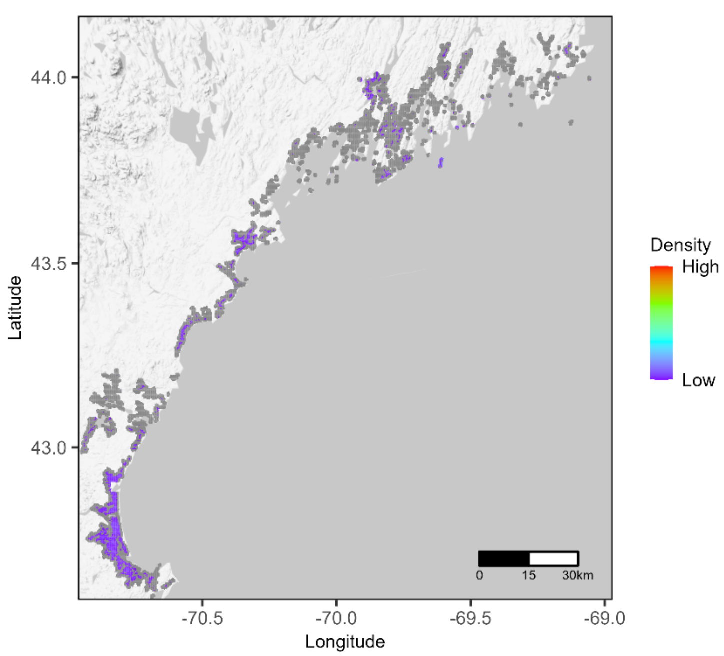

Figure 10. Predicted Saltmarsh Sparrow density from Rockland to Cape Ann based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

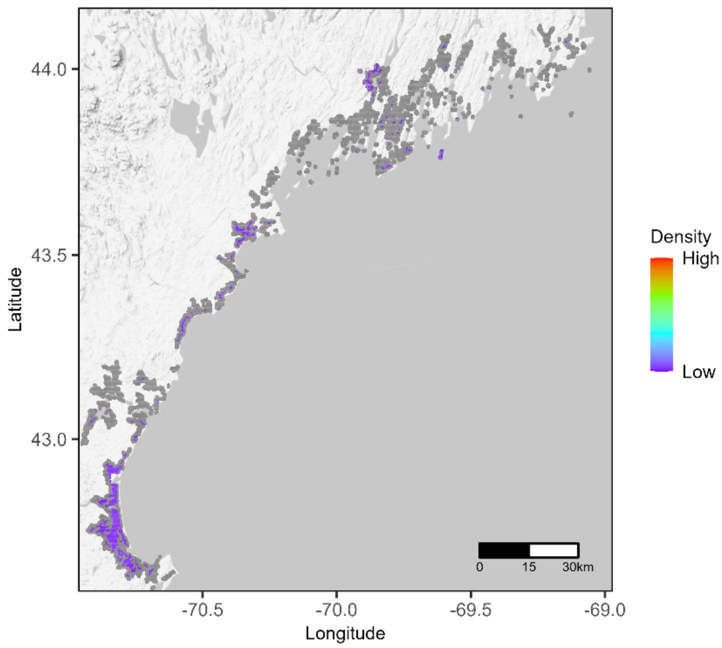

Figure 11. Predicted Sharp-tailed Sparrow density from Rockland to Cape Ann based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

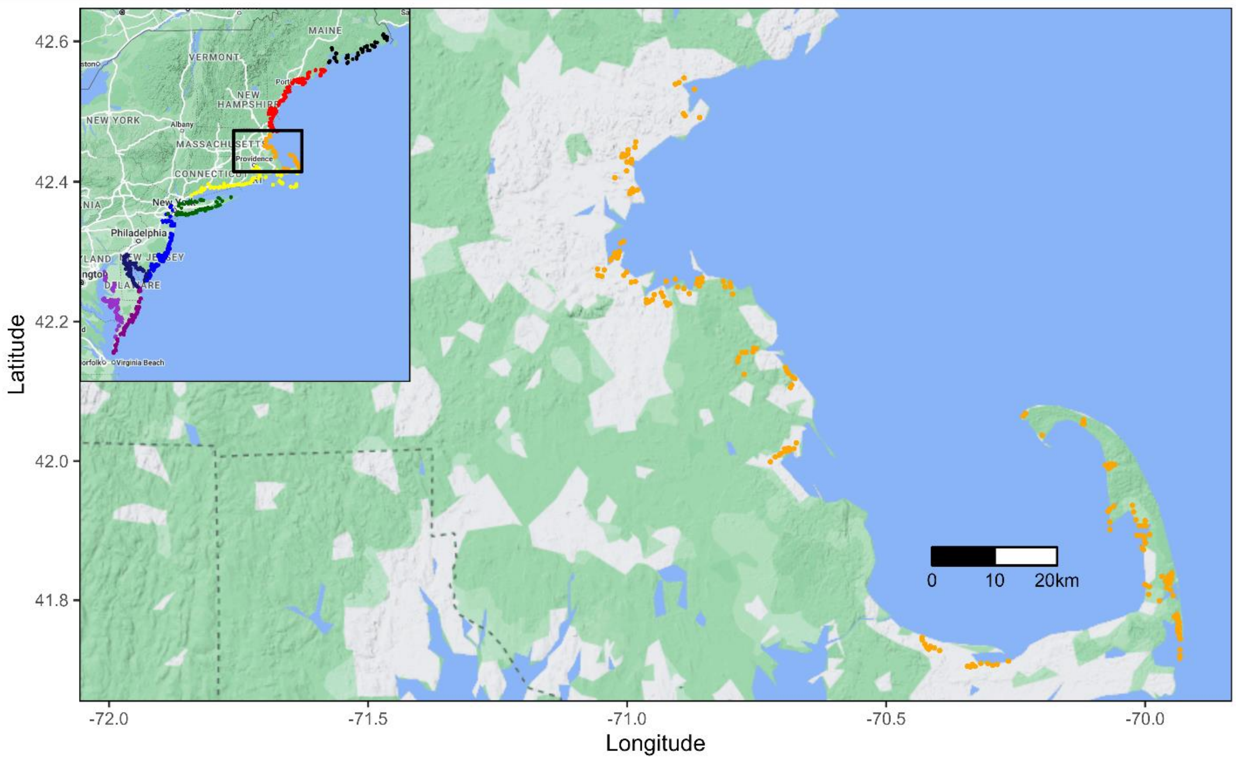

Figure 12. Study area and point count locations surveyed from 2011-2014 from Salem to Cape Cod.

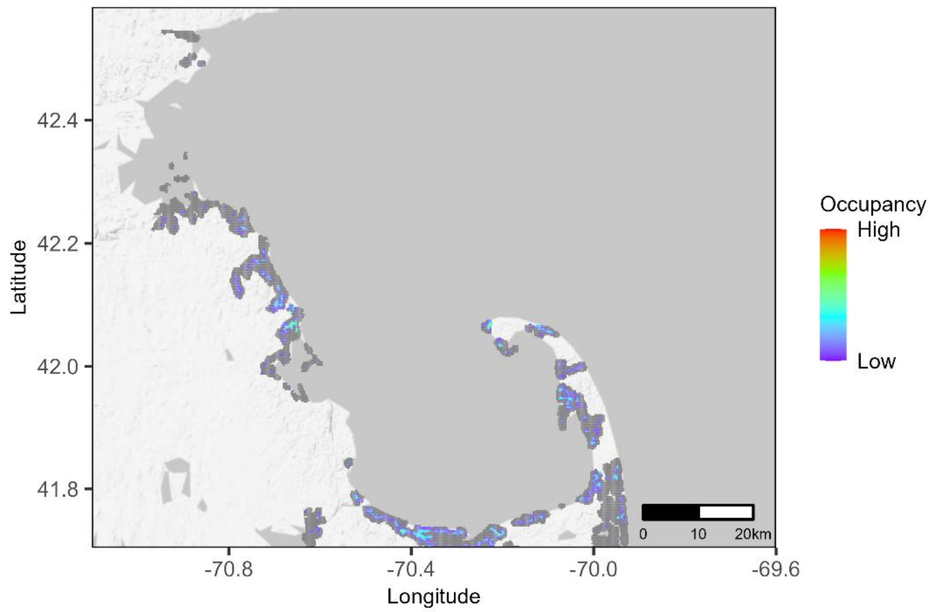

Figure 13. Predicted Saltmarsh Sparrow occupancy from Salem to Cape Cod based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

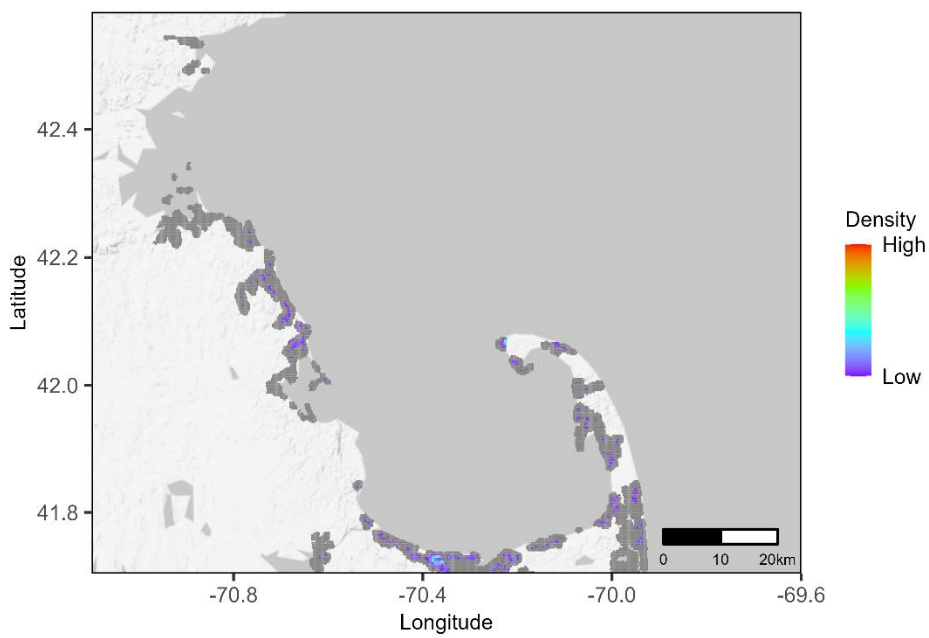

Figure 14. Predicted Saltmarsh Sparrow density from Salem to Cape Cod based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

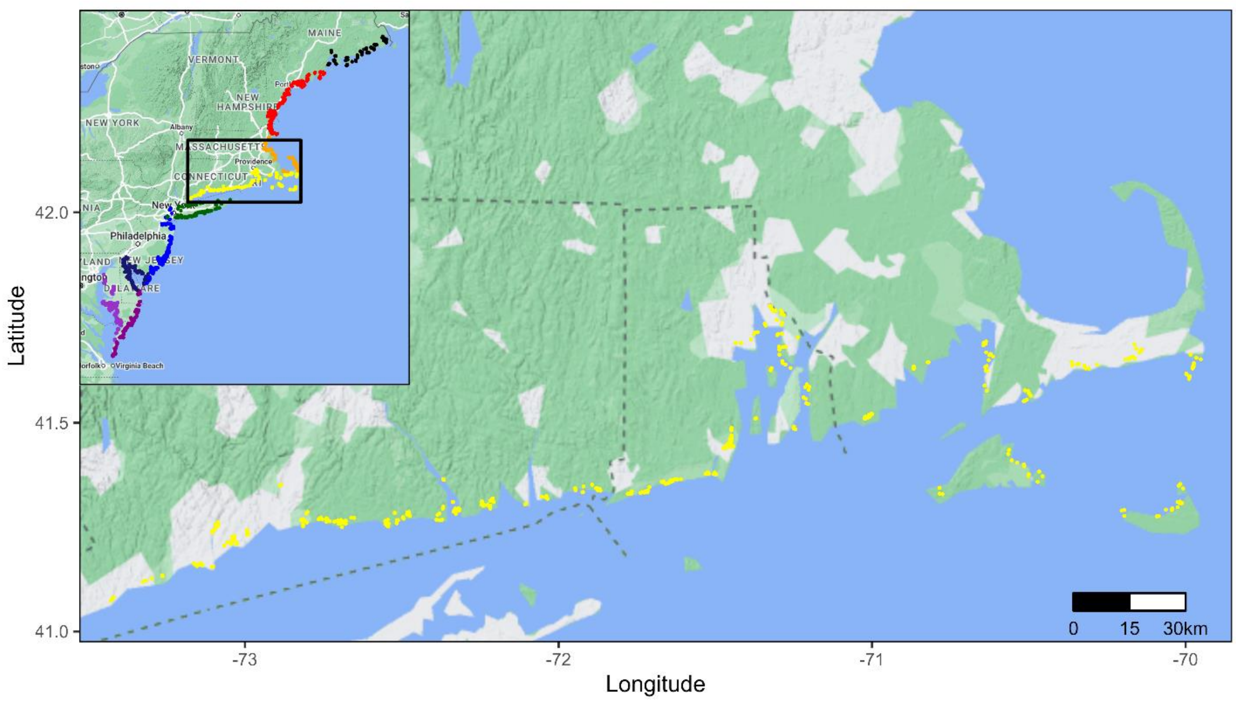

Figure 15. Study area and point count locations surveyed from 2011-2014 in Southern New England.

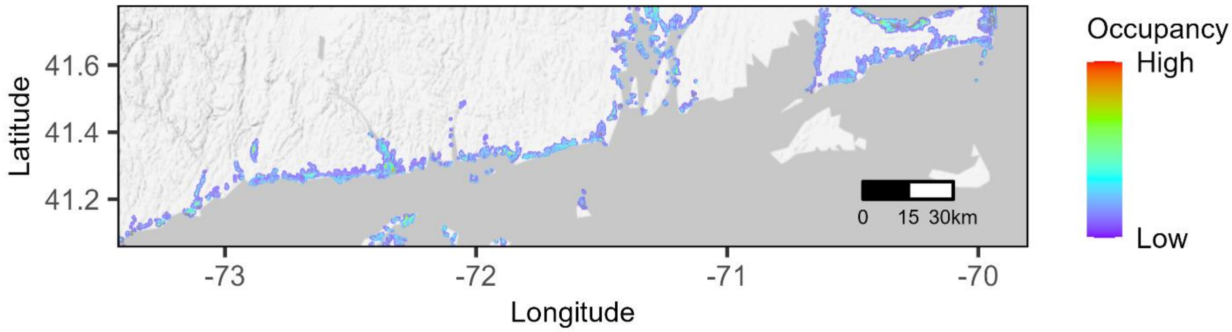

Figure 16. Predicted Saltmarsh Sparrow occupancy in Southern New England based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

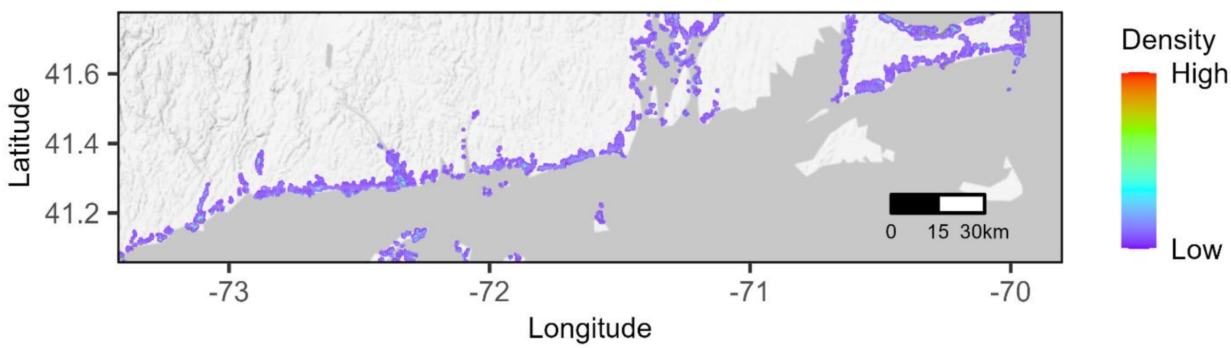

Figure 17. Predicted Saltmarsh Sparrow density in Southern New England based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

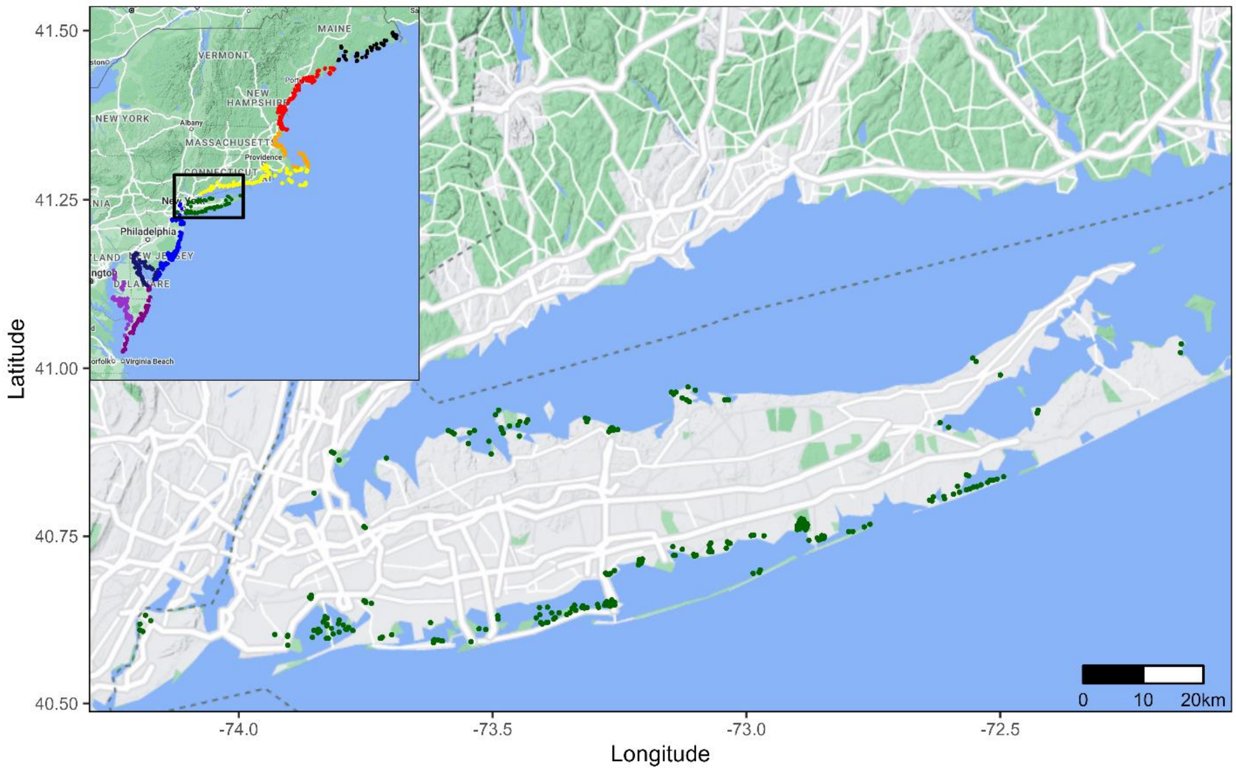

Figure 18. Study area and point count locations surveyed from 2011-2014 in Long Island.

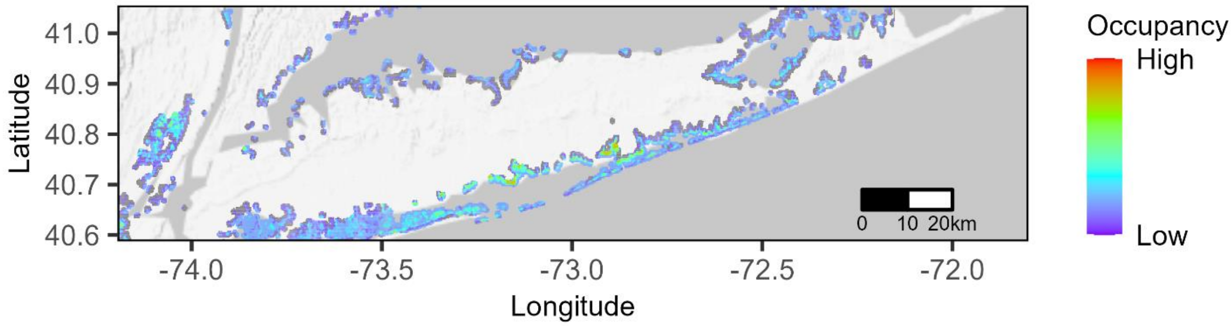

Figure 19. Predicted Saltmarsh Sparrow occupancy in Long Island based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

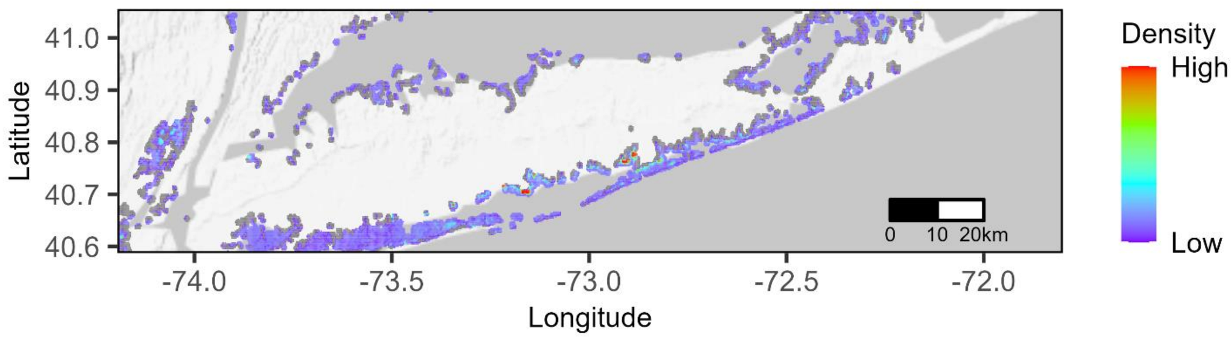

Figure 20, Predicted Saltmarsh Sparrow density in Long Island based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

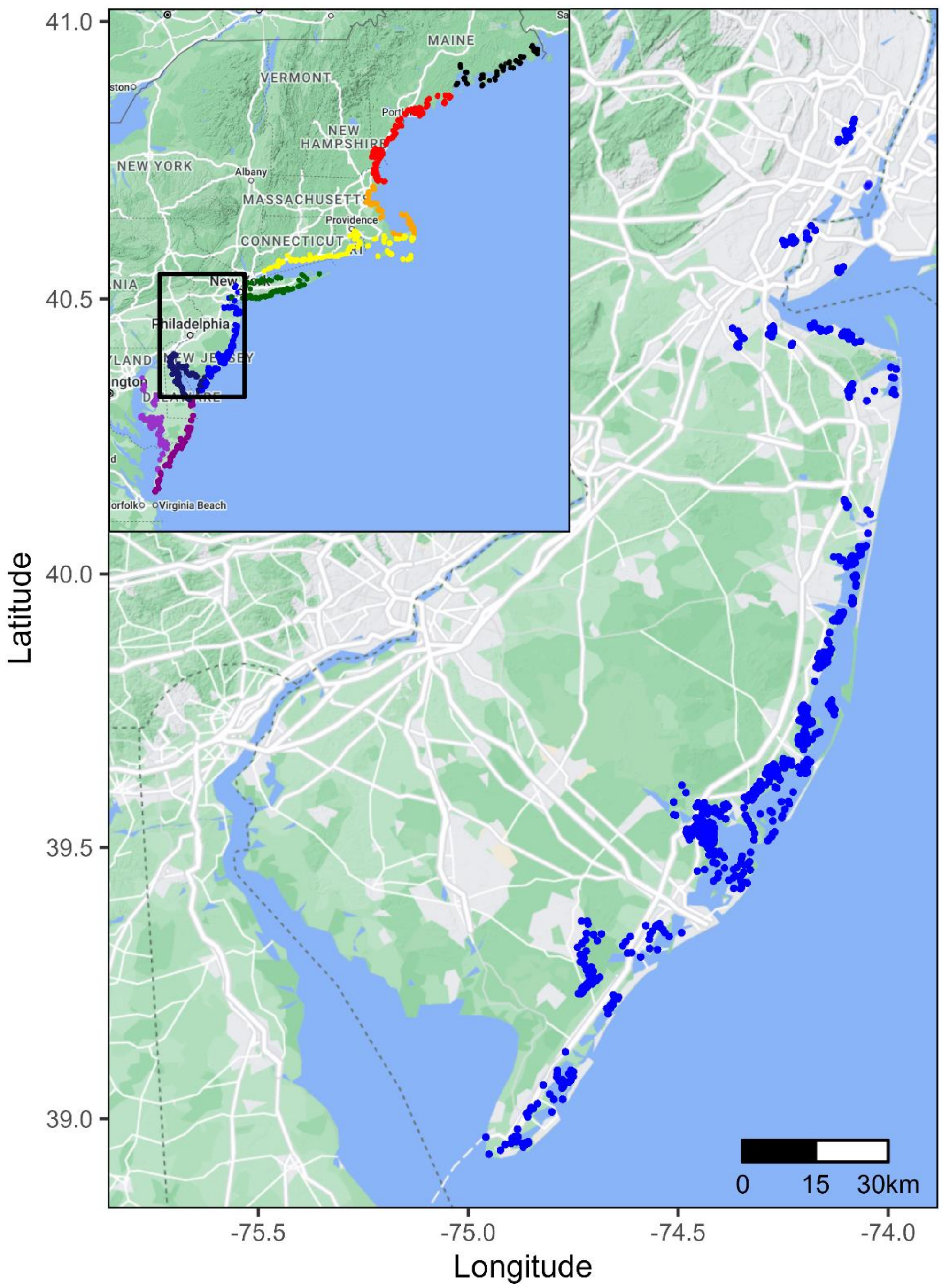

Figure 21. Study area and point count locations surveyed from 2011-2014 in Coastal New Jersey. Cells with occupancy and density values < 0.05 are dark gray.

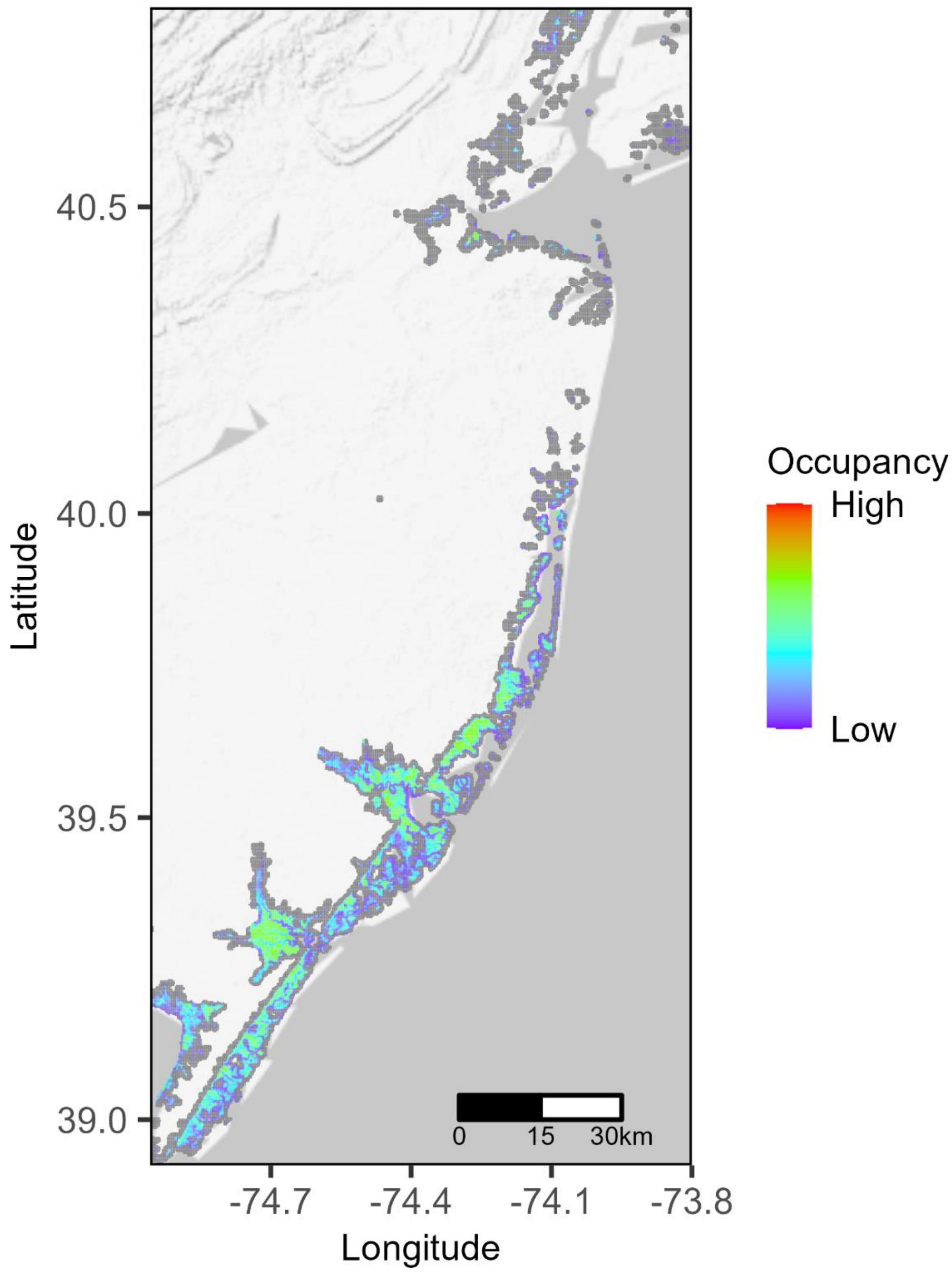

Figure 22. Predicted Saltmarsh Sparrow occupancy in Coastal New Jersey based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

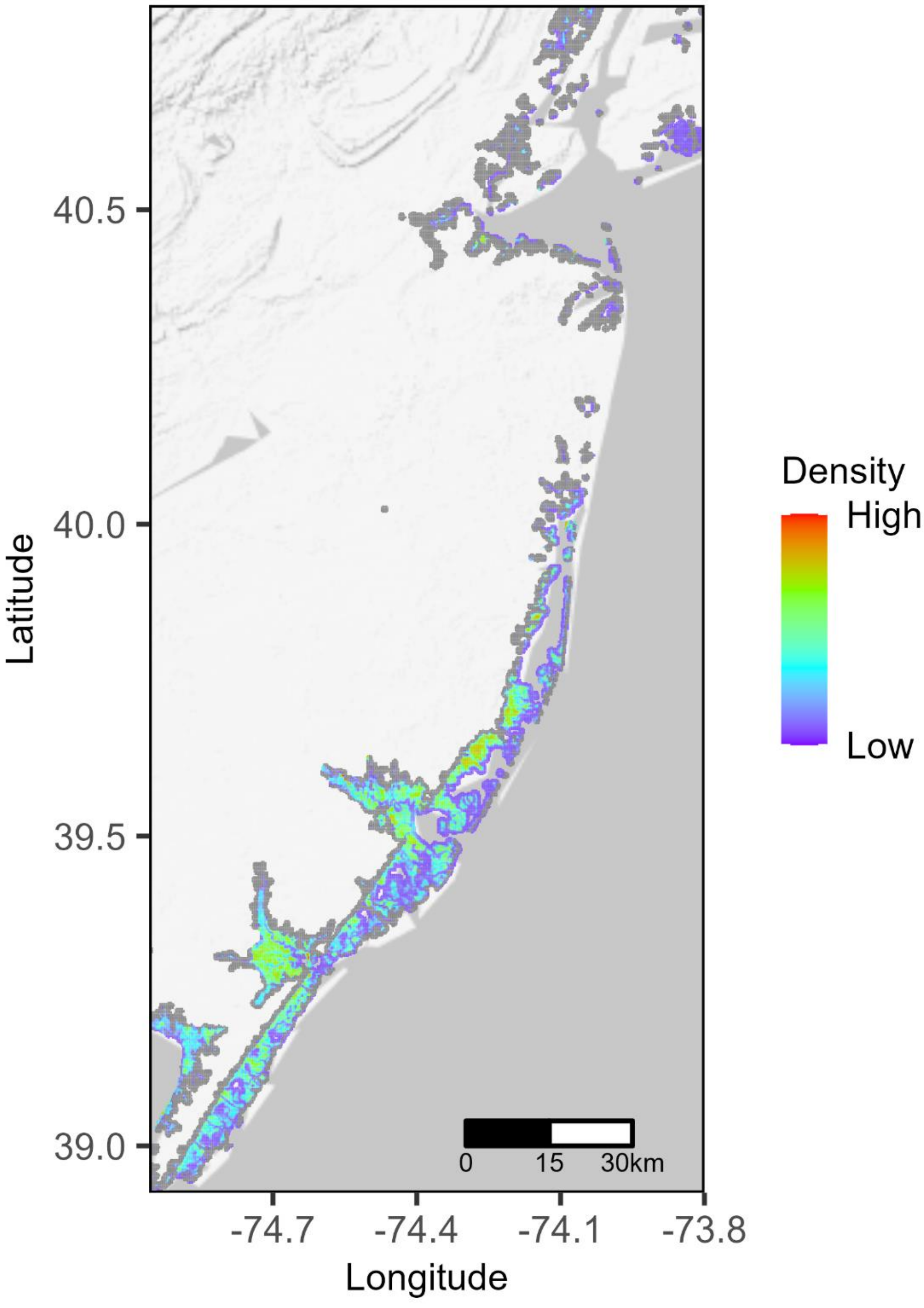

Figure 23. Predicted Saltmarsh Sparrow density in Coastal New Jersey based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

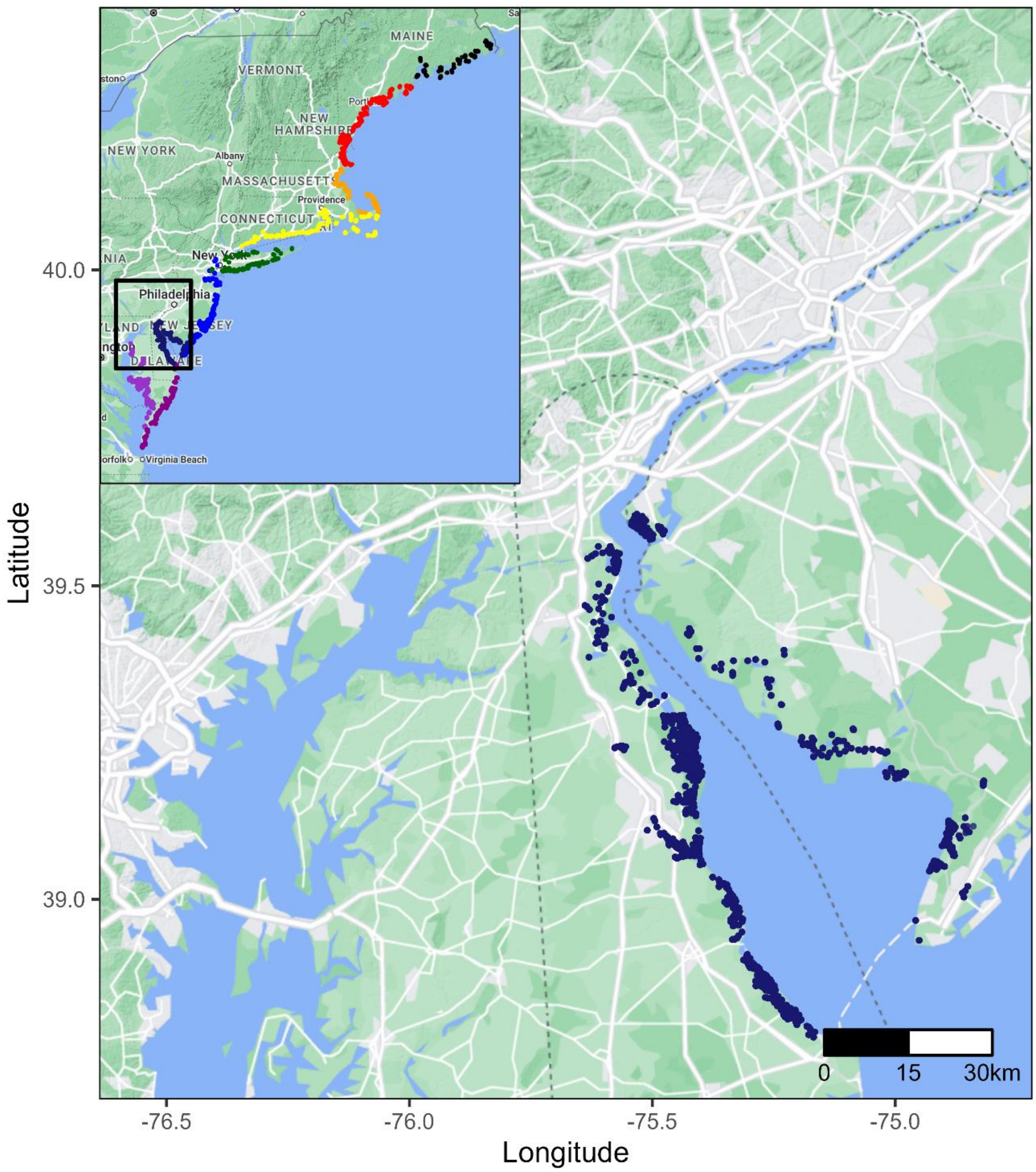

Figure 24. Study area and point count locations surveyed from 2011-2014 in Delaware Bay.

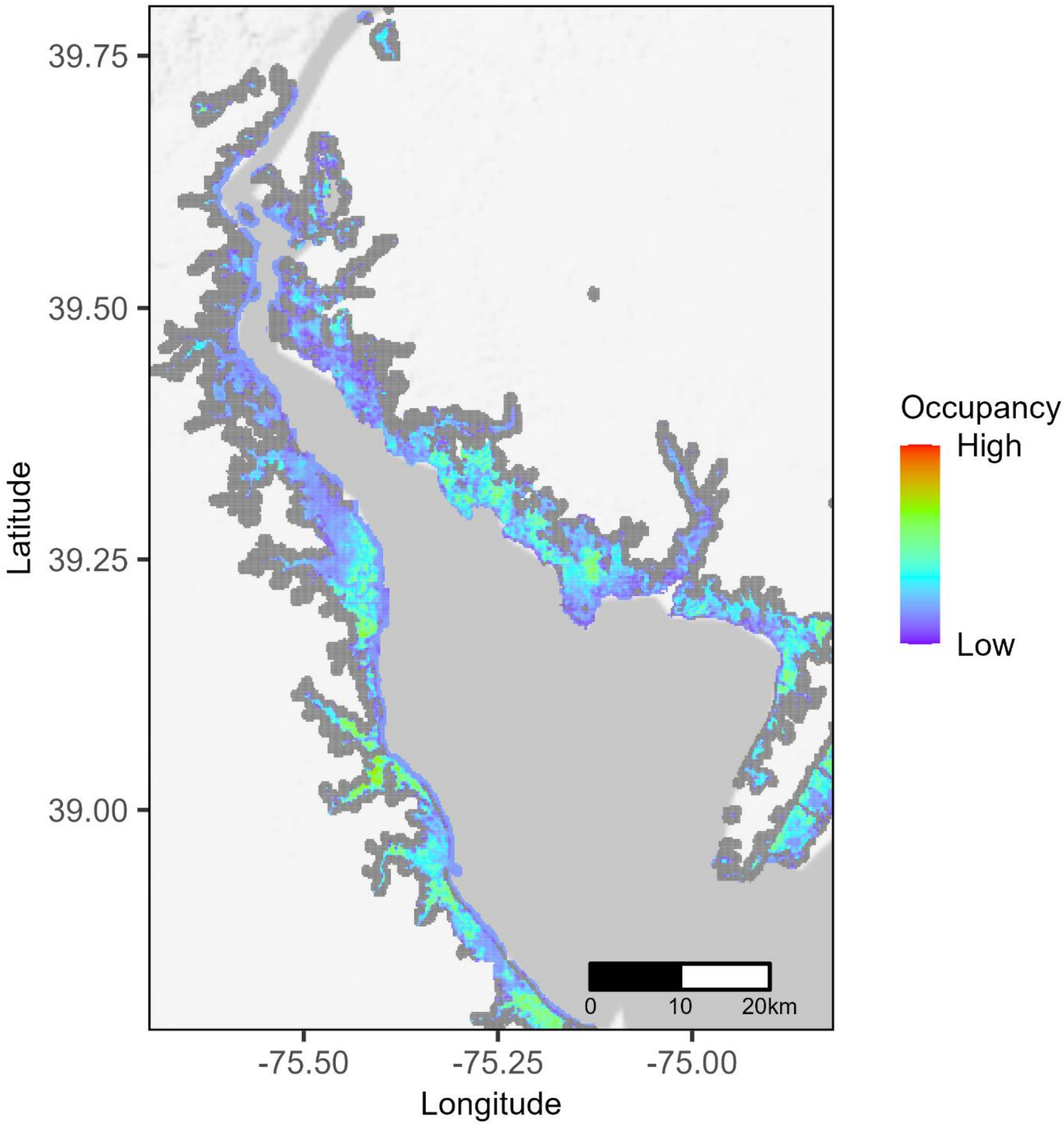

Figure 25. Predicted Saltmarsh Sparrow occupancy in Delaware Bay based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

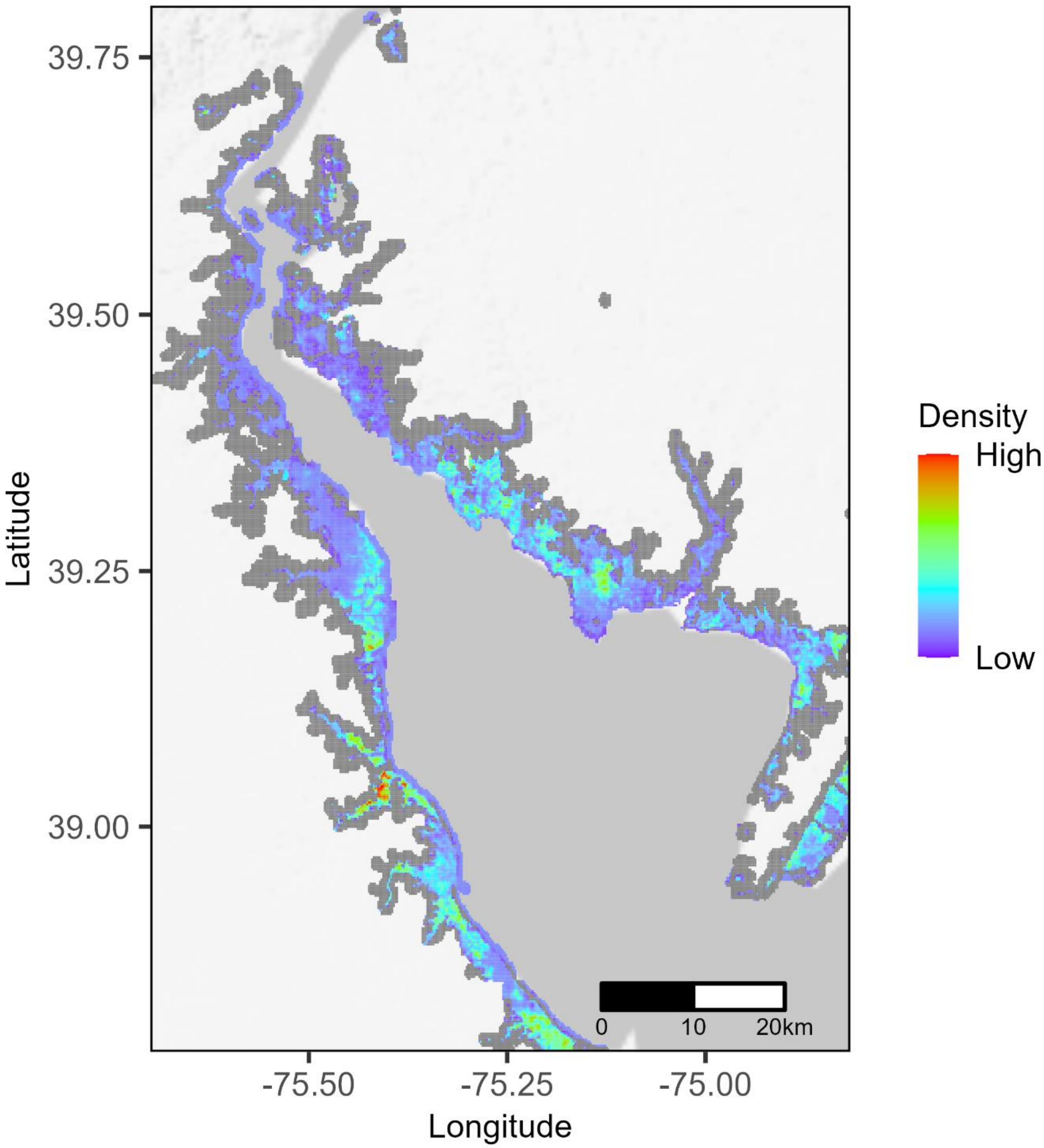

Figure 26. Predicted Saltmarsh Sparrow density in Delaware Bay based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

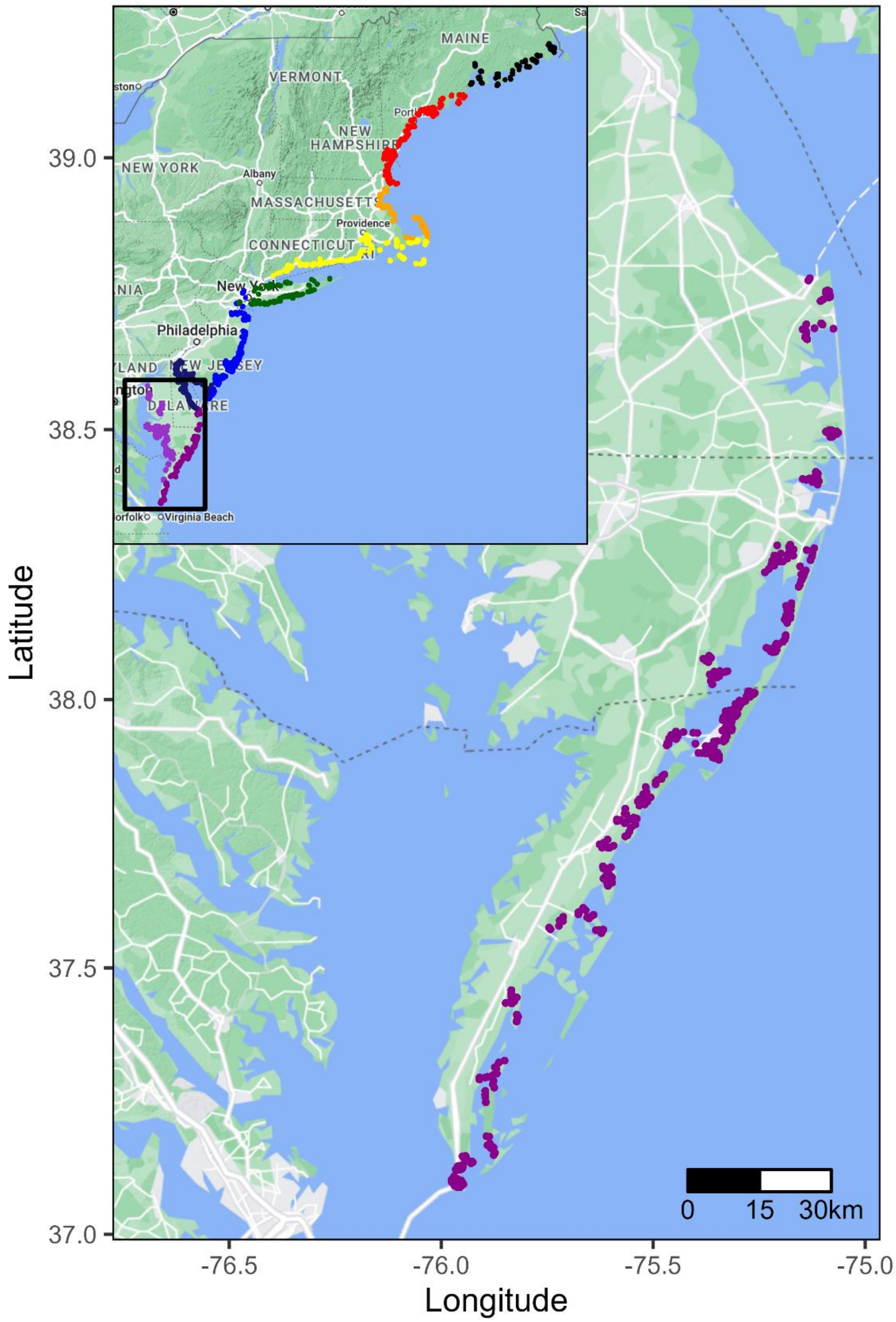

Figure 27. Study area and point count locations surveyed from 2011-2014 in Coastal Delmarva.

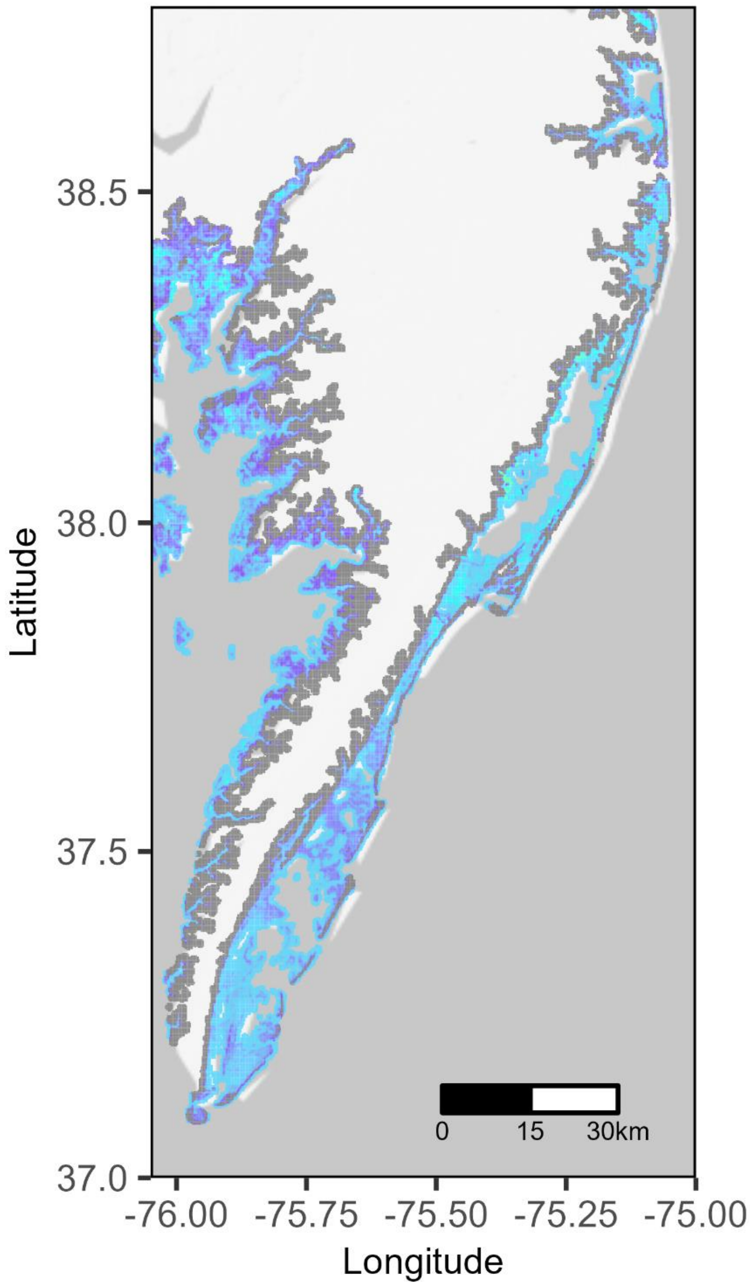

Figure 28. Predicted Saltmarsh Sparrow occupancy in Coastal Delmarva based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

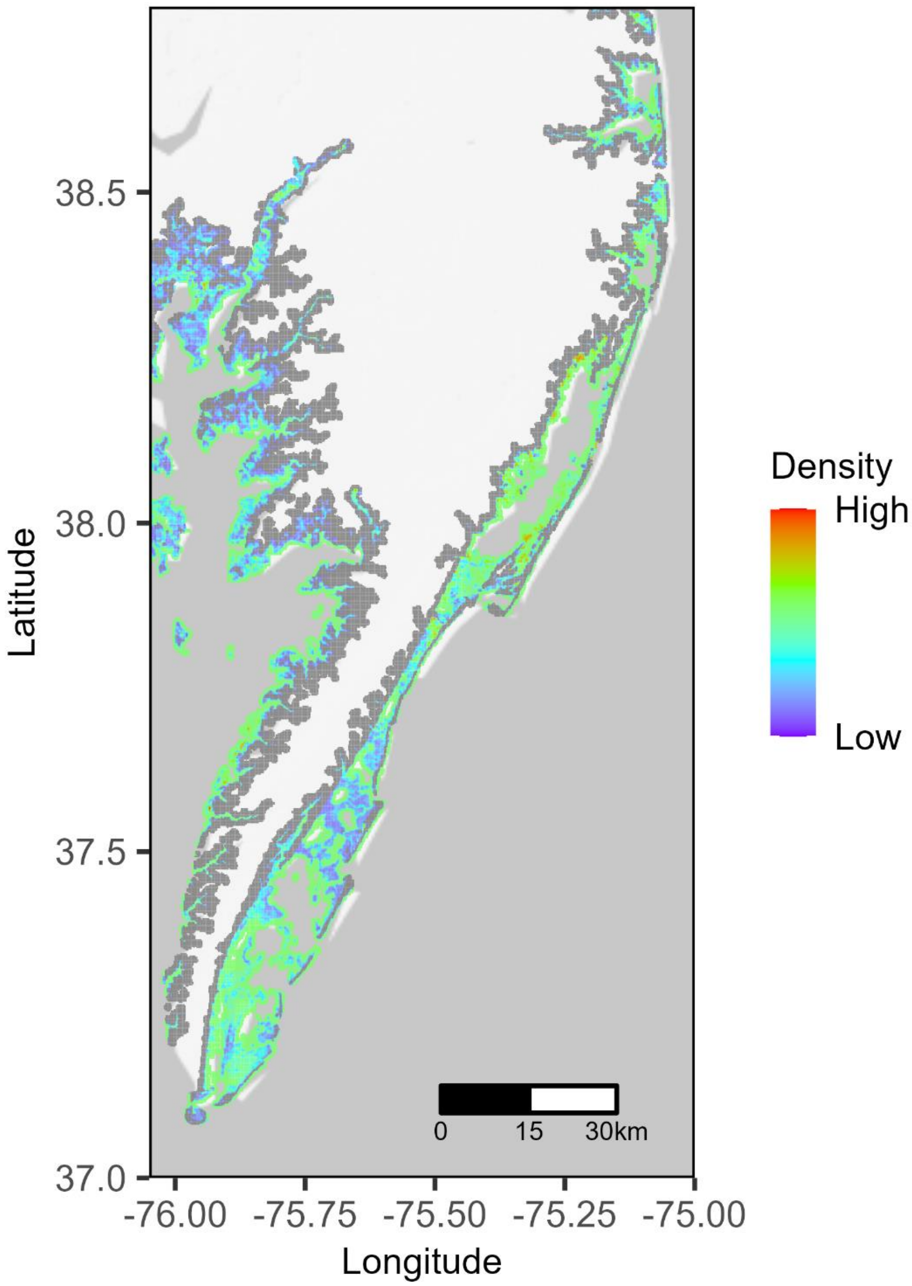

Figure 29. Predicted Saltmarsh Sparrow density in Coastal Delmarva based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

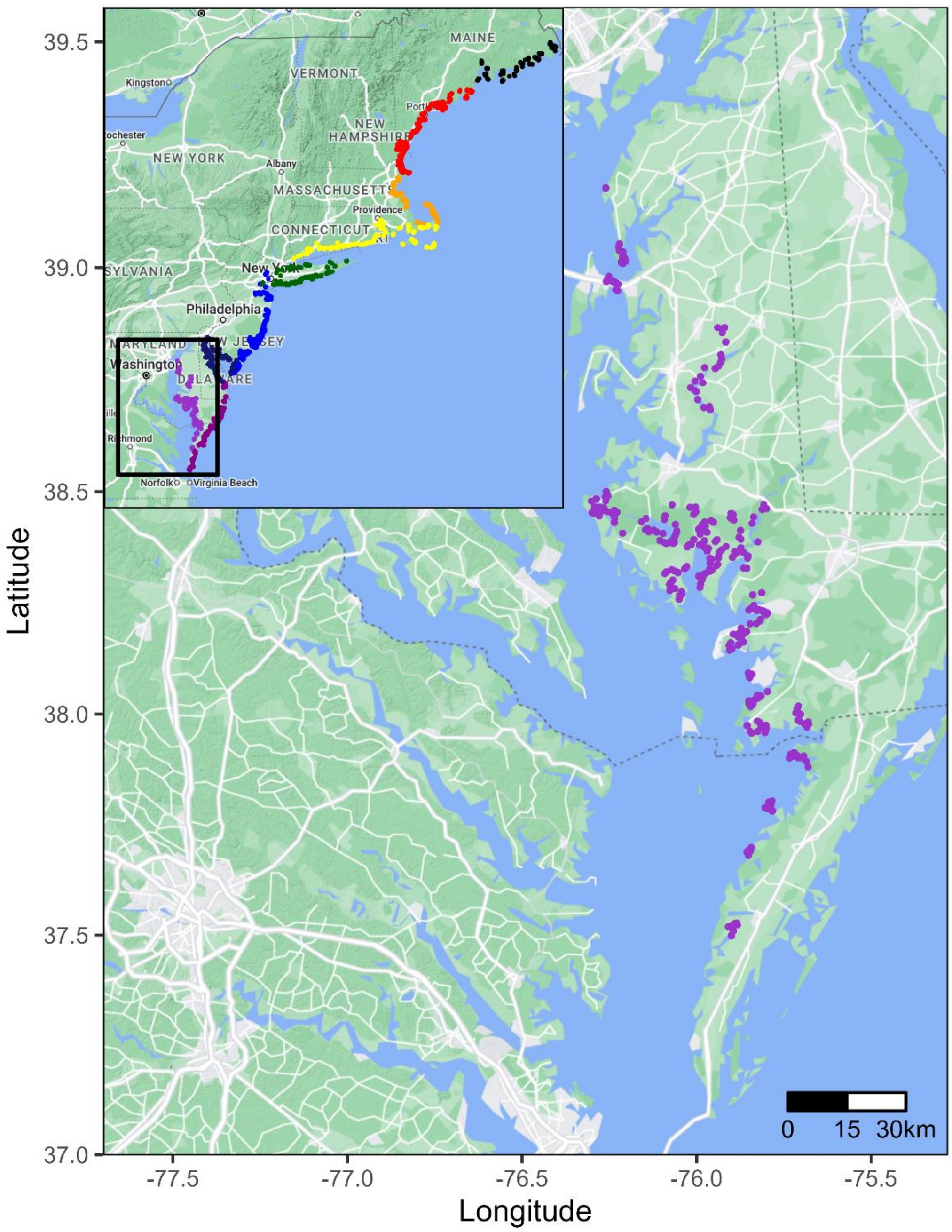

Figure 30. Study area and point count locations surveyed from 2011-2014 in Eastern Chesapeake Bay.

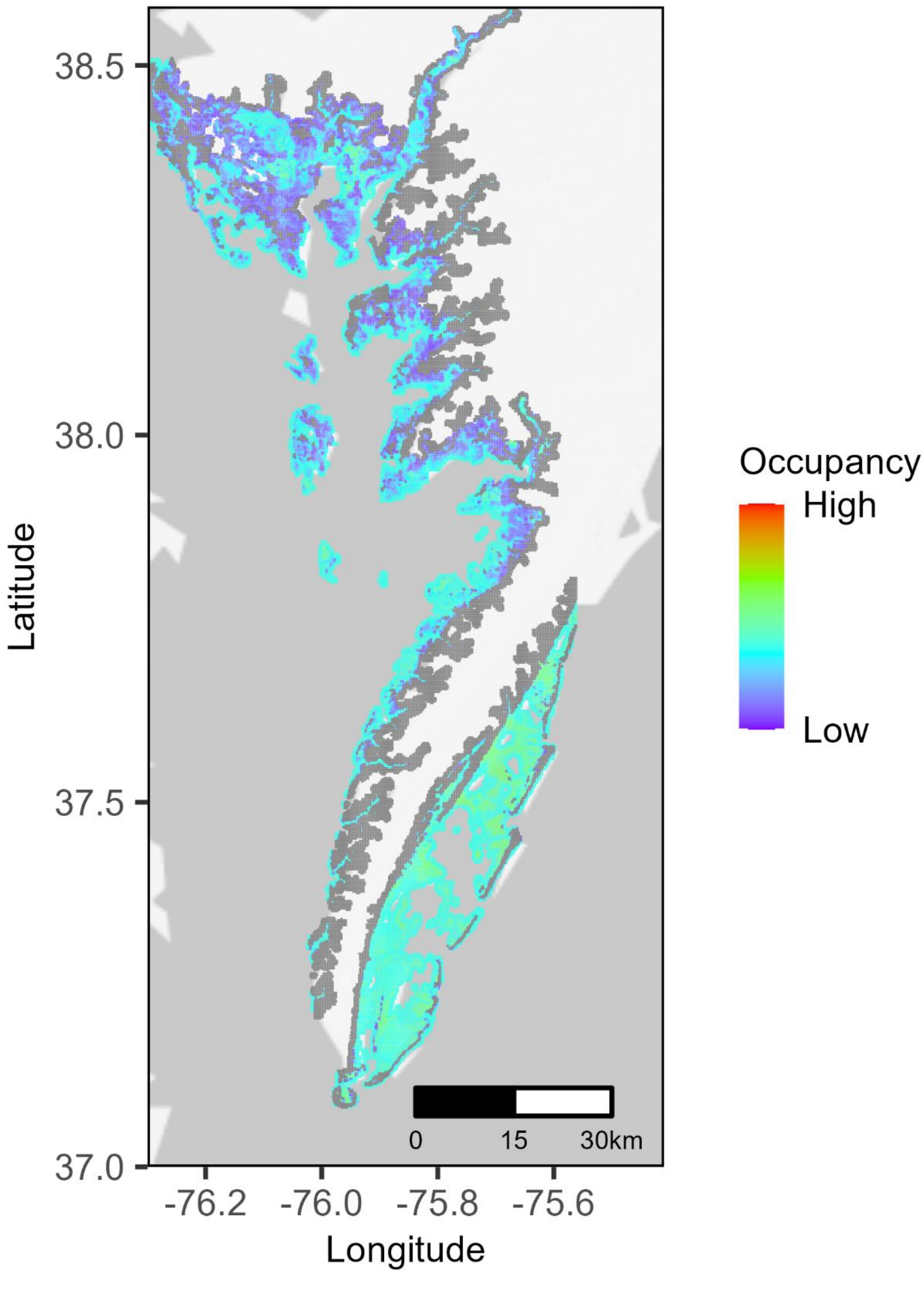

Figure 31. Predicted Saltmarsh Sparrow occupancy in Eastern Chesapeake Bay based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.

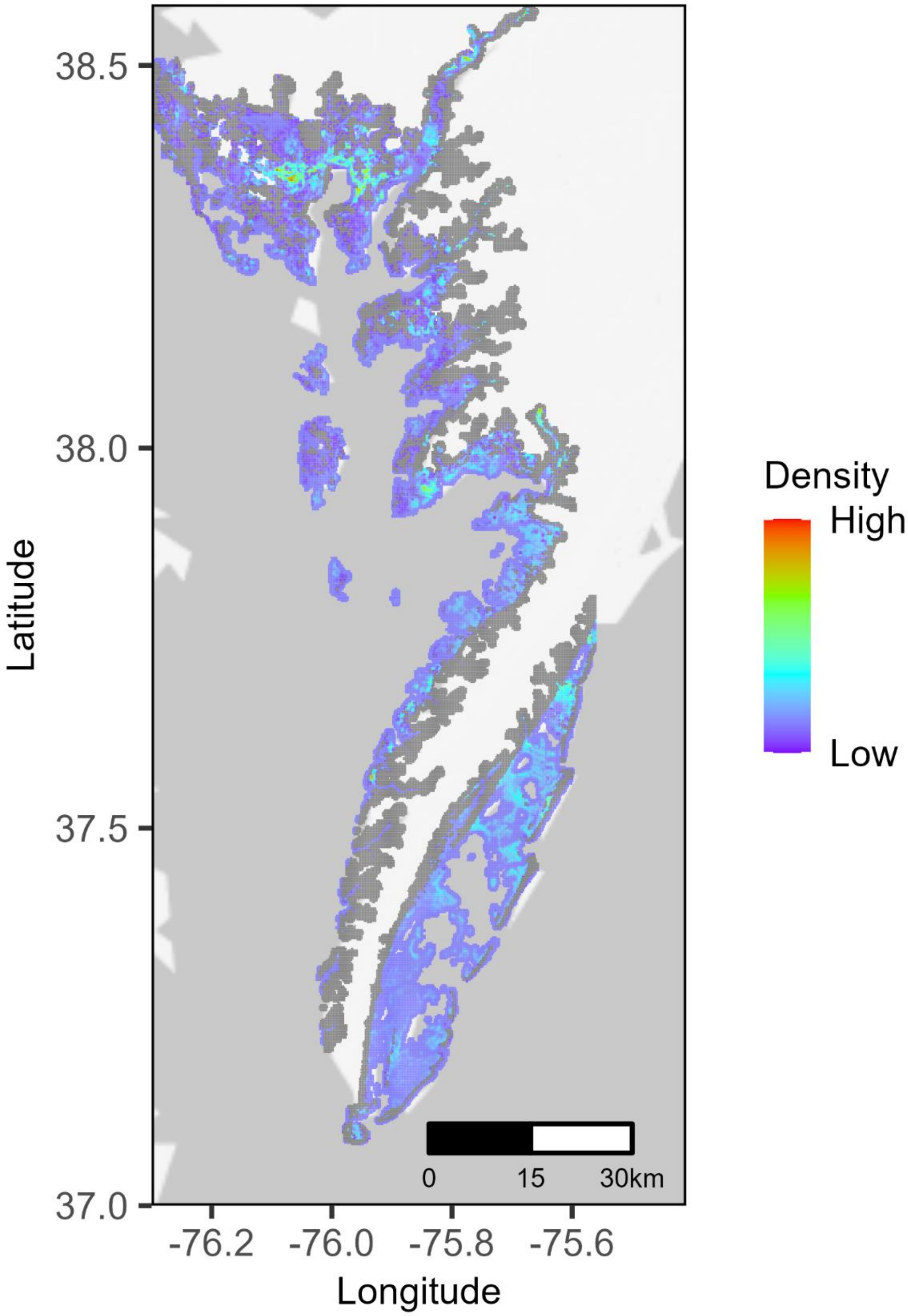

Figure 32. Predicted Saltmarsh Sparrow density in Eastern Chesapeake Bay based on survey data from 2011-2014. Cells with occupancy and density values < 0.05 are dark gray.