8.0 AVIAN PREDICTIVE MODEL

8.1 INTRODUCTION

Shipboard bird surveys are routinely used for mapping and to estimate density, spatial distribution, habitat use, predator-prey interactions and potential changes due to human disturbances and climate change (Veit et al. 1997; Fauchald et al. 2002; Hyrenbach and Veit 2003; Clarke et al. 2003; Reid et al. 2004; Certain et al. 2007; Karpouzi et al. 2007; Zador et al. 2008; Santora et al. 2009). The usefulness of these surveys is that observations and distribution data for a variety of bird species can be directly integrated with geo-spatial information (i.e., bathymetry, slope) providing a comprehensive look at the spatial ecology of marine birds (Wright and Begg 1997; Certain et al. 2007; Bailey and Thompson 2009; Santora et al. 2009). Herein, the objective of this section is to model bird density and determine the probability of bird occurrence in relation to time (i.e., season) and spatial distribution.

In conjunction with the NJDEP Ecological Baseline Study, spatial models for predicting changes in density and spatial distribution of birds were developed to identify important regions used by birds within the Study Area. The objective was to quantify where birds are most likely to concentrate in relation to geo-physical habitat features (e.g. depth [**Volume I: Figure 2-1**]; shoals [**Volume II: Figure 2-8**]) and predict where birds are likely to occur seasonally. Although prey distribution is important for understanding spatial distribution of marine birds (Wright and Begg 1997; Santora et al. 2009), they were not measured during these surveys and are not available at this time for modeling bird density; however, the response of birds to prey patches occurs generally at fine scales (e.g., <1 km [0.5 NM]) where feeding events are likely to occur. Our approach was to focus on broader scales (>1 km to 50 km [0.5 to 27.0 NM]) to predict where birds are most likely to concentrate within the Study Area.

The goal was to integrate two years of bimonthly shipboard surveys to estimate spatial variability of birds within the Study Area. The focus was on a variety of species (e.g., waterfowl, gulls, petrels) to examine species-specific distribution patterns. Strip-transect data collected during bi-monthly ship surveys within the Study Area were used to examine spatial variability in bird density, using spatial interpolation (e.g. kernel density), spatial regression and Generalized Additive Models (GAMs) to quantify the relationships between spatial covariates (e.g., bathymetric and distance based metrics) and bird density and spatial distribution.

Herein, results on species density estimates and high resolution map products along with spatial models are provided to examine the effect of spatial covariates on predicting changes in bird density and spatial distribution. The following questions are addressed in this section: (1) Where and when are birds (species) most likely to concentrate within the Study Area? (2) Are birds more or less concentrated evenly along the coast, or do some species exhibit specific spatial gradients (i.e., latitude/longitude variation)? (3) What is the relationship between bird density/distribution and depth, distance to shoreline, distance to shoals, and slope?

8.2 METHODOLOGY

A total of 13,250 km (7,154 NM) of avian strip transect survey data were collected over two years to estimate bird density (number/km^2) and distribution (monthly survey kilometer mean ± SD is 552 ± 252). Details of the survey protocol and summaries of the survey results (i.e. species composition) are located in **Chapter 2.0**. Briefly, bird density estimates (number/km^2) were calculated from standard strip-transect data by calculating the total number of birds (by species) divided by the total number of kilometers surveyed multiplied by the 300-m strip width. The observation dataset was filtered to include effort when the ship was transiting at≥7 kts, and for BSS ≤ 6. For more details on the survey methodology see **Section 2.1**.

8.2.1 Modeling Analysis

An overview of the statistical methodology is as follows: 1) bimonthly survey data was used to calculate density estimates (number/km^2) of birds (e.g., total birds, by species) 2) kernel density spatial interpolation was performed to grid bird density at un-sampled neighboring locations at seasonal scales to estimate bird probability density distributions, 3) data were stored in a GIS and grid cells were integrated with spatial covariates 4) using the seasonal gridded kernel density dataset, a series of spatially-explicit regression models were fitted to test whether spatial variability of bird density and distribution may be related to spatial covariates and 5) the effect of each spatial covariate were assessed for predicting changes in bird density.

8.2.1.1 Species Selection

The bird density variables selected for modeling are located in **Appendix M: Table M-1**. In addition to using total bird density, a variety of common species that represent a variety of avian life histories was selected. Northern Gannets were selected because they were abundant and widely distributed in the survey area and because they are the largest (body size) seabirds encountered. Northern Gannets also occur in dense flocks (i.e., gregarious) and perform plunge diving in pursuit of fish. Two species of diving ducks were modeled; Scoters and Long-tailed Ducks. These species are common in coastal waters in winter and often occur in dense aggregations near feeding locations. Herring Gull and Laughing Gulls were modeled to examine spatial distribution and habitat selection by local breeding gulls. The Common Tern was chosen to examine habitat selection by terns. Two species of loons (Common Loon and Red-throated Loon) were selected to examine difference in distribution of pursuit diving fish consumers. Lastly, spatial distribution patterns of two tube-nosed seabirds were examined: Wilson's Storm Petrel and Cory's Shearwater which are seasonal summer visitors in New Jersey waters.

8.2.1.2 Description and Derivation of Spatial Covariates

All avian density estimates were imported into ArcView 9.3 for spatial analysis. Six spatial covariates were derived to link with bird density observations. These included latitude and longitude, water depth (m), slope (degrees), distance to shoreline (feet) and distance to nearest shoal (feet). To derive the distance from shore the Point Distance geo-processing tool available in ESRI's Arc/Info® Toolbox 9.3 GIS software was used to measure the kernel density points to the coast of New Jersey. Distance from shoals was generated by the same process. Depth and slope for the kernel density points were derived using the Zonal Statistics function from ESRI's Spatial Analysis toolbox. The function compared each kernel location to a bathymetry and slope estimate and assigned the grid a value. Frequency histograms for spatial covariates are provided in **Appendix M: Figures M-1** through **M-6**.

The correlation matrix (Pearson product moment correlation coefficient) shows the relationship between derived covariates included in the modeling of bird density and distribution (**Table 8-1**). There is correlation ($p<0.001$; Zar 1999) between derived spatial covariates estimated from the observed sampling locations of bird density. This is to be expected when moving offshore or there is a strong negative relationship between depth and distance from shoreline. Moreover, the relationship between distance to shoal and slope indicates that as slope decreased, the distance to the nearest shoal decreased, indicating the movement toward shallow locations offshore the New Jersey coast.

Table 8-1. Relation between the covariates selected for modeling.

Spatial Covariate	Slope	Distance to Shoal	Depth	Distance to Shoreline
Slope	1			
Distance to shoal	-0.1485	1		
Depth	0.2229	-0.2736	1	
Distance to shoreline	-0.1082	0.2311	-0.8661	1

8.2.1.3 Geo-statistical Interpolation: Kernel Density Mapping

Kernel density spatial interpolation was used to estimate probability distribution maps for gridding bird density (number/km^2) by month and season. The kernel density (smoothing) spatial interpolation method is a non-parametric (e.g., distribution-free) method of discerning structure or relationships in the data, by estimating the probability density function of a random variable. Kernel density estimation, like any spatial interpolation method, involves estimating an attribute value (e.g., avian density) at an un-sampled site given measurements at neighboring sampled sites. An algorithm is used that incorporates a weighting function that prescribed relative contributions of individual sampled values as a function of the distance between the un-sampled and sampled sites.

The kernel density method operates on the premise that spatial autocorrelation between two points decreases (e.g., their semi-variance increases) asymptotically as their separation distance increases. For example, in the estimation of bird density at a given un-sampled site, bird count data at neighboring sites that are very close to the un-sampled site are given more weight than data at neighboring sites that are a further distance away (as parameterized by the kernel function K). Bird densities generated at each un-sampled site are estimates rather than exact values, since interpolation is required. The standard error in the estimates at a given un-sampled site generally varies directly with the magnitude of the spatial gradient (difference) in observed values in proximity to that site. The presence of anomalies can skew the data, introducing inaccuracies in the interpolation process.

The kernel density method disperses the mass of each observation around the observed value, with the amount of dispersion being governed by the kernel function K and bandwidth h (i.e., the smoothing parameter). The kernel function K is typically symmetric, such that the point mass is dispersed equally toward higher and lower values (Burt and Barber 1996). For example, narrow kernels (small h) concentrate mass more tightly around the central (observed) values than wide kernels (large h). The h value also governs the amount of detail in the estimated point density function g (x,y) and probability density function f (x,y): A large h value generates a broad, smooth density function with little fine structure, whereas a small h value generates a narrow density function with fine-scale variability.

Fine-scale variability is resolved using spatial modeling methods such as kernel density (with an appropriate bandwidth in the kernel function), which spreads the mass (e.g., abundances or counts) of each observation around the central (observed) value. The kernel function is a spatially decreasing function of distance (between the un-sampled site and a neighboring sampled site), such that the relative contribution (or weight) of each sampled site (i.e., longitude-latitude [lon-lat] location of the observed abundance) to the estimate at the un-sampled site (i.e., central lon-lat location of a grid-point) correlates negatively (inversely) with their separation distance. Generally, as separation distance increases, the degree of spatial autocorrelation decreases toward zero (and semi-variance increases asymptotically). To obtain the estimate of abundance at the un-sampled site (grid-point), the kernel values are summed over the number of neighboring sampled sites; and this process is repeated until estimates at all un-sampled sites are obtained, generating a spatial representation of the variation in the estimates.

The kernel function, modulated by the bandwidth (h) parameter, governs the degree of dispersion (spread) around the central value in a typically symmetric fashion, with relatively equal spreads toward higher and lower values. The kernel width is adjusted by the h parameter, which governs the degree of dispersion (rate of drop-off) of mass around the central value and hence the amount of spatial detail in the estimates. Narrow kernels (small h) concentrate the mass tightly around the central point, with a rapid decline in mass with increasing distance from the central point. Wider kernels (larger h) provide more dispersion or smearing.

The optimal choice of h to use in kernel density analysis depends on the underlying structure and variability in the observational data (i.e., spatial distribution of the avian sightings and measured abundances or counts). For example, if large changes in abundances are observed over small spatial scales, a large h value is recommended in order to smooth out small-scale fluctuations. Otherwise, wildly fluctuating, unrealistic estimates may be generated at nearby un-sampled sites during the interpolation process. On the other hand, if only small variations in abundances are observed over large distances, then a small h value is recommended in order to capture small-scale variability in the data.

For a sample size n, point density g(x,y; e.g., bird density) at an un-sampled site (x,y; e.g., lon-lat location) is estimated by summing the kernel values $K(d_i/h)$ of all n data points or neighboring sampled sites around the un-sampled site (Burt and Barber 1996):

$$g(x,y) = (1/h^2)*SUM[K(d_i/h)]$$

and probability density f(x,y) is given by: f(x,y) = g(x,y)/n, where d_i = spatial distance between the un-sampled site and sampled site "i"; n = number of neighboring sampled sites (in the vicinity of the un-sampled site); h = bandwidth or smoothing parameter; K is the kernel weighting function that generally decreases with increasing distance between the un-sampled and sampled sites. For example, a normal kernel is given by:

$$K(d_i/h) = ([1/(2*pi)]^{0.5})*exp[-0.5*(d_i/h)^2]$$

where pi=3.1415927. This function describes a Gaussian normal curve with a maximum value of $(1/[2*pi])^{0.5}$ at zero distance (d_i=0) and decreases with increasing distance d_i. The rate of decrease in K with increasing d_i is governed by the value of h: As h decreases, the rate of drop-off becomes more rapid, effectively concentrating the mass more tightly around the central (observed) value. The summation in the above equation for g(x,y) is conducted over the number of neighboring sampled sites n around the un-sampled site.

For the bird count data collected on the coastal and offshore surveys, the sampled sites are the lon-lat locations at which bird count data were collected; and the un-sampled sites are the 100 grid-points in the above-mentioned regular lon-lat grid system.

The Gaussian kernel estimator for point location data (Silverman 1986) was modified for continuous data by multiplying values of bird density (the continuous variable) by kernel weights and computing a weighted average:

$$\hat{\mu}(y \mid x) = \frac{\sum_{i=1}^{n} w(x, X_i, h) y_i}{\sum_{i=1}^{n} w(x, X_i, h)}$$

where y_i is the observed density (birds per square kilometer per visit) for each sub-segment represented by the coordinate pair X_i, $\hat{\mu}(y \mid x)$ is the estimated mean density at grid location x, h is the bandwidth or smoothing parameter, and

$$w(x, X_i, h) = exp\left[-\frac{1}{2h^2}(x - X_i)^T (x - X_i)\right]$$

where $(x – X_i)$ is a vector of length n. In vector notation, the superscript "T" denotes transpose of the vector, such that $(x – X_i)$ is a vector with n rows and 1 column, whereas $(x – X_i)^T$ is the transposed vector with 1 row and n columns. The pre-multiplication of the vector $(x – X_i)$ by its transpose results in a scalar (Bailey and Gatrell 1995). The smoothing parameter h dictates the degree of smoothing. The weighted average, $\hat{\mu}(y \mid x)$, was computed at each intersection of a longitude-latitude regular grid.

General assumptions made in the kernel density spatial interpolation analysis include:

1) Only birds observed within 300 m (984.3 ft) of the observer (in-zone observations), and only those data that were collected with vessel speeds greater than 7 kts (8.1 mph) were included in the analysis.

2) Given the observation date and time as well as the starting/ending times and starting/ending lon-lat locations of each transect on which the given observation occurred was identified. Then, to a first order approximation, the lon-lat locations were interpolated with respect to the times to estimate the lon-lat location of the observation.

3) Given the range, heading, and lon-lat location of the observation (e.g., observer location), the approximate location (in longitude-latitude coordinates) of the actual bird(s) was calculated. The accuracy of this value may vary, and the variability may be high if the magnitude of the ship's spatial deviation from the trackline is on the order of the range of the observation.

Given these assumptions, the ship and boat transect survey data were combined with GPS lon-lat information to generate spatial density maps using the kernel density spatial interpolation method. Input data for this method includes measured avian abundance (bird counts, z) collected at sampled lon-lat locations (x, y). The abundance data were spatially interpolated to obtain estimates of bird density (number/km^2) at un-sampled sites positioned on a regular lon-lat grid system.

To obtain a uniform spatial representation of estimates in kernel density analysis, a regular lon-lat grid system is often used; and estimates are obtained at each grid point on the grid. Spatial resolution can be enhanced with a finer regular grid (by decreasing the spacing interval between adjacent grid points). A 1-km (0.5-NM) grid system with 8,364 total grid points (82 longitude values by 102 latitude values) was adopted. Each grid-point represents an un-sampled site, and estimates of density/abundance at each site were generated by calculating a kernel function (modulated by bandwidth h) based on observed counts at neighboring sampled sites (i.e., lon-lat locations along transects passing in proximity to the grid-point), with the degree of weighting being inversely related to the separation distance between the grid-point and observation location.

The top five most abundant species (for all-behavior and sitting birds) for the 23 months, nine seasons, two years, and overall periods of the two-year survey are listed in **Appendix M: Table M-44**. Abundance, density, and bandwidth (dispersion factor) h are summarized for each species. Optimal values of h used in the kernel density analysis for each species and time period are also summarized in **Appendix M: Table M-44**.

8.2.1.4 Spatial Regression and Generalized Additive Models

Two complementary modeling techniques were used to measure the influence of spatial covariates on bird density within the Study Area. Spatial regression and GAMs are particularly useful for examining the response of predator density at sea in relation to environmental covariates (Wright and Begg 1997; Clarke et al. 2003; Certain et al. 2007; Zador et al. 2008; Bailey and Thompson 2009; Santora et al. 2009). These models have been used extensively to examine and predict the response of organisms to environmental variability (Gustafson 1998; Guisan and Zimmerman 2000; Austin 2002; Ferrier et al. 2002; Dormann et al. 2007), including amphibians (Araújo et al. 2006) marine mammals (Redfern et al 2006; Bailey and Thompson 2009) and in fisheries research (Daskalov 1999; Stoner et al. 2001; Denis et al. 2002; Venables and Dichmont 2004; Jensen et al. 2005). Available models for investigating the spatial distribution patterns of species were carefully reviewed and considered based on Legendre and Legendre (1998), Austin (2002) and Dormann et al. (2007).

8.2.1.5 Spatial Regression Models

A spatially-explicit regression model was used to account for effects of spatial autocorrelation (Feguson and Bester 2002; Tobin and Bjørnstad 2003; Wintle and Bardos 2006) and to assess the contribution of covariates on predicting changes in bird aggregations in space and time (Anselin et al. 2006; Dormann et al. 2007; Santora et al. 2009). The objective of the spatial regression model is to test whether spatial autocorrelation of bird aggregations might be explained by spatial covariates. That is, do covariates influence the spatial variability and clustering of bird aggregations? A weighted spatial average was computed across all seasons and years based on the gridded kernel density estimates. The resulting matrix of bird density values at each location was used to model the probable effect of spatial covariates on bird density. In addition, the Global Moran's I value was calculated (Anselin et al. 2006) to estimate the degree of aggregation (i.e., clumping) of birds in the study region. The Global Moran's I test is a straightforward test of spatial randomness (Getis and Ord 1992; Anselin 1995; Ord and Getis 1995) and is basically a spatially-explicit correlation coefficient that is based on the relationship between bird density values and a spatial weights matrix estimated by Euclidean distance between all sampling locations (i.e., grid points). A positive Moran's I index indicates tendency toward clustering while a negative Moran's I index value indicates tendency toward dispersion.

Spatial regression models are similar to generalized linear models, except they have spatially explicit parameters to account for both autocorrelation and spatial dependency (Anselin et al. 2006; Ferguson and Bester 2002). A spatial lag model was used (Anselin et al. 2006; GeoDaS Software) with Maximum Likelihood Estimation (Legendre and Legendre 1998; Burnham and Anderson 2002) to investigate the spatial dependency of bird density on spatial covariates. The model is:

$$Y = \rho Wy + Xi\beta + \varepsilon$$

where Y is bird density (per km^2), Xi is the covariate (i.e., latitude, longitude, depth, slope, distance metric), β is a regression coefficient, and ε is a random error term that is identically and independently distributed. The model has spatial lag components, ρ a spatial autoregressive coefficient, and Wy, a spatially varying lag term. The spatial lag model takes into account whether bird density (Y) in location i is affected by the covariates in both place i and j. That is, events in one place may predict an increased likelihood of similar events in neighboring places. The modeling procedure first fits the spatial lag component, based on a Euclidean distance weight matrix from the sampling locations, and then seeks to fit covariates using Maximum Likelihood Estimation (Burnham and Anderson 2002).

8.2.1.6 Generalized Additive Models (GAMs)

The power of GAMs is in their flexibility to combine model selection with nonparametric smoothers to examine the influence and shape of explanatory variables for predicting changes in the response variable (Hastie and Tibshirani 1990; Barry and Welsh 2002; Wood and Augustin 2002; Venables and Dichmont 2004). GAMs were used to model bird density in relation to spatial covariates (**Table M-1**). The general form of the GAMs is given by (Hastie and Tibshirani 1990):

$$E[y] = g^{-1}(\beta_0 + \sum_k S_k(x_k))$$

where E[y] is the expected value E of the response of a random variable y (bird density), g() is the link function (e.g., identity, logarithmic, exponential) defining the relationship between the response variable y and the additive predictor ($\beta_0 + \sum_k S_k(x_k)$), β_0 is an intercept term, x_k is the value of the kth spatial covariate, and $S_k()$ represents smooth functions of the k covariates. GAMs were fitted with an identity link function and Gaussian error distribution with spatial smoothed covariate terms as a cubic spline s.

Terms specified by smoothing functions are broken down into a single degree of freedom for the linear component and the remainder for the nonparametric component. A simultaneous scoring test is performed for all terms, where the nonparametric component is set to zero and the linear element is updated, while holding all other nonparametric terms fixed (Hastie and Tibshirani 1990).

GAMs were fitted using the statistical program R using the GAM package (R core development team 2008). The GAM including smoothed covariates for predicting changes in bird density is:

$$Density \sim s(Depth) + s(Slope) + s(DistShore) + s(DistShoal) + s(Lon) + s(Lat)$$

where s(x) is a univariate cubic smoothing function of covariate "x" (see **Table M-1** for spatial covariates). For example, $s(x) = a_o + a_1{*}x + a_2{*}x^2 + a_3{*}x^3$. Year and season factor terms were included in the model where applicable (i.e. for certain seasonal species). These terms were not included in the model when species were present only in one year or season.

8.2.2 Model Validation, Evaluation, and Selection Criteria

Backward stepwise selection and Akaike's Information Criterion (AIC) minimization were used to perform model selection for continuous spatial covariates (Hastie and Tibshirani 1990; Barry and Welsh 2002; Wood and Augustin 2002; Venables and Dichmont 2004). The objective of this method is to begin with the initial fully functional model (with all terms included), and then sequentially remove model terms one at a time from the original formula to attempt to achieve a better model fit. The AIC is first computed for the initial model, and then N candidate models are generated, where N equals the number of terms in the current model. Each of the N candidate models has one less term than the original model. In each subsequent step, a single term is dropped from the initial model and the AIC is computed for each model. The model that provides the greatest reduction in AIC is selected as the best model. The significance values are presented for the smoothed spatial covariates in the initial model and the final selected model in tables for each bird variable. The output of the GAMs are tables listing the model AIC and the probability level for each covariate. The initial (global) model and the selected model are reported.

To examine the effect of each spatial covariate in the GAM, the fitted contribution of each spatial covariate on bird density was plotted against the value of the covariate (Hastie and Tibshirani 1990; Barry and Welsh 2002; Wood and Augustin 2002; Venables and Dichmont 2004). Covariates that had an effect were plotted and were selected by stepwise selection criteria using AIC minimization. The 95% CIs are plotted around the best fitted 'smooths' for the main effects. The y-axis reflects the relative effect of each covariate on bird density. The x-axis shows the density of points (i.e. rug plot) for each covariate included in the model. Importantly, the "conditional effect" of each variable is the effect of the particular covariate, given the presence of the other variables in the best fit model, based on the backward stepwise section criteria. The GAM 'effect plots' of covariates on bird density are useful because the change in bird density can be directly compared to the exact value of the covariate. These plots were used to identify the magnitude of change and range in bird density and distribution in relation to each spatial covariate selected in the final GAM. We classified the effect (partial effect of covariate X on bird density) against distance to shoreline by determining the range of successive positive values before the effect became negative (i.e. crossing the zero on the y-axis). For example, for the covariate distance to shoreline (measured in feet), we determined if there was an effective positive range on bird density by identifying the maximum range point where the effect approximately became negative (i.e. below zero on the y-axis).

The effect of each covariate on bird density was characterized as either positive '+', negative '-', or mixed/curvilinear '+/-'(**Table M-3**). For example, if depth was found to be a positive contributor to bird density, then it was concluded that bird density increased in deeper waters. In addition, if distance to shoreline was found to be a negative contributor to bird density, then it was concluded that bird density increased with proximity (closeness) to the coastline. The outline of these results is summarized in **Table M-4**.

8.3 RESULTS

General additive, spatial regression and kernel density methods were used to model the avian shipboard and coastal survey data. Supporting data for general additive and spatial regression models can be found in **Appendix M** (**Tables M-5** through **M-43** and **Figures M-1** through **M-113**). Kernel density spatial maps are shown **in Appendix M: Figures M-114** to **M-532**.

8.3.1 Estimation of Avian Density and Distribution: Kernel Density Interpolation

All density data is reported as the number of birds/km^2. The following discussion of kernel density spatial analysis results is divided into following sections:

> **Seasonal Analysis:** Each species is discussed separately one at a time based on the seasons in which the given species is among the top five most abundant (both all-behavior and sitting birds).

Total-Birds: Seasonal Analysis and Total Birds: Annual and Overall Cumulative Analyses: Total-bird results are discussed first according to season, and then according to an annual (2008, 2009) and overall cumulative two-year analysis.

Annual Analysis: Following the annual analysis of the Total-birds, the top five most abundant species in each year (2008, 2009) and the two-year period are discussed, in the context of the component species that partially (though not completely, since Total-birds encompasses ALL birds, not just the top five most abundant) contribute to the annual results for the Total-birds.

Spatial Analysis: Spatial gradients are discussed in terms of variations in the magnitude and distribution of densities (number/km^2) in the onshore-offshore direction and in the north-south direction. Nearshore (coastal) variations are discussed in terms of proximity to coastal cities (e.g., Ocean City, Atlantic City) and to bays and inlets (e.g., Barnegat Bay in the north, Great Egg Harbor Bay in the central region, Hereford Inlet in the south). The term "nearshore" refers to regions within approximately 5 km (2.7 NM) of the coastline, and the "offshore" region extends from 5 km (2.7 NM) to the outer limit of the Study Area (approximately 37 km [20 NM] away from the coast). This offshore region is divided into two sub-regions: "midshore", extending from 5 km (2.7 NM) to approximately midway within the offshore region; and "far-offshore", extending from this midway point to the outer limit of the Study Area.

The kernel density figures are organized into eight broad categories as follows:

- M-114 to M-251: Monthly Maps – All-Behavior Birds
- M-252 to M-388: Monthly Maps – Sitting Birds
- M-389 to M-442: Seasonal Maps – All-Behavior Birds
- M-443 to M-496: Seasonal Maps – Sitting Birds
- M-497 to M-508: Annual Maps – All-Behavior Birds
- M-509 to M-520: Annual Maps – Sitting Birds
- M-521 to M-526: Overall Maps – All-Behavior Birds
- M-527 to M-532: Overall Maps – Sitting Birds

8.3.1.1 Seasonal Analysis

The monthly components for each season of the two-year survey period are: winter 2008 (January and February); spring 2008 (March, April, and May); summer 2008 (June and July 2008); fall 2008 (August, September, October, and November); winter 2009 (December 2008, January and February 2009); spring 2009 (March, April, and May); summer 2009 (02 June [no surveys in July); fall 2009 (August, September, October, and November); and winter 2010 (December 2009).

Species abundances for each season are calculated by combining the abundances in each month comprising the given species. Likewise, annual abundances are calculated by combining the abundances over all of the months in the given year. Some similarities in the identities of the top five most abundant species are noted among a given season and its composite months, since each month provides a weighted contribution to seasonal totals; however, it is noted that some differences may arise in the identities of the top five most abundant species between the season and the composite months. For example, if a certain species is highly abundant in one month but virtually absent in the other two months comprising a given season, it's possible that this species may be ranked Number 1 in its abundant month but not rank in the top five in its season, particularly if other species are moderately abundant in all three months so as to displace the given species due to higher cumulative seasonal abundances. On the other hand, it is possible for a given species to be ranked in the top five seasonal list while not ranked in the top five in any of the component months. For example, this species may be ranked Number 6 in each of the months comprising the season, while species ahead of it in any one month may have very low abundances in the other months, thus enabling the given species to displace them and rank in the top five for the season.

Because of the extensive number of spatial maps, the following discussion is restricted to the seasonal, annual, and overall (cumulative two-year) analysis of results (**Appendix M: Figures M-389** to **M-532**). For individual monthly results, the reader is referred to **Appendix M: Figures M-114** to **M-388**, while recognizing the specific individual months comprising each season.

The following species are analyzed separately according to the seasons in which the given species is among the five most abundant (**Appendix M: Table M-44**).

- Scoter: winter 2008, spring 2008, fall 2008, winter 2009, spring 2009, fall 2009, and winter 2010 (all-behavior); winter 2008, spring 2008, winter 2009, spring 2009, and winter 2010 (sitting; **Appendix M: Figures M-389, M-395, M-408, M-413, M-419, M-434, M-437, M-444, M-449, M-467, M-473,** and **M-491**).

Scoters comprise the individual species, Black Scoter, Surf Scoter, White-winged Scoter, and Dark-winged Scoter (Black Scoter and/or Surf Scoter).

In winter 2008, elevated Scoter densities occurred in a small coastal region between Atlantic City and Brigantine, with a maximum of 475. Moderate densities on the order of 25 occurred in the coastal region both north (from Brigantine to Little Egg Inlet) and south (from Ocean City to midway between Ocean City and Hereford Inlet) of the maximum. In comparison, two years later, in winter 2010, Scoter maximum density migrated slightly northward along the coast, to between Brigantine and Little Egg Inlet, and decreased in magnitude from 475 to 115. A sub-maximum occurred just off the coast of Brigantine, and moderate densities on the order of 25 to 50 occurred along most of the entire coastline. In both winter seasons, Scoter density was lower offshore than nearshore. Spatial variability was detected throughout the offshore region. In the intervening winter season, winter 2009, Scoter densities were relatively more abundant, with numerous density maxima occurring nearshore along most of the coastline, including Barnegat Light (with maxima of 835 and 310), in the vicinity of Little Egg Inlet (205), region between Atlantic City and Brigantine (185 and 290), just south of Atlantic City (275), Ocean City (470), and midway between Ocean City and Hereford Inlet (150). Moderate densities on the order of 25 occurred midshore in the central and southern regions of the Study Area.

In spring 2008, a Scoter maximum density of 730 occurred nearshore off Ocean City, with a smaller density maximum of 135 occurring further offshore southeast of Ocean City. Elevated densities also occurred in a nearshore localized region northeast of Hereford Inlet. One year later, in spring 2009, the maximum density that was previously at Ocean City moved slightly eastward and decreased in magnitude, to 145. In addition, a density maximum of 355 was present nearshore just south of Barnegat Light. Several additional localized regions of elevated densities (on the order of 50 and higher) occurred nearshore between Little Egg Inlet and Ocean City. In both spring seasons, densities were relatively uniformly distributed (on the order of 25-50) elsewhere along the coastline, and densities were generally lower and more patchily distributed moving offshore. Comparison of the all-behavior and sitting maps for spring 2008 shows that most of the observed Scoters were sitting nearshore and flying offshore: In spring 2008, the nearshore density maximum of 730 occurs for both all-behavior and sitting Scoters, whereas the offshore density maximum of 135 for all-behavior Scoters did not occur for sitting Scoters. In spring 2009, the nearshore density maximum of 355 for all-behavior Scoters decreased to 150 for sitting Scoters, whereas the nearshore density maximum of 145 for all-behavior decreased slightly to 140 for sitting.

In fall 2008, a string of maximum Scoter densities occurred along a northwest-to-southeast transect extending from nearshore to midshore southeast of Little Egg Inlet, with maxima of 1,445, 1,710, 235, and 235 moving offshore. Additional density maxima were present nearshore in the vicinity of Barnegat Light (115), midshore off Little Egg Inlet (145), and midshore south of Ocean City (225). In contrast, Scoter densities were lower one year later, in fall 2009, when only one relatively minor density maximum (110) occurred nearshore off Little Egg Inlet, and other minor localized regions of elevated densities (on the order of 50 and higher) occurred nearshore north of Little Egg Inlet and around and south of Ocean City and Great Egg Harbor Bay. In both fall seasons, densities were generally higher nearshore than offshore.

Comparison of the Scoter all-behavior and sitting-bird maps shows that the majority of Scoter occurring at the maximum (115) and sub-maximum regions in winter 2010 were sitting. In contrast to all-behavior Scoter, which exhibit a continuous band of moderate densities along the coastline, the moderate densities of sitting Scoter occurred in clumps in localized regions along the coastline: in the vicinity of Barnegat Light; in the northern part of Little Egg Inlet; and a southern region between Ocean City and Hereford Inlet. Sitting Scoter, like all-behavior Scoter, exhibit relatively lower and a more spatially homogeneous distribution of densities offshore than nearshore. In winter 2009, most of the all-behavior Scoter density maxima occurring nearshore in the central and southern regions also occurred for sitting Scoter, indicating that a majority of the observed Scoters in these regions were sitting; however, the two all-behavior Scoter density maxima (835 and 310) occurring nearshore around Barnegat Light did not occur for sitting Scoter, indicating that most of the Scoters observed in this northern region were flying. In winter 2008, the all-behavior Scoter density maximum (475) between Atlantic City and Brigantine did not occur for sitting Scoters, indicating that most of the Scoters comprising this density maximum were flying rather than sitting.

- Bonaparte's Gull: spring 2008 and fall 2009 (sitting; **Appendix M: Figures M-453** and **M-489**).

In fall 2009, sitting densities were generally higher and more spatially heterogeneous nearshore than offshore, with a maximum density of 185 occurring on the coastline from Atlantic City southward to a point midway between Atlantic City and Great Egg Harbor Bay, and a sub-maximum density occurring around Barnegat Light. In contrast, in spring 2008, sitting densities were higher and more spatially heterogeneous offshore than nearshore, with a moderate maximum density on the order of 25 occurring just outside the coastal region offshore of Brigantine. Further offshore, sub-maximum densities (less than 25) occurred in four separate localized regions uniformly distributed spatially in the northeast-to-southwest direction. Thus, it appears that Bonaparte's Gull prefers to sit nearshore in fall and migrate to sit offshore in spring.

- Common Loon – All-Behavior: spring 2008, spring 2009, winter 2009, and winter 2010 (**Appendix M: Figures M-398, M-416, M-421,** and **M-440**).

In these two spring seasons, all-behavior density ranges between low and moderate (less than 25/km^2) are distributed relatively uniformly in the coastal and offshore regions. In spring 2009, a vague maximum density (approximately 25) occurred just on the border between the nearshore and offshore regions, in the southern part of the Study Area between Ocean City and Hereford Inlet. In the two winter seasons, while Common Loon species occurred both nearshore and offshore, densities were slightly higher nearshore than offshore. In winter 2009, a maximum density of 170 occurred on the coastline at Hereford Inlet, and several regions of vague sub-maximum densities occurred along the coast, at Brigantine, Little Egg Inlet, and Barnegat Light. Nearshore and offshore densities were lower in winter 2010 than in winter 2009, with a maximum density (approximately 25 km [13.5 NM]) occurring nearshore north of Hereford Inlet. Densities were generally higher and more spatially homogeneous nearshore along the coastline than offshore. In the offshore region, densities were generally higher in the northern and southern regions than in the central region, reflecting greater survey effort in the former two regions than in the latter region for this season (winter 2010).

- Common Loon - Sitting: winter 2008, spring 2008, fall 2008, winter 2009, spring 2009, summer 2009, and winter 2010 (**Appendix M: Figures M-446, M-451, M-465, M-470, M-476, M-481,** and **M-493**).

In fall 2008, sitting densities were generally low (on the order of 25 and less) and sporadically distributed in the nearshore and offshore regions, with the lowest densities occurring in the northeast region of the Study Area. Nearshore densities were lower in the coastal region extending from Brigantine to a point midway between Atlantic City and Great Egg Harbor Bay, compared to the other nearshore regions in the Study Area. Densities were also higher mid-shore than far offshore, particularly in the northeastern and eastern regions of the Study Area. In the two spring seasons, densities were generally low to moderate (up to approximately 25) and sporadically distributed in the nearshore and offshore regions. In spring 2008, nearshore densities were lower just off Little Egg Inlet and Brigantine than in other nearshore regions, and these two locations exhibited higher densities in spring 2009 than in spring 2008. Offshore densities were also generally higher in spring 2009 than in spring 2008, particularly in the south-central offshore region. In summer 2009, both nearshore and offshore densities were generally lower than in the above mentioned fall and spring seasons, with higher densities occurring in some localized south-central offshore regions than in nearshore regions. Within the nearshore region, the highest densities occurred off Little Egg Inlet, but overall densities were generally low (approximately 25 and less) for the entire Study Area in summer 2009. In winter 2008, densities were low (less than 25) throughout most of the Study Area, with the highest densities occurring in the northern offshore region. The highest nearshore density occurred in proximity to Barnegat Light. Higher densities occurred (with relatively homogeneous spatial distributions) one year later, in winter 2009, with relatively higher densities nearshore. In winter 2009, a maximum nearshore density of 170 occurred at Hereford Inlet (in the southern region of the Study Area), and several high densities occurred nearshore off Barnegat Light, Great Egg Inlet, Little Egg Inlet, and Brigantine. Densities were relatively spatially uniform in the nearshore and mid-offshore regions (with a slight decrease in density with increasing offshore distance), and were lower in far-offshore regions.

- Common Tern: summer 2008, fall 2008, and summer 2009 (all-behavior; **Appendix M: Figures M-402, M-411,** and **M-427**).

In the two summer seasons (2008 and 2009), all-behavior densities were generally 25 and less. In summer 2008, densities were higher and more spatially homogeneous nearshore than offshore, with a concentration in density near Barnegat Light. Within the nearshore region, densities were lowest in the region in proximity to Barnegat Light (in the northern region of the Study Area). Within the offshore region, densities were slightly higher mid-shore than far-offshore, with the lowest densities occurring in the northeastern, south-central, and southeastern regions. In summer 2009, high densities occurred offshore. Offshore densities were distributed sporadically, with the lowest densities occurring in the north-central region, and the southern half exhibiting higher densities on average than the northern half. Nearshore densities were highest in regions just off Ocean City, Atlantic City, and the region midway between Barnegat Light and Little Egg Inlet. In fall 2008, a density maximum of 105 occurred midshore off Barnegat Light, and densities were relatively uniformly distributed (order of 25 and higher) along most of the entire coastline and in the midshore regions, with a general decrease in density moving further offshore.

- Cory's Shearwater: summer 2008 (all-behavior and sitting) **Appendix M: Figures M-405** and **M-457**).

In summer 2008, all-behavior densities were 25 and sporadically distributed throughout the nearshore and offshore regions, with slightly higher densities offshore than nearshore. The highest nearshore densities occurred in the region spanning from Brigantine to Ocean City (in the central region of the Study Area). Offshore, relatively high-density regions include the northeast corner and north-central far-offshore regions, and low-density regions include the southeast corner and the north-central midshore regions. In contrast, sitting densities throughout the Study Area in this same season were lower than all-behavior densities, indicating that most of the birds observed were flying rather than sitting. Highest nearshore sitting density occurred just south of Ocean City, and the highest offshore sitting density occurred in the north-central far-offshore region at the same latitude as Little Egg Inlet.

- Great Black-backed Gull: summer 2008, fall 2008, summer 2009, and fall 2009 (sitting; **Appendix M: Figures M-458, M-463, M-482,** and **M-488**).

Sitting densities were higher, particularly nearshore, in fall 2008 than in 2009. In both seasons, densities were higher and more uniform nearshore than offshore. In fall 2008, a maximum nearshore density of 130 occurred north of Barnegat Light, in the northern region of the Study Area; and a sub-maximum density occurred in the extreme northern part of the nearshore region, north of Barnegat Light. Within the offshore region, the highest densities were located midshore, particularly in the central, northern, and southern midshore regions, with lower densities located offshore. In fall 2009, densities were generally lower (on the order of 25 and less) than in fall 2008. Nearshore densities were more homogeneously dispersed (with no localized regions of maximum density). Comparing the two summer seasons to the two fall seasons, sitting densities were generally lower in summer than in fall, with higher densities occurring nearshore compared to offshore. In summer 2008, highest nearshore densities occurred in four localized regions: around Barnegat Light; northern part of Little Egg Inlet; region extending from the southern part of Little Egg Inlet to Brigantine; and a region between Ocean City and Hereford Inlet. Offshore densities were very low throughout (on the order of 10 and less). Overall densities were even lower in summer 2009 than in summer 2008, with two localized regions of higher nearshore density: region around and extending south of Barnegat Light; and in the vicinity of Little Egg Inlet. One small area of higher offshore density occurred midshore just outside the nearshore region, southeast of Little Egg Inlet.

- Herring Gull – All-Behavior: winter 2008, spring 2008, spring 2009, summer 2009, fall 2009, and winter 2010 (**Appendix M: Figures M-390, M-397, M-422, M-429, M-433,** and **M-441**).

In fall 2009, densities were higher and more uniform nearshore than offshore, with regions of maximum densities (order of 50) occurring just north of Barnegat Light and in a region midway between Barnegat Light and Little Egg Inlet. A nearshore sub-maximum density was located south of Ocean City. Lowest nearshore densities occurred just off Hereford Inlet and in the vicinity of Little Egg Inlet. Offshore densities were broadly distributed, with a maximum density (order of 25 to 50) occurring in the north-central midshore region at a latitude slightly south of Barnegat Light. In the two spring seasons (2008 and 2009), densities were relatively uniform in spatial distribution, with slightly higher densities nearshore than offshore. No nearshore maximum density was detected in spring 2008, with lowest densities located near Brigantine, and Hereford Inlet. Offshore, low densities were located midshore in the southern region of the Study Area (offshore between Ocean City and Hereford Inlet). In spring 2009, maximum nearshore density (on the order of 50) occurred at Little Egg Inlet, with vague sub-maximum densities occurring midway between Barnegat Light and Little Egg Inlet, and in the northern part of the nearshore region. Offshore densities, like nearshore densities, were relatively spatially uniformly distributed. Offshore densities were generally higher in the northern and southern regions than in the central region. Overall densities were generally lower in summer 2009 than in the two spring seasons (2008 and 2009), with highest densities on the order of 25 and less. Within the nearshore region, lowest densities occurred between Little Egg Inlet and Brigantine, and in the northern part off Little Egg Inlet. Densities were patchily distributed within the offshore region, with higher densities in the north and less and uniformly distributed throughout. In winter 2008, a density maximum occurred nearshore between Great Egg Harbor Bay and Atlantic City, with smaller density maxima occurring south of Ocean City. Densities were generally lower two years later, in winter 2010, when these density maxima were less. In both of these winter seasons, densities outside of these density maxima were generally low (order of 25 and less) and patchily distributed along the coastline, and densities decreased moving offshore.

- Herring Gull - Sitting: spring 2008, fall 2008, winter 2009, summer 2009, fall 2009, and winter 2010 **(Appendix M: Figures M-452, M-464, M-471, M-483, M-487,** and **M-494**).

In fall 2008, sitting densities were generally higher nearshore than offshore, with a maximum nearshore density of 170 occurring in the vicinity of Barnegat Light. A vague sub-maximum nearshore density also occurred in the region midway between Barnegat Light and Little Egg Inlet. Lowest nearshore densities occurred around and south of Great Egg Harbor Bay and Ocean City, and around and north of Hereford Inlet. Offshore densities were patchily distributed throughout the offshore region, with generally higher densities in the northern region. Both nearshore and offshore densities were generally lower in fall 2009 than one year earlier (fall 2008). The spatial patterns of sitting densities for fall 2009 mimics those of all-behavior densities for this same season, except that sitting densities were generally lower than all-behavior densities, indicating the presence of both flying and sitting birds. In fall 2009, the sitting densities (like the all-behavior densities) were higher and more spatially uniform nearshore than offshore, with regions of maximum densities (order of 50) located north of Barnegat Light, and in a region between Barnegat Light and Little Egg Inlet. A nearshore sub-maximum density was located south of Ocean City. Offshore densities were patchily distributed, with a maximum density occurring in the north-central midshore region south of Barnegat Light.

In spring 2008, nearshore and offshore sitting densities were sporadically distributed, with generally higher densities nearshore than offshore. A maximum density was located midshore in the north-central region, south of Barnegat Light. In summer 2009, sitting densities were generally very low (order of 5-10 and less), with higher densities nearshore than offshore. Highest nearshore densities occurred in the region between Barnegat Light and Little Egg Inlet, and in the region north of Hereford Inlet. In winter 2009, sitting densities were higher nearshore than offshore, with a maximum nearshore density (order of 25 to 50) occurring between Ocean City and Hereford Inlet. A sub-maximum nearshore density was located at Little Egg Inlet. Offshore densities were sporadically distributed, with some local far-offshore regions (northeast and south-central areas) exhibiting slightly higher densities than adjacent midshore regions. Densities were low in winter 2010 than one year earlier (winter 2009), with nearshore densities generally higher than offshore densities. The highest densities occurred in the northern regions of the Study Area, both nearshore and offshore (midshore region). Nearshore densities were higher north of Little Egg Inlet than south of Little Egg Inlet. Maximum nearshore densities (order of 25 and less) occurred just south of Seaside Heights and of Barnegat Light.

- Laughing Gull: summer 2008, fall 2008, summer 2009, and fall 2009 (all-behavior and sitting; **Figures M-401, M-407, M-425, M-432, M-455, M-461, M-480,** and **M-486**).

In fall 2008, high localized densities occurred nearshore and offshore for both all-behavior and sitting birds, with nearshore densities generally higher than offshore densities. In the nearshore region, a maximum all-behavior density of 725 and a maximum sitting density of 585 occurred in the vicinity of Barnegat Light. In addition, a maximum all-behavior density of 140 and a sub-maximum sitting density (order of 25 to 50) located just north of Hereford Inlet. A sub-maximum all-behavior density was also located nearshore just off Little Egg Inlet. In the offshore region, a maximum all-behavior density of 150 and a maximum sitting density of 140 occurred in the southern region of the Study Area, southeast of Hereford Inlet. In the offshore region, spatial distribution was more uniform for all-behavior birds than for sitting birds, with generally higher densities midshore than far-offshore. Both the all-behavior and sitting were somewhat lower in fall 2009 compared to one year earlier (fall 2008), with the maximum nearshore densities migrating southward (from north of Barnegat Light to the region around and north of Little Egg Inlet) and decreasing in magnitude (e.g., from 585 to 135 sitting density) over the one-year period. Sub-maximum nearshore densities occurred at and around Ocean City for both all-behavior and sitting birds. In fall 2009 (like fall 2008), both the all-behavior and sitting densities were higher nearshore than offshore, all-behavior densities were higher than sitting densities, and offshore densities were more uniformly distributed for all-behavior birds than for sitting birds, with generally higher densities midshore than far-offshore.

Both the all-behavior and sitting densities were lower in the two summer seasons (2008 and 2009) than in the two fall seasons (2008 and 2009), with densities generally higher nearshore than offshore. In summer 2008, a maximum nearshore all-behavior density of 110 occurred at Ocean City. The corresponding sitting density at Ocean City was not nearly as high but was locally higher than in the regions immediately north and south of Ocean City. Outside of Ocean City, nearshore densities were otherwise more uniformly distributed along the coastline for all-behavior birds than for sitting birds. Nearshore sitting densities were highest along the central coastline, moderate in the south, and lowest in the north. Offshore densities were more homogeneously distributed for all-behavior birds than for sitting birds, with lowest densities occurring far-offshore in the northeast and southeast regions of the Study Area. Both all-behavior and sitting densities were lower in summer 2009 compared to one year earlier (summer 2008). In summer 2009, the lowest nearshore densities occurred just south of Ocean City, just south of Barnegat Light, and of Seaside Heights. Nearshore densities are lower and more sporadically distributed for sitting birds than for all-behavior birds, with highest nearshore densities occurring around Brigantine, around and south of Atlantic City, and in the region midway between Ocean City and Hereford Inlet. In summer 2009 (like summer 2008), offshore densities were generally lower than nearshore densities; however, offshore all-behavior densities were more sporadically distributed in summer 2009 than in 2008. Offshore densities of sitting birds were very low in summer 2009, with midshore densities slightly higher than density offshore.

- Long-tailed Duck: winter 2008, winter 2009, spring 2009, and winter 2010 (all-behavior and sitting; **Appendix M: Figures M-392, M-414, M-423, M-438, M-447, M-468, M-475,** and **M-492**).

In spring 2009, high localized densities occurred nearshore for both all-behavior and sitting birds, with nearshore densities generally greater than offshore densities. In the nearshore region, a maximum all-behavior density on the order of 250 and a maximum sitting density of 215 occurred just south of Barnegat Light. Sub-maximum nearshore densities (for all-behavior and sitting birds) also occurred in the vicinity of Barnegat Light. The lowest nearshore densities were located south of Atlantic City to north of Hereford Inlet. Offshore densities are generally low, with the highest offshore densities occurring midshore in the north-central region (in proximity to Barnegat Light) and in the southern region (in proximity to Hereford Inlet).

Among the three winter seasons (2008, 2009, and 2010), all-behavior and sitting densities were lowest in winter 2008, highest in winter 2009, and moderate in winter 2010, with nearshore densities generally higher than offshore densities. In winter 2008, localized regions of maximum nearshore density occurred along Little Egg Inlet, with generally higher densities in the region from Barnegat Light to Brigantine and in the region north of Hereford Inlet. In winter 2009, nearshore densities were high for both all-behavior and sitting birds, with numerous regions of maximum nearshore density occurring in the vicinity of Barnegat Light and in the vicinity of Little Egg Inlet. Maximum nearshore all-behavior densities were on the order of 200 to 300 and higher. Maximum nearshore sitting densities were 110, 275, and 175 north of Barnegat Light, south of Barnegat Light, and Little Egg Inlet, respectively. Smaller sub-maximum nearshore densities also occurred in the region between Ocean City and Hereford Inlet, and the lowest nearshore density occurred just south of Atlantic City.

Offshore densities were lower and more uniformly distributed in space compared to nearshore densities (for both all-behavior and sitting birds), with relatively higher densities midshore than far-offshore. In winter 2010, overall densities for both all-behavior and sitting birds were intermediate between those for winter 2008 (low) and winter 2009 (high). A maximum nearshore all-behavior density (on the order of 50 and higher) occurred just north of Barnegat Light, with a smaller sub-maximum density occurring south of Seaside Heights. Nearshore densities were generally higher along the northern and central coastlines than along the southern coastline, and offshore densities were very low (order of 5-10 and less) throughout the offshore region, for both all-behavior and sitting birds, reflecting the relatively lower survey effort offshore in winter 2010.

- Northern Gannet: spring 2008-2009, summer 2008-2009, fall 2008-2009, and winter 2008, 2009, 2010 (all-behavior and sitting; **Appendix M: Figures M-391, M-396, M-404, M-409, M-417, M-420, M-426, M-431, M-439, M-443, M-450, M-456, M-462, M-474, M-479, M-485,** and **M-495**).

In the two fall seasons (2008 and 2009), high localized densities occurred nearshore for both all-behavior and sitting birds, with nearshore densities higher than offshore densities. In fall 2008, a maximum nearshore all-behavior density of 300 occurred just off Ocean City. A smaller nearshore maximum density (on the order of 50 and higher) was located in the vicinity of Barnegat Light for both all-behavior and sitting birds. Additional nearshore sub-maximum densities were located between Ocean City and Hereford Inlet for all-behavior birds. Offshore, several localized regions of maximum density (for all-behavior birds only) were located midshore in the southern region of the Study Area, southeast of Ocean City. In fall 2009, several nearshore maximum densities occurred for both all-behavior and sitting birds. For all-behavior birds, a maximum nearshore density of 160 occurred between Little Egg Inlet and Barnegat Light, and another maximum density of 290 occurred midshore between Little Egg Inlet and Brigantine. Analogous sitting maximum densities were on the order of 50 and 200. Other regions of sub-maximum densities for all-behavior birds included the nearshore region of Barnegat Light and midshore regions south of Atlantic City, south of Ocean City, and the region between Ocean City and Hereford Inlet.

Comparing the two spring seasons (2008 and 2009) to the two fall seasons (2008 and 2009), overall densities (number/km^2) were generally lower in spring than in fall, with nearshore densities higher than offshore densities. In spring 2008, a localized maximum nearshore density of 240 occurred for all-behavior birds just north of Hereford Inlet. For sitting birds, an analogous maximum nearshore density of a lower magnitude (on the order of 50 and higher) occurred in the same region. A sub-maximum nearshore density also occurred just south of Barnegat Light for both all-behavior and sitting birds.

Densities for both all-behavior and sitting birds were generally lower in spring 2009 compared to one year earlier (spring 2008). In the northern offshore region, a localized maximum density of 155 occurred for all-behavior birds.

Comparing the two summer seasons (2008 and 2009) to the above spring and fall seasons, overall densities were generally lower in summer than in fall and spring, with no localized regions of maximum densities. Densities were generally distributed sporadically in the nearshore and offshore regions, with nearshore densities generally higher than offshore densities. Within the nearshore region, both the all-behavior and sitting densities were generally higher in the northern region (in the vicinity of Barnegat Light) than in the central and southern regions. Within the offshore region, midshore densities were generally higher than far-offshore densities.

Among the three winter seasons (2008-2010 for all-behavior birds, 2008 and 2010 for sitting birds), overall densities were generally lower in winter and summer (non-migration seasons) than in spring and fall. In winter 2008, densities were higher offshore than nearshore. Within the nearshore region, densities were higher in the northern (in the vicinity of Barnegat Light) and central (Little Egg Inlet) regions than elsewhere. In winter 2009, localized regions of maximum density were located nearshore off Barnegat Light and off Little Egg Inlet. The lowest nearshore densities occurred in the southern region, from Hereford Inlet extending up halfway to Ocean City. In winter 2010, nearshore all-behavior density distribution along the coastline was relatively homogeneous, whereas sitting densities exhibited minor localized maxima nearshore in the vicinity of Barnegat Light and around Ocean City and Great Egg Harbor Bay; and nearshore densities were higher than offshore densities for both all-behavior and sitting birds.

- Red-throated Loon: spring 2008 (all-behavior) and winter 2008 (all-behavior and sitting; **Appendix M: Figures M-393, M-399,** and **M-445**).

In spring 2008, bird densities were higher and more uniformly dispersed than offshore densities. Nearshore densities were on the order of 25 and relatively constant over the entire coastline of the Study Area. In the offshore region, low-density patches (order of 5 to 10 and less) occurred in the northern region (in the vicinity of Barnegat Light), south-central region (southeast of Atlantic City and Ocean City), and the extreme southern tip of the Study Area (southeast of Hereford Inlet). In winter 2008, for both all-behavior and sitting birds, both the nearshore and offshore densities are sporadically distributed; however, the offshore gradient in density is reversed between the all-behavior birds (higher densities nearshore than offshore) and sitting birds (higher densities offshore than nearshore), indicating that a greater relative proportion of sitting birds (compared to flying birds) occurs offshore. In the nearshore region, the lowest all-behavior densities occurred in the vicinity of Barnegat Light, in a small region off Little Egg Inlet, and just south of Atlantic City; and the highest sitting densities occurred south of Seaside Heights, along Little Egg Inlet, and in a small region halfway between Ocean City and Hereford Inlet.

- Scaup species: winter 2009 (all-behavior and sitting; **Appendix M: Figures M-415** and **M-469**).

In winter 2009, maximum nearshore densities were located at Little Egg Inlet (1,885) north of Hereford Inlet (510), and near Ocean City (105). Within the nearshore region, densities were generally higher in the central and southern regions (south of Little Egg Inlet) than in the northern regions. Densities were higher nearshore than offshore. Within the offshore region, no spatial gradients were detected for either the all-behavior or the sitting birds, with densities (outside of the above-mentioned localized maxima) generally on the order of 5 to 10 or less.

- Scoter species: fall 2008-2009 (all-behavior), winter 2008 (sitting), spring 2008-2009, summer 2008-2009, winter 2009-2010 (all-behavior and sitting; **Appendix M: Figures M-395, M-408, M-413, M-419, M-434, M-437, M-444, M-449, M-467, M-473,** and **M-491**).

In fall 2008, numerous localized regions of maximum density (all-behavior) were located nearshore and midshore. A nearshore maximum density of 115 occurred in the vicinity of Barnegat Light. Several midshore maximum densities occurred, including: 145 in proximity to Little Egg Inlet; 225 (one among four localized maxima) southeast of Ocean City; and maxima of 1,445, 1,710, 235, and 235 along a line transect extending southeast of Little Egg Inlet. Because of the magnitude, location, and number of these localized maximum densities, density was higher offshore than nearshore in fall 2008; however, the general offshore density gradient was reversed in fall 2009 (one year later), with higher densities nearshore than offshore. Overall densities were lower in fall 2009 than in fall 2008. In fall 2009, a nearshore maximum density of 110 occurred between Little Egg Inlet and Brigantine, with several nearshore density maxima (order of 25) occurring off Ocean City and Great Egg Harbor Bay and in a region further south of Ocean City. Within the offshore region, densities were generally higher midshore than far-offshore in both fall seasons (2008 and 2009).

In spring seasons (2008 and 2009), localized nearshore and midshore density maxima occurred but in different locations, with sitting densities generally mirroring (but lower in magnitude than) all-behavior densities, reflecting the presence of both flying and sitting birds. For both spring seasons, densities were generally higher nearshore than offshore, and densities were higher in spring 2008 than in spring 2009. In spring 2008 for all-behavior birds, a nearshore maximum density of 730 occurred just south of Ocean City, a maximum that was mirrored by sitting birds, indicating that most/all of the birds in this region were sitting rather than flying. In addition, a sub-maximum nearshore density (on the order of 50 and higher) occurred north of Hereford Inlet, and a maximum midshore density of 135 occurred southeast of Ocean City. In spring 2009, for all-behavior birds, localized nearshore maximum densities of 355 and 145 occurred just south of Barnegat Light, and off Great Egg Harbor Bay, respectively. Analogous density maxima at these two locations were mirrored by the sitting birds but with lower density magnitudes (150 and 140, respectively), reflecting the contributions of both flying and sitting birds to the all-behavior densities. Within the offshore region, midshore densities were generally higher than far-offshore densities, for both spring seasons for both all-behavior and sitting birds.

In winter 2008 for sitting birds, densities were very low (on the order of 5 to 10 and less) in both the nearshore and offshore regions, with the higher densities occurring offshore of Little Egg Inlet, Atlantic City, and Ocean City. Aside from these three broad regions of moderately higher densities, no spatial variability in density was detected in the nearshore or offshore regions.

Both all-behavior and sitting densities were higher in winter 2009 than in winter 2010, reflecting the relatively lower survey effort in winter 2010. In winter 2009, numerous localized density maxima occurred nearshore for all-behavior birds, including: 835 and 310 at and just south of Barnegat Light (not mirrored by sitting birds); 205 in the vicinity of Little Egg Inlet (mirrored by sitting birds at 195); 290, 185, and 275 stretching from Brigantine to south of Atlantic City (mirrored by sitting birds at 285, 285, and 370); 470 just south of Ocean City (mirrored by sitting birds at 460); and 150 between Ocean City and Hereford Inlet (mirrored by sitting birds at 150). The two northern density maxima that were not mirrored by sitting birds indicate that most of the birds in the Barnegat Light region were flying rather than sitting. There were a fewer number of localized nearshore density maxima in winter 2010 than in winter 2009. In winter 2010, a nearshore density maximum of 115 occurred for both all-behavior and sitting birds between Brigantine and Little Egg Inlet (indicating that all of the birds in this region were sitting rather than flying). Several sub-maximum densities (order of 25 and less) occurred at Brigantine and just north of Barnegat Light for both all-behavior and sitting birds. Moving offshore, densities generally decreased, and a sub-maximum density occurred midshore southeast of Atlantic City for all-behavior birds, which was not mirrored by the sitting birds (indicating that most of the birds in this midshore region were flying rather than sitting). For winter seasons (2009 and 2010), all-behavior and sitting densities were higher nearshore than offshore, and densities were higher midshore than far-offshore. In winter 2010, offshore densities were higher in the northern and southern regions than in the central region, reflecting the relatively lower survey effort in the latter region.

- Wilson's Storm-Petrel: fall 2008, fall 2009, summer 2009 (all-behavior), summer 2008 (all-behavior and sitting; **Appendix M: Figures M-403, M-410, M-428, M-435,** and **M-459**).

In fall 2008, a sharp localized offshore density maximum of 485 was located in the southern tip of the Study Area, southeast of Hereford Inlet. Offshore densities were generally higher and more spatially uniform than nearshore densities. Furthermore, within the nearshore region, the highest densities occurred at the offshore edge rather than up against the coastline. Maximum nearshore densities occurred off the coast in the vicinity of Barnegat Light, in the northern region of the Study Area. In fall 2009, both nearshore and offshore densities were relatively low (order of 25 and less), and densities in both regions were higher in the northern regions of the Study Area than in the southern region. Nearshore densities were lower off Little Egg Inlet, between Brigantine and Atlantic City, and from Hereford Inlet to just south of Ocean City. Likewise, in summer (2008 and 2009), nearshore and offshore densities were similarly lower in magnitude (order of 25 and less), with no distinct localized density maxima. In summer, densities were patchily distributed and were higher offshore than nearshore. In summer 2008, offshore densities were generally higher in the southern than in the northern regions, whereas in summer 2009, offshore densities were highest in the northern region, moderate in the southern region, and lowest in the central region. In summer 2008, nearshore densities were higher around Little Egg Inlet and in regions around and north of Hereford Inlet, compared to other nearshore regions. Densities were relatively lower in summer 2009 than in summer 2008, with the highest nearshore densities occurring in a small region midway between Hereford Inlet and Ocean City.

8.3.1.2 Total-Birds: Seasonal Analysis

Kernel density maps for total all-behavior birds and total sitting birds reflect all bird species in the given time period. For most seasons, nearshore densities were higher than offshore densities (for both all-behavior and sitting birds). Within the offshore region, densities were generally higher midshore than far-offshore.

In fall 2008, numerous localized density maxima were located nearshore, midshore, and offshore as a result of contributions of individual species. A total of 24 detectable density maxima occurred for all-behavior birds within the Study Area, ranging in magnitude from 105 to 1,740 (the latter of which is located midshore southeast of Little Egg Inlet. The majority of these maxima were not mirrored by the sitting birds, indicating that most of the total birds in the regions of these density maxima were flying rather than sitting. Compared to 24 density maxima for all-behavior birds, only four density maxima occurred for the sitting birds: 1) 945 nearshore in the vicinity of Barnegat Light (compared to 1,420 for all-behavior birds); 2) 120 nearshore in the region midway between Little Egg Inlet and Barnegat Light (compared to 135 for all-behavior birds); 3) 145 midshore southeast of Hereford Inlet (compared to 170 for all-behavior birds); 4) 140 far-offshore southeast of Hereford Inlet (compared to 565 for all-behavior birds). Except for this far-offshore density maximum, far-offshore densities were generally lower than midshore densities. Total bird density (all-behavior and sitting) were generally lower in fall 2009 than in fall 2008 (a year earlier). In fall 2009, five localized density maxima occurred for all-behavior birds: 1) 180 nearshore at Barnegat Light (compared to 125 for sitting birds); 2) 260 nearshore between Barnegat Light and Little Egg Inlet (compared to 145 for sitting birds); 3) 300 midshore southeast of Little Egg Inlet (compared to 215 for sitting birds); 4) 300 nearshore just south of Atlantic City (compared to 235 for sitting birds); 5) 100 nearshore just south of Ocean City (mirrored by a sub-maximum density on the order of 50). In addition, numerous density maxima (on the order of 50) for all-behavior birds also occurred, both nearshore and midshore, some of which were mirrored by the sitting birds.

Comparing spring and fall for the 2008 and 2009, densities were relatively lower in spring than in fall. In spring 2008, three distinct localized density maxima occurred for all-behavior birds: 1) 745 nearshore just off Ocean City (compared to 730 for sitting birds, indicating that the majority of the birds in this region were sitting rather than flying); 2) 335 nearshore off Hereford Inlet (mirrored by a sub-maximum density on the order of 50 for sitting birds); 3) 135 km^{-2} midshore southeast of Ocean City (which is not mirrored by the sitting birds). In spring 2009, four distinct localized density maxima occurred for all-behavior birds: 1) 585 nearshore just south of Barnegat Light (compared to 370 for sitting birds); 2) 130 offshore east of Barnegat Light (which is not mirrored by the sitting birds); 3) 150 nearshore between Great Egg Harbor Bay and Atlantic City (compared to 140 for sitting birds); 4) 120 nearshore just off Hereford Inlet (compared to 110 for sitting birds).

Overall densities were generally lower in summer than in fall and spring for 2008 and 2009. In summer 2008, only one distinct localized density maximum occurred: 110 nearshore off Ocean City. Several sub-maximum densities (on the order of 25) occurred for all-behavior birds around Atlantic City and

Brigantine. Densities were generally higher nearshore than offshore, and offshore densities were more patchily distributed for sitting birds than for all-behavior birds. Overall densities were slightly lower in summer 2009 than in summer 2008. In summer 2009, the spatial distribution of all-behavior density was more uniform nearshore than offshore Nearshore sitting bird densities were lowest around Ocean City and Great Egg Harbor Bay, the region between Brigantine and Little Egg Inlet, and a small region just north of Little Egg Inlet.

Among winter and summer, overall densities were generally higher in winter than in summer (for both all-behavior and sitting birds). Among the three winter seasons, densities were generally lowest in 2008, highest 2009, and intermediate in 2010, partly reflecting the lower survey effort in the latter season. In all three winter seasons, densities were higher nearshore than offshore, and all-behavior densities were higher than sitting densities, reflecting the presence of both flying and sitting birds. In winter 2008, two localized density maxima occurred for all-behavior birds: 1) 475 nearshore between Atlantic City and Brigantine; 2) 120 nearshore between Great Egg Harbor Bay and Atlantic City. In winter 2009, densities were higher than in winter 2008 (one year ago), with 13 localized nearshore density maxima occurring for all-behavior birds (ranging from 125 to 1,740) along the entire coastline, from Seaside Heights to Hereford Inlet. Eight of these 13 density maxima were mirrored by the sitting birds (ranging from 170 to 1,715). In winter 2010, five localized nearshore density maxima occurred: 1) 135 nearshore in the vicinity of Barnegat Light (compared to 110 for sitting birds); 2) 105 nearshore between Little Egg Inlet and Barnegat Light; 3) 235 nearshore between Brigantine and Little Egg Inlet (compared to 105 for sitting birds); 4) 120 nearshore at Brigantine (compared to 50 for sitting birds); 5) 105 nearshore midway between Ocean City and Hereford Inlet (compared to 50 for sitting birds).

8.3.1.3 Total Birds: Annual and Overall Cumulative Analysis

Kernel density maps were estimated for all-behavior and sitting densities for 2008 and 2009, and the combined two-year period 2008-2009. Numerous localized density maxima for all-behavior and sitting birds were located nearshore, midshore, and far-offshore, with the vast majority of these maxima occurring nearshore. A small portion of these density maxima for all-behavior birds are mirrored by the sitting birds, reflecting differences in the numbers of flying and sitting birds. For example, eight and 15 localized sitting density maxima occurred in 2008 and 2009, respectively; and 24 such maxima occurred in the overall cumulative two-year period, most of which occurred nearshore. In 2008, the eight sitting density maxima ranged from 110 to 830 (the latter occurring in the vicinity of Barnegat Light); and in 2009, the 15 sitting density maxima ranged from 115 to 735 (the latter occurring in the vicinity of Little Egg Inlet). In the overall cumulative two-year period, the 24 sitting density maxima ranged from 115 to 1,480 (the latter occurring in the vicinity of Little Egg Inlet). For the all-behavior birds, the highest density maxima were 1,425 in 2008 (midshore southeast of Little Egg Inlet), 1,730 in 2009 (nearshore in the vicinity of Little Egg Inlet), and 1,805 (on the offshore edge of the nearshore region, between Little Egg Inlet and Brigantine).

Observing these annual and overall cumulative spatial kernel density maps, the following general conclusions can be made:

1) Nearshore densities are higher than offshore densities, supporting an offshore gradient of decreasing densities with increasing offshore distance.

2) Within the offshore region, midshore densities were generally higher than far-offshore densities.

3) All-behavior densities were higher than sitting densities, reflecting the presence of both all-behavior and sitting birds.

4) The highest nearshore densities occurred up against the coastline rather than on the offshore edge of the nearshore region.
5) All-behavior density maxima that are mirrored by sitting birds reflect a balance between flying and sitting birds. If the sitting density is less than the all-behavior density, then both flying and sitting

birds are present. If the sitting density is equal to or near the all-behavior density, then most/all of the birds in the given region are sitting rather than flying.

6) All-behavior density maxima that are not mirrored by sitting birds indicate that the majority of birds in the given region were flying rather than sitting.

8.3.1.4 Annual Analysis

- Year 2008 (**Appendix M: Figures M-497** to **M-502** and **Figures M-509** to **M-514**).

For 2008, the top five most abundant all-behavior species were Scoter species, Northern Gannet, Laughing Gulls, Herring Gull, and Wilson's Storm-Petrel; and the top five most abundant sitting species were Scoter species, Laughing Gull, Northern Gannet, Great Black-backed Gull, and Herring Gull (**Appendix M: Table M-44**).

For Scoter species, ten localized all-behavior density maxima (along with several sub-maximum densities on the order of 25 to 50 and higher) were estimated nearshore and midshore, ranging from 120 to 760 (the latter occurring midshore southeast of Little Egg Inlet). In addition to 760, other high density maxima include 720 (nearshore off Barnegat Light), 660 (nearshore off Little Egg Inlet), and 530 (nearshore off Ocean City). Most of these ten maxima are clustered nearshore around Barnegat Light, midshore southeast of Little Egg Inlet, nearshore off Atlantic City, and nearshore/midshore around Ocean City. Only two of these ten density maxima were mirrored by the Scoter species sitting birds: 1) 165 (all-behavior) versus 120 (sitting) nearshore just south of Atlantic City; 2) 775 (all-behavior) versus 530 (sitting) nearshore off Ocean City.

For Northern Gannet, two localized all-behavior density maxima (along with several sub-maximum densities on the order of 25 to 50) were estimated: 1) 250 nearshore off Ocean City (which was not mirrored by the sitting birds); 2) 245 nearshore north of Hereford Inlet (compared to 105 for sitting birds). In addition, a vague sub-maximum density (on the order of 25 to 50) for both all-behavior and sitting birds was located nearshore in the vicinity of Barnegat Light.

For Laughing Gull, four localized all-behavior density maxima (along with several sub-maximum densities on the order of 25 to 50) were estimated: 1) 685 nearshore in the vicinity of Barnegat Light (compared to 555 for sitting birds); 2) 110 nearshore off Ocean City (which was not mirrored by the sitting birds); 3) 145 nearshore north of Hereford Inlet (compared to a sub-maximum density on the order of 25); 4) 200 midshore southeast of Hereford Inlet (compared to 185 for sitting birds).

For Herring Gull, two localized all-behavior density maxima (along with several sub-maximum densities on the order of 25 to 50) were estimated: 1) 180 nearshore midway in the vicinity of Barnegat Light (compared to 130 for sitting birds); 2) 110 nearshore south of Ocean City (which was not mirrored by the sitting birds). In addition, sub-maximum densities (on the order of 25 to 50) were located nearshore between Atlantic City and Great Egg Harbor Bay (for all-behavior birds only), and between Barnegat Light and Little Egg Inlet (for both all-behavior and sitting birds).

For Wilson's Storm-Petrel, one localized all-behavior density maximum was estimated: 500 offshore in the southeast corner of the Study Area, southeast of Hereford Inlet. Moderate densities (on the order of 25-50) were patchily distributed nearshore and were generally higher offshore than nearshore.

For Great Black-backed Gull, one localized sitting density maximum was estimated: 130 nearshore in the vicinity of Barnegat Light. In addition, one sub-maximum density on the order of 25 to 50 was located nearshore just north of this maximum density.

- Year 2009 (**Appendix M: Figures M-503** to **M-508,** and **Figures M-515** to **M-520**).

For 2009, the top five most abundant all-behavior species were Scoter species, Northern Gannet, Long-tailed Duck, Herring Gull, and Scaup species; and the top five most abundant sitting species were Scoter species, Long-tailed Duck, Northern Gannet, Common Loon, and Scaup species (**Appendix M: Table M-44**).

For Scoter species, nine localized all-behavior density maxima (including one vague sub-maximum density on the order of 50) were estimated in nearshore and midshore waters, ranging from 135 to 345 (the latter occurring nearshore just south of Barnegat Light). Each of these nine density maxima was mirrored by the sitting Scoter species: 1) 345 (all-behavior) versus 135 (sitting) nearshore just south of Barnegat Light; 2) 215 (all-behavior) versus 205 (sitting) nearshore in the vicinity of Little Egg Inlet; 3) 145 (all-behavior) versus 115 (sitting) nearshore southeast of Little Egg Inlet; 4-6) 235, 240, and 295 (all-behavior) versus 230, 230, and 250 (sitting) nearshore around Atlantic City and Brigantine; 7) 135 (all-behavior) versus 145 (sitting) nearshore at and north of Ocean City and Great Egg Harbor Bay; 8-9) 215 and a sub-maximum density on the order of 50 and higher (all-behavior) versus 205 and 105 (sitting) midshore midway between Hereford Inlet and Ocean City.

For Northern Gannet, four localized all-behavior density maxima (along with several vague sub-maximum densities on the order of 25 to 50 and higher) were estimated: 1) 140 offshore east of Barnegat Light (which was not mirrored by the sitting birds); 2) 155 nearshore between Little Egg Inlet and Barnegat Light (mirrored by a sub-maximum sitting density on the order of 25 to 50 and higher); 3) 305 midshore southeast of Little Egg Inlet (compared to 225 for sitting birds); 4) 110 midshore south of Atlantic City (mirrored by a sub-maximum sitting density on the order of 50 and higher).

For Long-tailed Duck, four localized all-behavior density maxima (along with several sub-maximum densities on the order of 25 to 50 and higher) were estimated: 1) 265 nearshore south of Seaside Heights (compared to 125 for sitting birds); 2-3) 230 and 390 nearshore around Barnegat Light (compared to 220 and 340 for sitting birds); 4) 180 nearshore in the vicinity of Little Egg Inlet (compared to 165 for sitting birds). In addition, a sub-maximum density (on the order of 50 and higher) was located for both all-behavior and sitting birds nearshore midway between Hereford Inlet and Ocean City.

For Scaup species, two localized all-behavior density maxima were estimated: 1) 1,885 nearshore in the vicinity of Little Egg Inlet (compared to 1,885 for sitting birds); 2) 510 nearshore north of Hereford Inlet (which was not mirrored by the sitting birds). In addition, a sub-maximum density (on the order of 25 to 50) was located nearshore south of Ocean City for all-behavior birds.

For Herring Gull, several maximum all-behavior densities (on the order of 25 to 50 and higher) were located nearshore and offshore. Nearshore locations include a region midway between Hereford Inlet and Ocean City, and a stretch of isolated regions from south of Seaside Heights to Little Egg Inlet; and the offshore regions include sporadic areas east of Barnegat Light.

For Common Loon, one localized sitting density maximum was generated: 160 nearshore at Hereford Inlet. In addition, several sub-maximum sitting densities (on the order of 25 and less) were located: nearshore region north of Hereford Inlet; regions along Little Egg Inlet; and a region at Barnegat Light.

- Overall Cumulative Two-year Period (**Appendix M: Figures M-521** to **M-532**).

For the two-year period, the top five most abundant all-behavior species were Scoter species, Northern Gannet, Laughing Gull, Long-tailed Duck and Herring Gull; and the top five most abundant sitting species were Scoter species, Northern Gannet, Long-tailed Duck, Common Loon and Laughing Gull (**Appendix M: Table M-44**).

For scoter species, 15 localized all-behavior density maxima (along with several sub-maximum densities on the order of 25 to 50 and higher) were estimated in nearshore and midshore waters, ranging from 115 to 945 (the latter occurring midshore southeast of Little Egg Inlet). Eight of these density maxima were mirrored by sitting Scoter species, including: 1) 305 (all-behavior) versus (sitting) nearshore south of Barnegat Light; 2) 220 (all-behavior) versus 210 (sitting) nearshore in the vicinity of Little Egg Inlet; 3) 945 (all-behavior) versus 120 (sitting) nearshore between Little Egg Inlet and Brigantine; 4) 285 (all-behavior) versus 280 (sitting) nearshore south of Brigantine; 5) 420 (all-behavior) versus 345 (sitting) nearshore just south of Atlantic City; 6) 155 (all-behavior) versus 150 (sitting) nearshore between Atlantic City and Ocean City; 7) 725 (all-behavior) versus 690 (sitting) nearshore between just off Ocean City; 8) 220 (all-behavior) versus 210 (sitting) nearshore midway between Hereford Inlet and Ocean City.

For Northern Gannet, eight localized all-behavior density maxima (along with several sub-maximum densities on the order of 25 to 50 and higher) were estimated: 1) 130 offshore east of Barnegat Light (which was not mirrored by the sitting birds); 2) 105 nearshore at Barnegat Light (which was not mirrored by the sitting birds); 3) 135 and 160 nearshore between Little Egg Inlet and Barnegat Light (mirrored by a sub-maximum sitting density on the order of 50 and higher); 4) 275 midshore southeast of Little Egg Inlet (compared to 205 for sitting birds); 5) 255 just off Ocean City (which was not mirrored by the sitting birds); 6) 180 nearshore midway between Hereford Inlet and Ocean City (mirrored by a sub-maximum sitting density on the order of 50 and higher); 7) 260 nearshore north of Hereford Inlet (compared to 110 for sitting birds).

For Laughing Gull, nine localized all-behavior density maxima (along with several vague sub-maximum densities on the order of 25 to 50 and higher) were estimated: 1-2) 110 and 555 nearshore in the vicinity of Barnegat Light (compared to 110 and 430 for sitting birds); 3) 165 nearshore midway between Little Egg Inlet and Barnegat Light (compared to 155 for sitting birds; 4) 120 nearshore along Little Egg Inlet (mirrored by a sub-maximum sitting density on the order of 25 to 50 and higher); 5) 100 nearshore just off Ocean City (which was not mirrored by the sitting birds); 6) 105 nearshore south of Ocean City (compared to 105 for sitting birds); 7) 125 nearshore north of Hereford Inlet (compared to 125 for sitting birds); 8) 130 nearshore off Hereford Inlet (compared to 110 for sitting birds); 9) 195 midshore southeast of Hereford Inlet (compared to 180 for sitting birds).

For Long-tailed Duck, five localized all-behavior density maxima (along with several vague sub-maximum densities on the order of 25 to 50 and higher) were estimated: 1) 250 nearshore in the vicinity of Barnegat Light (mirrored by a sub-maximum sitting density on the order of 25 to 50 and higher); 2-4) 150, 245, and 375 in the vicinity of Little Egg Inlet (compared to 115, 230, and 325 for sitting birds); 5) 200 nearshore in the vicinity of Little Egg Inlet (compared to 180 for sitting birds). In addition, a sub-maximum density (on the order of 50 and higher) occurred for both all-behavior and sitting birds nearshore midway between Hereford Inlet and Ocean City.

For Herring Gull, three localized all-behavior density maxima (along with several sub-maximum densities on the order of 25 to 50) were estimated: 1) 205 nearshore in the vicinity of Barnegat Light; 2) 155 nearshore between Little Egg Inlet and Barnegat Light; 3) 105 nearshore south of Ocean City. Herring Gull sitting birds were not included among the top five most abundant species.

For Common Loon, one localized sitting density maximum was estimated: 205 nearshore at Hereford Inlet. In addition, several vague sub-maximum sitting densities (on the order of 25 and less) occurred: nearshore region north of Hereford Inlet; regions along Little Egg Inlet; and a region at Barnegat Light. Common Loon all-behavior birds were not included among the top five most abundant species.

8.4 GENERALIZED ADDITIVE MODELS AND SPATIAL REGRESSION MODELS

Spatial models were used for assessing relationships between covariates on avian density and distribution. Figures and tables for these tables are located in **Appendix M**.

8.4.1 Modeling Summary Total Birds: All Years and Seasons

Total bird density (all behavior) was modeled to determine the primary attributes (among the candidates longitude, latitude, depth, slope, distance to shoreline, and distance to nearest shoal) for predicting where birds are likely to concentrate along the New Jersey coastline. In summary, across all years and seasons, the spatial lag model shows that the density of total birds is spatially auto-correlated and related to depth and distance to shoreline (**Table M-1**). Furthermore, slightly more birds were encountered in 2008 than in 2009 (**Figure M-7**), but overall, bird density is greatest in the fall (**Figure M-8**). The best selected GAM included depth, distance to shoreline, longitude, and latitude (**Table M-2**). For example, the effect of depth on predicting changes in total bird density was positive, indicating that bird density declined in waters greater than 20 m (65.6 ft; **Figure M-9**). The effect of distance from shoreline shows that bird density declined with increasing distance from the shoreline, especially with distances greater than 40,000 ft (7.6 mi, **Figure M-10**). Overall, in examining the combined effects of latitude and longitude, spatial distribution of bird density was greatest in the southwest region of the Study Area (**Figures M-11** and **M-12**).

8.4.1.1 Total Birds: Fall

Total bird density and distribution in fall was clustered and bird aggregations were dense and patchy (**Table M-6**). The spatial lag model shows that depth was the most important factor for predicting the spatial variability of bird aggregations in fall (**Table M-6**). The best selected GAM for predicting changes in bird density and distribution in fall included depth, distance to shoreline, longitude, and latitude (**Table M-7**). Bird density and distribution declined steeply in waters greater than 20 m (65.6 ft; **Figure M-13**), and approximately 40,000 ft (7.6 mi) from the coastline (**Figure M-14**). Furthermore, the effect of spatial variation attributed to longitude and latitude on bird density indicates that during fall there are more birds in the southwest region of the Study Area (**Figures M-15** and **M-16**).

8.4.1.2 Total Birds: Spring

Total bird density and distribution in spring was spatially auto-correlated indicating that bird aggregations were dense and patchy (**Table M-8**). The spatial lag model shows that longitude and latitude are the important factors for predicting the spatial variability of bird aggregations in spring (**Table M-8**). The best selected GAM for predicting changes in bird density and distribution in spring included depth, distance to shoreline, longitude, and latitude (**Table M-9**). Bird density and distribution increased in waters greater than 20 m (65.6 ft; **Figure M-17**), and approximately 30,000 ft (5.7 mi) from the coastline (**Figure M-18**). Furthermore, the effect of spatial variation attributed to longitude and latitude on bird density indicates that during spring there are more birds in the western region along the entire north-south extent of the Study Area (**Figures M-19** and **M-20**).

8.4.1.3 Total Birds: Summer

Although bird density in summer was less than in other seasons, they were still found in dense patches and were spatially auto-correlated (**Table M-10**). The spatial lag model shows that depth, distance to shoreline, and latitude are important factors for predicting the spatial variability of bird aggregations in summer (**Table M-10**). The best selected GAM for predicting changes in bird density and distribution in summer included depth, distance to shoreline, distance to nearest shoal, longitude and latitude (**Table M-11**). The effect of depth on summer bird density and distribution showed that birds were concentrated in waters <10 m (32.8 ft) and increased in waters greater than 30 m (98.4 ft; **Figure M-21**). The effect of distance to shoreline indicated that bird density and distribution declined steeply after approximately 60,000 ft (11.4 mi) from the coastline (**Figure M-22**). In addition, bird density was associated with shoals (**Figure M-23**). The effect of spatial variation attributed to longitude and latitude on bird density indicates that during summer there are more birds in the southeastern region of the Study Area (**Figures M-24 and M-25**).

8.4.1.4 Total Birds: Winter

Total bird density and distribution in winter is clustered, indicating bird aggregations were dense and patchy (**Table M-12**). The spatial lag model shows that depth and distance to nearest shoal are important factors for structuring the spatial variability of bird aggregations in winter (**Table M-12**). The best selected GAM for predicting changes in bird density and distribution in winter included all variables: depth, slope, distance to shoreline, distance to nearest shoal, longitude, and latitude (**Table M-13**). Bird density and distribution decreased steeply in waters greater than 15 m (49.2 ft; **Figure M-26**), and approximately 40,000 ft (7.6 mi) from the coastline **Figure M-28**). The effect of distance to nearest shoal was a predictor of bird density and distribution indicating that birds exhibited an affinity for shallow water (**Figure M-29**). Furthermore, the effect of spatial variation attributed to longitude and latitude on bird density indicates that during spring there are more birds in the western region along the entire north-south extent of the Study Area (**Figures M-30** and **M-31**). Together, the effect of spatial covariates on winter bird density suggests the importance of shallow habitat features in the southeast.

8.4.1.5 Total Sitting Birds: All Years and Seasons

In summary, across all years and seasons, the spatial lag model shows the density of total sitting birds is clustered and the spatial variability of bird aggregations is related to depth and distance to nearest shoal (**Table M-14**). Furthermore, the probability of encountering sitting birds was greater in 2009 than in 2008. (**Figure M-32**), but overall, sitting bird density is similar in fall, spring, and winter with fewer birds in summer (**Figure M-33**). This is likely attributed to the seasonal presence/absence of wintering diving ducks.

The best selected GAM for predicting changes in total sitting bird density included depth, distance to shoreline, and latitude (**Table M-15**). For example, the effect of depth on predicting changes in total bird density was positive, indicating that bird density declined sharply in waters greater than 15 m (49.2 ft; **Figure M-34**). The effect of distance from shoreline shows that sitting bird density declined with increasing distance from the shoreline; approximately around distances greater than 20,000 ft (3.8 mi) from the coastline (**Figure M-35**). The effect of latitude (north/south variation) suggests that sitting bird density was relatively evenly concentrated along the coastline (**Figure M-36**). This is likely attributed to seasonal concentrations of diving ducks.

8.4.1.6 Total Sitting Birds: Fall

The spatial lag model shows that the density of total sitting birds in fall is clustered and the spatial variability of bird aggregations is related to depth, slope, and distance to nearest shoal (**Table M-16**). The best selected GAM for predicting changes in sitting bird density in fall included all covariates: depth, slope, distance to shoreline, distance to nearest shoal, latitude, and longitude (**Table M-17**). For example, the effect of depth on predicting changes in total bird density was positive, indicating that bird density declined sharply in waters greater than 20 m (65.6 ft; **Figure M-37**). The effect of slope indicated an increase in sitting bird density in waters where the slope increased by one degree (**Figure M-38**). The effect of distance from shoreline shows that sitting bird density in fall declined with increasing distance from the shoreline; approximately around distances greater than 20,000ft (3.8 miles) from the coastline (**Figure M-39**). The effect of latitude and longitude (northeast/southwest variation) suggests that sitting bird density similar in the north and south portion of the Study Area (**Figures M-41** and **M-42**).

8.4.1.7 Total Sitting Birds: Spring

The spatial lag model shows that the density of total sitting birds in spring is clustered and the spatial variability of bird aggregations is related to distance to nearest shoal and longitude (**Table M-18**). The best selected GAM for predicting changes in sitting bird density in spring included depth, distance to shoreline, longitude, and latitude (**Table M-19**). For example, the effect of depth on predicting changes in total sitting bird density was negative, indicating that bird density declined in waters less than 20 m (65.6 ft; **Figure M-43**). The effect of distance from shoreline shows that sitting bird density in spring declined approximately 20,000 ft (3.8 mi) from the coastline, but increased again after 90,000 ft (17 mi; **Figure M-44**), indicating that sitting birds occurred in both inshore and offshore waters. The effect of latitude and longitude on total sitting birds in spring suggests that birds were more abundant in the northwest region of the Study Area (**Figures M-45** and **M-46**).

8.4.1.8 Total Sitting Birds: Summer

The spatial lag model shows that the density of total sitting birds is spatially auto-correlated and the spatial variability of bird aggregations is related to distance to nearest shoal (**Table M-20**). The best selected GAM for predicting changes in sitting bird density in summer included depth, distance to shoreline, distance to nearest shoal, longitude, and latitude (**Table M-21**). The effect of depth on predicting changes in total sitting bird density showed that bird density increased in waters greater than 30m (**Figure M-47**). Moreover, the effect of distance from shoreline shows that sitting bird density in spring declined approximately 60,000 ft (11.4 mi) from the coastline, but increased again at 120,000 ft (22.3 mi) from the coastline (**Figure M-48**), indicating that sitting birds occurred in both inshore and offshore waters. Sitting birds were positively associated with shoals and density peaked around 60,000ft (11.4 miles), possibly indicating that birds were present between shoals (**Figure M-49**). The effect of latitude and longitude on total sitting birds in summer suggests that birds were abundant inshore and offshore, especially at mid-latitudes in the Study Area (**Figures M-50** and **M-51**).

8.4.1.9 Total Sitting Birds: Winter

The spatial lag model shows that the density and spatial variability of total sitting birds is related to depth and distance to nearest shoal (**Appendix M: Table M-22**); however, the best selected GAM for predicting changes in sitting bird density in winter included depth, and distance to shoreline, (**Table M-23**). Bird density declined in waters greater than 10 m (32.8 ft), indicating that birds were selecting to sit in shallow waters depth (i.e., principally diving ducks closer to the coastline; **Figure M-52**). Moreover, the effect of distance from shoreline shows that sitting bird density in winter declined approximately 20,000 ft (3.8 mi) from the coastline, further supporting the importance of nearshore habitat utilized by birds (**Figure M-53**).

8.4.2 Modeling Summary Species Accounts

8.4.2.1 Northern Gannet

Northern Gannets were highly conspicuous members of the avian community and were present in all seasons. There were slightly more gannets present in 2009 than in 2008 (**Figure M-54**), and there were more gannets in fall and spring than in summer and winter (**Figure M-55**), indicating that seasonal transitions are important factors for predicting the presence of gannets in the Study Area. The spatial variability of northern gannet density was modeled across all seasons using spatial regression models. A relationship was not found between spatial covariates and the spatial variability of Northern Gannet aggregations (**Table M-24**); however, a GAM fitted to the density of Northern Gannets revealed a complex relationship between spatial covariates and predicting changes in bird density at sea (**Table M-25**). The best selected GAM included depth, distance to shoreline, distance to nearest shoal, longitude and latitude (**Table M-25**). The density of Northern Gannets were chiefly found in waters greater than 10 m (**Figure M-56**), and ranged approximately 50,000 ft (9.5 mi) from the coastline (**Figure M-57**). In addition, Northern Gannets were highly associated with shoals and were typically found within 10,000 ft (1.9 mi) from the nearest shoal (**Figure M-58**). In relation to changes in latitude and longitude, the probability of encountering Northern Gannets increased in the southwest region of the Study Area (**Figures M-59** and **M-60**). Together, these results suggest that predicting changes in density of Northern Gannets is governed by the presence of shoals, within 50,000 ft (9.5 mi) from the coastline in the southwest region of the Study Area.

8.4.2.2 Diving Ducks

Changes in density of diving ducks were modeled to assess the importance of coastal habitat for these species that are abundant in winter off of New Jersey. These species are typically found in large aggregations that are persistent throughout winter months in coastal waters. The spatial variability of Scoters and Long-tailed Ducks was chosen to be modeled.

Species of Scoters (Surf, Black, and White-winged) were combined to examine the relative importance of coastal habitat utilized by these diving birds. There were slightly more Scoters present in 2008 than in

2009 (**Figure M-61**), and there were more Scoters in winter than in fall and/or spring (**Figure M-62**), indicating these birds reach peak density levels in winter. The spatial variability of Scoter density across all seasons was modeled using spatial regression models. The spatial variability of Scoter aggregations was found to be influenced by distance to shoreline and longitude and latitude (**Table M-26**), indicating that Scoters were selecting specific regions along the New Jersey coastline. This is visualized in the kernel density maps. A GAM fitted to the density of Scoters shows the effect of each spatial covariate on predicting changes in bird density (**Table M-27**). The best selected GAM included depth, distance to shoreline, distance to nearest shoal, longitude, and latitude (**Table M-27**). The density of Scoters peaked in waters 10 m (**Figure M-63**), and ranged approximately 20,000 ft (3.8 mi) from the coastline, but declined 40,000-60,000 ft (7.6-11.4 mi) and increased again offshore at approximately 100,000 ft (19 mi) from the coast (**Figure M-64**). In addition, Scoters were highly associated with shoals and were typically found within 10,000 ft (1.9 mi) to 20,000 ft (3.8 mi) from shoals (**Figure M-65**), which may possibly indicate that they are feeding at and between shoals. In relation to changes in latitude and longitude, the probability of encountering Scoters increased moving west (inshore) and north in the Study Area (**Figures M-66** and **M-67**).

There were more Long-tailed Ducks in 2009 than in 2008 (**Figure M-68**), and there were more ducks present in winter than in spring (**Figure M-69**). The spatial variability of Long-tailed Duck density was modeled across winter and spring using spatial regression models. The spatial variability of Long-tailed Duck aggregations was found to be influenced by depth, slope and distance to shoals (**Table M-28**), indicating that Long-tailed Ducks were selecting specific regions along the New Jersey coastline. This is visualized in the kernel density maps. A GAM fitted to the density of Long-tailed Ducks shows the effect of each spatial covariate on predicting changes in bird density (**Table M-29**). The best selected GAM included slope, distance to shoreline, distance to nearest shoal, longitude, and latitude (**Table M-29**). The density of Long-tailed Ducks peaked in waters where the slope was 2° (**Figure M-70**), and ranged approximately 50,000 ft (9.5 mi) from the coastline, but declined steadily thereafter (**Figure M-71**). In addition, Long-tailed Ducks were positively associated with distance to shoals and were typically found 30,000 ft (5.7 mi) from shoals (**Figure M-72**). In combination with the effect of slope, it is possible that Long-tailed Ducks are concentrating on the edges of the shoals. In relation to changes in latitude and longitude, the probability of encountering Long-tailed Ducks increased greatly beyond -74.2°W (moving east) and their density was greater in the southern portion of the Study Area (**Figures M-73** and **M-74**).

8.4.2.3 Loons

The survey data reported more Common Loons in 2009 than in 2008 (**Figure M-75**) and were present in spring, fall and winter (**Figure M-76**) (loons migrate further north to breeding grounds during summer). The spatial variability of Common Loons was modeled across fall, winter and spring using spatial regression models. We found that the spatial variability of Common Loons is influenced by depth (**Table M-30**). A GAM fitted to the density of Common Loons shows the effect of each spatial covariate on predicting changes in bird density (**Table M-31**). The best selected GAM included depth and longitude (**Table M-31**). The density of Common Loons declined steeply with increasing depth and the density of loons is generally located in water depths up to 10 m (32.8 ft; **Figure M-77**). This can also be seen in the effect of longitude on Common Loon density (**Figure M-78**). Loon density declined steeply between -74.8° to -74.6° longitudes and change in density flattened out thereafter suggesting that Common Loons are tightly coupled to the coastline of New Jersey. Therefore, the probability of encountering Common Loons decreases greatly beyond -74.6°W (moving east).

The survey data reported more Red-throated Loons in winter than in spring (**Figure M-79**). The spatial variability of Red-throated Loons was modeled across winter and spring using spatial regression models. The spatial variability of Red-throated Loons was found to be influenced by distance to shoreline, longitude, and latitude (**Table M-32**). A GAM fitted to the density of Red-throated Loons shows the effect of each spatial covariate on predicting changes in bird density (**Table M-33**). The best selected GAM included depth, distance to shoreline, distance to shoal, longitude, and latitude (**Table M-33**). The density of Red-throated Loons declined gradually with increasing depth and showed no effect after 20 m (65.6 ft), indicating that loons were utilizing waters ranging from 1 to 20 m (3.3 to 65.6 ft) in depth (**Figure M-80**). The effect of distance to shoreline showed that the density of loons utilizing onshore and offshore waters

(**Figure M-81**, ranging between 0 to 40,000 ft (7.6 mi) inshore and 90,000 (17 mi) to 120,000 ft (23 mi) offshore). The effect of distance to shoal shows that the density of loons was generally located between 20,000 (3.78 mi) and 60,000 ft (11.4 mi) from shoals (**Figure M-82**). The probability of encountering Red-throated Loons increased when moving west at mid-latitudes in the survey area (**Figures M-83** and **M-84**).

8.4.2.4 Gulls and Terns

Changes in density of Herring Gulls were modeled to determine factors important for predicting their location. The survey data reported more Herring Gulls in 2009 than in 2008 and slightly fewer gulls in summer compared to fall, spring, and winter (**Figures M-85** and **M-86**). The spatial variability of Herring Gulls was modeled using spatial regression models and found that all spatial covariates were important in predicting the clustering of gull aggregations (**Table M-34**). A GAM fitted to the density of Herring Gulls shows the effect of each spatial covariate on predicting changes in bird density (**Table M-35**). The best selected GAM included depth, slope, distance to shoreline, distance to shoal, longitude, and latitude (**Table M-35**); however, due to their conspicuousness in coastal waters, the only clear effects on gull density were depth, distance to shoreline, longitude, and latitude. The effect of depth on gull density declined steeply and showed that gulls were chiefly occupying water depths between 1 to 15 m (3.3 to 49.2 ft; **Figure M-87**). The largest gull densities were encountered offshore (distances greater than 60,000 ft (11.4 mi) from the coastline, (**Figure M-89**). The probability of encountering Herring Gulls increased moving west and there were more birds at southern latitudes (**Figures M-91** and **M-92**).

The survey data reported no difference in density of Laughing Gulls in 2008 and 2009, but there were more gulls present in fall than in summer (**Figures M-93** and **M-94**). This is attributed to the fact that Laughing Gulls are local breeders off New Jersey and the increase in gull density in fall is likely attributed to young birds recruiting to the population. The spatial variability of Laughing Gulls was modeled using spatial regression models. Depth and distance to shoal were important in predicting the clustering of gull aggregations (**Table M-36**). A GAM fitted to the density of Laughing Gulls shows the effect of each spatial covariate on predicting changes in bird density (**Table M-37**). The best selected GAM included depth, distance to shoreline, longitude, and latitude (**Table M-37**). The effect of depth on gull density showed that gulls were chiefly occupying water depths between 1 to 15 m (**Figure M-95**). The effect of distance to shoreline on gull density declined steeply with increasing distance and showed that gulls were found from the shoreline up to 25,000 ft (4.7 mi) from the coast (**Figure M-96**). The probability of encountering Laughing Gulls declined when west and north (**Figures M-97** and **M-98**).

Changes in density of Common Terns were modeled to determine factors important for predicting their location. Common Terns are local breeders in New Jersey and are typically found during summer months (**Figure M-99**). The spatial variability of Common Terns was modeled using spatial regression models. Distance to shoreline, longitude and latitude were important in predicting the clustering of tern aggregations (**Table M-38**). A GAM fitted to the density of Common Terns shows the effect of each spatial covariate on predicting changes in bird density (**Table M-39**). The best selected GAM included distance to shoreline, distance to shoal, longitude, and latitude (**Table M-39**). The effect of distance to shoreline on tern density showed that terns were found from the shoreline up to 60,000 ft (11.4 mi) from the coast (**Figure M-100**). In addition, tern density increased slightly with increasing distance from shoals (**Figure M-101**). The probability of encountering Common Terns increased greatly when moving south and east in the survey area (i.e., declined moving northwest, **Figures M-102** and **M-103**).

8.4.2.5 Storm-Petrels and Shearwaters

Although storm-petrels and shearwaters occur less frequently than the other species reported, their densities tend to dominate the summer avifauna off of the coast of New Jersey. In 2008, there was an influx of Wilson's Storm-Petrels and Cory's Shearwaters in the survey area. The densities of storm-petrels and shearwaters were modeled to investigate the effect of spatial covariate on predicting changes in their density in the Study Area. These species are generally found in offshore waters.

The spatial variability of Wilson's Storm-Petrels was modeled using spatial regression models and found that depth and distance to shoreline are important in predicting the clustering of storm petrel aggregations (**Table M-40**). A GAM fitted to the density of Wilson's Storm-Petrels shows the effect of each spatial covariate on predicting changes in bird density (**Table M-41**). The best selected GAM included depth, distance to shoreline, distance to shoal, longitude, and latitude (**Table M-41**). The effect of depth on storm-petrel density showed that petrels were found in waters up to 20 m (**Figure M-104**). The effect of distance from shoreline on storm-petrels showed that storm-petrel density increased sharply after 50,000 ft (9.8 mi) from the coastline (**Figure M-105**). In addition, storm-petrel density increased slightly with increasing distance from shoals (**Figure M-106**). The probability of encountering Wilson's Storm-Petrels increased greatly when moving north and west in the survey area (i.e., declined moving southeast; **Figures M-107** and **M-108**).

The spatial variability of Cory's Shearwaters was modeled using spatial regression models. Distance to shoals was important in predicting the clustering of shearwater aggregations (**Table M-42**). A GAM fitted to the density of Cory's Shearwaters shows the effect of each spatial covariate on predicting changes in bird density (**Table M-43**). The best selected GAM included depth, distance to shoreline, distance to shoal, longitude, and latitude (**Table M-43**). The effect of depth on shearwater density showed that shearwaters were principally found in deeper waters, with their density steeply increasing in waters greater than 30 m (98.4 ft; **Figure M-109**). The effect of distance from shoreline on shearwaters showed that their density decreased moving offshore to 20,000 ft (3.29 mi) and increased abruptly after 90,000 ft (17 mi) from the coastline (**Figure M-110**). Shearwater density showed a peak around 60,000 ft (11.4 mi) from shoals (**Figure M-111**). The effect of longitude shows that increased shearwater density occurred in the east at mid-latitudes in the survey area (**Figures M-112** and **M-113**).

8.5 DISCUSSION

Two years of shipboard surveys were synthesized to model and predict the spatial distribution of birds using kernel density interpolation and spatial regression. Spatial models were developed to quantify the effect of each spatial covariate for predicting changes in bird density and distribution. In summary, along with the kernel density maps that show where/when birds are likely to concentrate, the modeling showed that distance to shoreline and depth are useful and important predictors of changes in bird density and distribution. The total bird density was greater in the southeast portion of the Study Area during fall, summer, and winter, but was more concentrated in the north during spring; however, this pattern was not consistent across all species (**Appendix M: Tables M-2** and **M-3**). Therefore, the density and distribution of bird species in New Jersey coastal waters is dynamic with respect to seasonality and is driven by species specific responses.

Using the kernel density maps, spatial covariates were calculated to develop insight into the geographic distribution to describe the basic attributes of coastal habitat utilized by birds. By incorporating these data in a geographic information system, changes in bird density were quantified as a function of depth, slope, distance to shoreline, and distance to shoals. In addition, it was determined whether there was a spatial gradient in bird density (north/south or east/west) for a variety of species. The collection of kernel density maps were a valuable tool for identifying important locations where and when (by month and season) birds are most likely to concentrate. These data were also used to develop a semi-qualitative environmental sensitivity index that is discussed in **Volume I: Chapter 4.0**.

Spatial regression and GAMs were used to assess the contribution of each covariate in predicting spatial variability of bird aggregations and to plot their effect on bird density. A summary of these results is outlined in **Appendix M: Tables M-2** and **M-3**. In general, depth and distance to shoreline were important predictors of bird density and distribution. For example, using the combined two-year dataset, it was determined that bird density and distribution declined in waters greater than 20 m and 7.6 mi from the coastline; however, there was a strong seasonal effect in these values that is important to consider. Although bird density was generally greater in the fall (migration and seasonal visitors take up residence along the New Jersey coastline), birds were principally concentrated in waters up to 20 m in depth and 7.6 mi from the coastline; the same result observed for the entire dataset. In spring, birds were concentrated in deeper waters (>20 m) than in the fall (<20 m). Moreover, in summer, bird density ranged further offshore (11.4 mi) and increased in waters greater than 30 m in depth. In winter, we found that bird density was concentrated in waters less than 15 m in depth and within 7.6 mi from the coastline.

Total sitting bird densities were modeled to identify where birds are most likely to reside, concentrate, and for some species, feed (i.e., loons, ducks, and gulls sitting on the water may indicate foraging locations). In general, sitting birds were most likely to occur in waters less than 15 m in depth and within 3.8 mi from the coastline. In fact, in fall, spring, and winter, sitting bird density was concentrated in waters within 3.8 mi from the coastline, whereas in summer the distance increased to 11.4 mi.

The seasonal changes in density and distribution of total birds were dynamic and related to changes in bird community composition. For example, in the fall and winter there were dense concentrations of diving ducks that are absent in the summer when the bird community was primarily composed of terns, gulls and storm-petrels. This difference in community composition was likely responsible for the varying degree of bird density clustered inshore and offshore. The models detected this and quantified the usage of coastal habitat by total birds as a function of depth and distance to shoreline. These dynamics were investigated further to quantify the effect of covariates for predicting changes in species distribution. Scoter density and distribution exhibited a peak in waters 10 m in depth and were concentrated within 3.8 mi from the coast and increased offshore around 19 mi from the coast. Northern Gannets, which were present in each season, were generally concentrated in waters greater than 10 m in depth that was within 9.5 mi from the coastline. Laughing Gulls and Common Terns, which are seasonal summertime breeders in New Jersey, displayed interesting distribution patterns. Laughing Gulls were generally concentrated within 4.7 mi from the coast and decreased in waters greater than 15 m in depth. On the other hand, Common Terns ranged further offshore and their density declined around 11.4 mi from the coast, and thereby occupied a wider range of coastal habitat than Laughing Gulls. The density and distribution of Cory's Shearwaters, which were also summertime visitors, showed an increase in density offshore in waters greater than 30 m in depth around 17 mi from the coastline.

In conclusion, bird density and spatial distribution exhibited a striking onshore to offshore gradient that was highly variable among seasons and linked to changes in community composition. The results in this section pinpoint where repeated maximum densities were likely to occur in relation to a variety of species. This information is integral to the understanding of the spatial ecology of marine birds along the New Jersey coastline and should be used to examine potential changes in habitat due to environmental changes from human activity. Physical attributes were used for describing species density and distribution. Future studies should investigate the biological aspects (i.e., prey distributions) for predicting finer scale species distribution. We found predictable locations where large concentrations of sitting (rafting) birds were found. These locations likely represent important feeding areas for birds and more information is needed on why these areas are attractive to birds. For example, some of these locations were distributed at or near the location of river mouths which may enhance the likelihood of nutrient flux and or prey concentration. Although more birds were present in fall and winter in comparison to spring and summer, in these latter seasons, the locations highlighted as important bird concentration likely reflect the habitat selection for foraging by coastal breeding species that may be sensitive to offshore development (in and around breeding colonies). Therefore, future studies ought to address these potential changes to coastally breeding species (e.g. common tern, laughing gulls) to determine their specific habitat requirements.

The modeling results in this section provide a baseline understanding on where birds are likely to concentrate in geographic space along the NJ coast with respect to season. Although we focused on understanding the broad scale distribution patterns of birds among seasons, the modeling framework can be scaled down to specific locations (i.e. database can be sectioned to smaller areas) and similar question can be addressed on finer scales all along the coast. The data and modeling results presented in this section can be used to address questions regarding birds and offshore wind energy development. The main result coming from this section is that water depth, distance to shoreline and distance to shoals are important for understanding the spatial distribution patterns of total bird density and for a variety of species from difference families (e.g. gannets, gulls, ducks). The basic effects of covariates listed and described in this section should provide management with a basic understanding of where and when birds are likely to concentrate and ultimately in what water depths and how close to shore. To generalize, determining suitable offshore wind energy development may be considered as a tradeoff between distance to shoreline and water depth. The data and modeling results presented in this section focused on this tradeoff for birds as well. This study on the baseline distribution characteristics of birds off NJ represents a first step in making this a reality to potentially minimize the effect of offshore wind energy development on birds.

8.6 SUMMARY

In conjunction with the NJDEP Ecological Baseline Study, spatial models were developed for predicting changes in density and spatial distribution of birds to identify important regions used by birds within the Study Area. Our objective was to quantify where birds were most likely to concentrate in relation to geo-physical habitat features (e.g., depth, shoals) and predict where birds were likely to occur seasonally.

8.6.1 Methods

Two years of bimonthly shipboard surveys were investigated to estimate spatial variability of birds within the Study Area. The focus was placed on a variety of species (e.g., waterfowl, gulls, storm-petrels) to examine species-specific distribution patterns. Strip-transect data collected during bimonthly ship surveys within the Study Area were examined to determine spatial variability in bird density. Interpolation (e.g., kernel density), spatial regression, and GAMs were used to quantify the relationship between spatial covariates (e.g., bathymetric- and distance-based metrics) and birds.

8.6.2 Results and Main Conclusions

In summary, along with the kernel density maps that show where/when birds were likely to concentrate, it was determined that distance to shoreline and depth were useful and important predictors of changes in bird density and distribution. The collection of kernel density maps were a valuable tool for identifying important locations where and when (by month and season) birds were most likely to concentrate. Depth and distance to shoreline were important predictors of bird density and distribution. Overall, bird density declined in waters greater than 20 m and 7.6 mi from the coastline. Total bird density was greater in the southeast portion of the Study Area during fall, summer, and winter but was more concentrated in the north during spring; however, there was a strong seasonal effect in these values that was important to consider. Although bird density was generally greater in the fall (migration and seasonal visitors take up residence along the New Jersey coastline), birds were principally concentrated in waters up to 20 m in depth and 7.6 mi from the coastline; the same result observed for the entire dataset. When we modeled spring, it was determined that birds were concentrated closer to the coast (most density was within 5.7 mi), but occurred in deeper waters (>20 m) than in the fall (<20 m). Moreover, in summer, bird density ranged further offshore (11.4 mi) and increased in waters greater than 30 m in depth. In winter, bird density was concentrated in waters less than 15 m in depth and within 7.6 mi from the coastline.

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