Radar Analysis of Fall Bird Migration Stopover Sites in the Northeastern U.S.

Final Report

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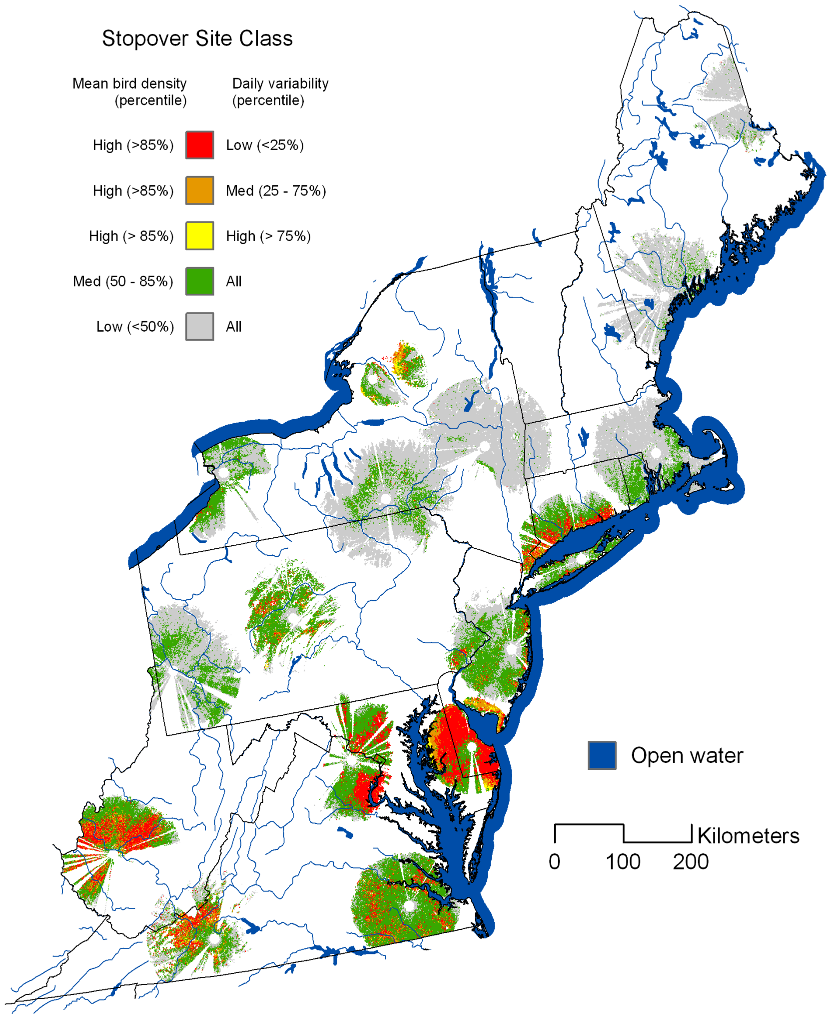

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EXECUTIVE SUMMARY

The national network of weather surveillance radars (WSR-88D/NEXRAD) detects birds in flight, and has proven to be a useful remote-sensing tool for ornithological study. We used data collected during Fall 2008 and 2009 by 16 WSR-88D and 3 terminal Doppler weather radars in the northeastern U.S. (U.S. Fish and Wildlife Service Region 5) to study the spatial distribution of landbirds shortly after they leave daytime stopover sites to embark on nocturnal migratory flights. The aerial density of birds, as estimated by radar reflectivity, was georeferenced to the approximate locations on the ground from which birds emerged. We classified bird stopover use by the magnitude and variation of radar reflectivity across nights; areas were considered ‘important’ stopover sites from a conservation perspective if relative bird density was consistently or occasionally high. These results were used to develop models to predict potentially important stopover sites in portions of the region not sampled by the radars, based on land cover, ground elevation, and geographic location. Locally important stopover sites generally were associated with deciduous forests embedded within landscapes dominated by developed or agricultural lands, or near the shores of major water bodies. Large areas of regionally important stopover sites were located along the coastlines of Long Island Sound, throughout the Delmarva Peninsula, in areas surrounding Baltimore and Washington, along the western edge of the Adirondack Mountains, and within the Appalachian Mountains of southwestern Virginia and West Virginia. Important stopover sites, both within and outside radar-sampled areas and on 34 national wildlife refuges sampled by the radars, were mapped in a Geographic Information System, providing base maps for conservation uses and a sampling frame for field surveys to ‘ground truth’ the radar and analytical results. Our analysis indicates that preserving patches of natural habitat, particularly deciduous forests, in developed or agricultural landscapes and along major coastlines should be a priority for conservation plans addressing the stopover requirements of migratory landbirds in the northeastern U.S.

INTRODUCTION

Identification and protection of important migration stopover areas is fundamental to the development of comprehensive strategies for the conservation of migratory bird populations (Moore and Simons, 1992; Hutto, 2000; Rich et al., 2004; Mehlman et al., 2005; Moore et al., 2005; Faaborg et al., 2010a, 2010b), many of which have declined significantly over recent decades (Robbins et al., 1989; Askins et al., 1990; Sauer et al., 2011). Losses in the extent and quality of habitats are the primary causes of population declines in migratory birds during the breeding and wintering periods of the annual cycle (Faaborg et al., 1995, 2010b; Sherry and Holmes, 1995), and conservation efforts for migratory landbirds in North America have focused on protecting or enhancing breeding habitat. However, migration may be the period in the annual cycle when mortality is highest (Sillett and Holmes, 2002; Newton, 2006), and therefore it likely has an important role in limiting migratory bird populations (Sherry and Holmes, 1995; Hutto, 2000; Newton, 2006).

Most migratory landbirds are nocturnal migrants, embarking on migratory flights *en masse* at around dusk and landing sometime before dawn. They take up to one third of each annual cycle to complete their biannual migrations, spending upwards of 95% of this time resting and refueling rather than in actual migratory flight (Hedenström and Alerstam, 1997; Alerstam, 2003). Their successful migration thus depends on the availability of suitable stopover sites. Although landbirds generally migrate along a broad front, with a seemingly large number of places to stop *en route*, in parts of North America a lack of favorable habitats may threaten successful or timely migration (e.g., Tankersley and Orvis, 2003). This is of particular concern for the northeastern U.S., where human-dominated land-use/cover currently occupies 78% of the land area and is increasing faster than in other regions (Brown et al., 2005).

The national network of weather surveillance radars (model WSR-88D or NEXRAD) routinely detects a variety of bird movements across the U.S. In particular, these radars have been used to observe the spatial distribution of birds during migratory stopover by measuring the amount of returned electromagnetic radiation reflected from birds in the radar beam shortly after they leave daytime stopover sites at the onset of nocturnal migratory flight (e.g., Gauthreaux and Belser, 2003; Diehl and Larkin, 2005; Bonter et al., 2009; Buler and Diehl, 2009). By observing the magnitude and variability of bird density through one or more migration seasons, these radars allow for a spatially-explicit assessment of the relative use of migratory stopover sites across large geographic areas.

From an ecological perspective, the nature of how migrants use stopover sites varies across a range of intrinsic factors (e.g., resource availability) and extrinsic constraints (e.g., proximity to a geographic barrier, physiological condition of the bird, weather) that operate at multiple scales (Hutto, 1985; Moore et al., 2005; Buler et al., 2007). Stopover sites have been categorized into different functional types along a continuum (Mehlman et al., 2005), based on their capability to support the continued migration or survival of migrants at a given point in space or time.

At one end of the continuum are “fire escapes” (Mehlman et al., 2005), sites that are not used regularly by migrants, but are vital to birds that are exhausted or in emergency situations (e.g., sudden, severe weather). Fire escapes typically are small isolated habitat patches adjacent to geographic barriers, such as large bodies of water, or within highly altered landscapes (e.g., cities). Examples include islands in the Gulf of Mexico (Moore and Kerlinger, 1987) and the tips of peninsulas along the Atlantic Coast or Great Lakes (Dunn, 2001). They offer short-term resting spots, but lack sufficient resources for migrants to replenish energy reserves. Density of migrants using fire escapes can be high. However, because weather is thought to be a main factor driving their use, intra- and interannual variation in migrant densities also may be high.

In the center of the continuum are “convenience store” stopover sites. These are sites that are of moderate quality, offering some resources for replenishment of energy reserves, and typically located in an unsuitable landscape matrix. Examples include forested patches in central Illinois, and parks within metropolitan areas (Brawn and Stotz, 2001; Seewagen and Slayton, 2008). Use of convenience stores by migrants may be consistently high over time.

At the other end of the continuum are stopover sites that are “full service hotels”, where resources are plentiful and migrants may rest and replenish their energy reserves with low risk of predation. Examples include extensive areas of forest. Migrants consistently use these sites in great numbers, though densities may be low owing to the large extent of the habitat (Gauthreaux and Belser, 1998, 1999a).

Data from weather surveillance radars can be used to estimate and map migrant densities and landscape context, two of the factors used to classify and prioritize stopover sites, but these radars do not provide measures of the third factor, the intrinsic characteristics of sites (e.g., abundance of resources). However, from a conservation perspective, stopover sites that are consistently used by migrants in relatively high densities are “important” (sensu Mehlman et al., 2005) because these sites will harbor the most individual birds per unit area through the course of a migration season, regardless of their ecological function. In fact, sites that exhibit consistent high-density use can occur along the entire continuum of functional types.

In this study, we used data collected by weather surveillance radars (WSR) in U.S. Fish and Wildlife Service (USFWS) Region 5 (the 13 states from Virginia north to Maine; Figure 1) to map landbird use of stopover sites during the fall migration. Region 5 includes the first stopover site(s) for many southward-bound migrants, including millions of juvenile birds on their first migratory flights. Although WSR data have been used previously to identify migrant stopover sites in portions of Region 5 (Mabey et al., 2007; Bonter et al., 2009; Mizrahi et al. in prep.), this is the first comprehensive and standardized assessment using all radars within the region. Recent advances in radar technology and data processing made this an ideal time to conduct a region-wide assessment. In Spring 2008, the spatial resolution of the data collected by WSR-88D radars in the national network was increased eight-fold. Also, Buler and Diehl (2009) have developed radar data processing techniques that reduce biases in radar measures to produce more accurate and precise quantitative measures of bird distributions during stopover. The large number of radars involved allowed us to also develop statistical models to predict potentially important stopover sites in portions of Region 5 not sampled by the radars, using geographic location, land cover, elevation, or other characteristics that explain variability in relative bird density within the radar-sampled areas.

OBJECTIVES

Our overall objective was to map important stopover sites within USFWS Region 5 used by landbirds during the fall migration. Specific objectives included: 1) use WSR data to identify and map important stopover sites within roughly 80 km of radar stations (i.e., radar-sampled areas), 2) assess migrating landbird use of National Wildlife Refuges within the radar-sampled areas, 3) develop statistical models to predict and map potentially important stopover sites in portions of the region not sampled by the radars, and 4) continue to develop new and improved radar data processing algorithms and software to help automate data screening, identify biological targets, and quantify bird densities. The maps produced are intended to be used as decision support tools for conservation planning, and can serve as a sampling frame for future field surveys to 'ground truth' the radar and analytical results.

STUDY AREA

We used observations from 16 WSR-88D radars and three Terminal Doppler Weather Radars (TDWR) located within Region 5 (Figure 1). WSR-88D radars are operated by the National Weather Service of the National Oceanic and Atmospheric Administration (NOAA) or the Department of Defense (DOD), and TDWR are operated at some major airports by the Federal Aviation Administration. The cumulative sampling area among radars potentially covers approximately 26 million of the 63 million hectares (42%) of land area within Region 5. The radars also potentially provide direct observation

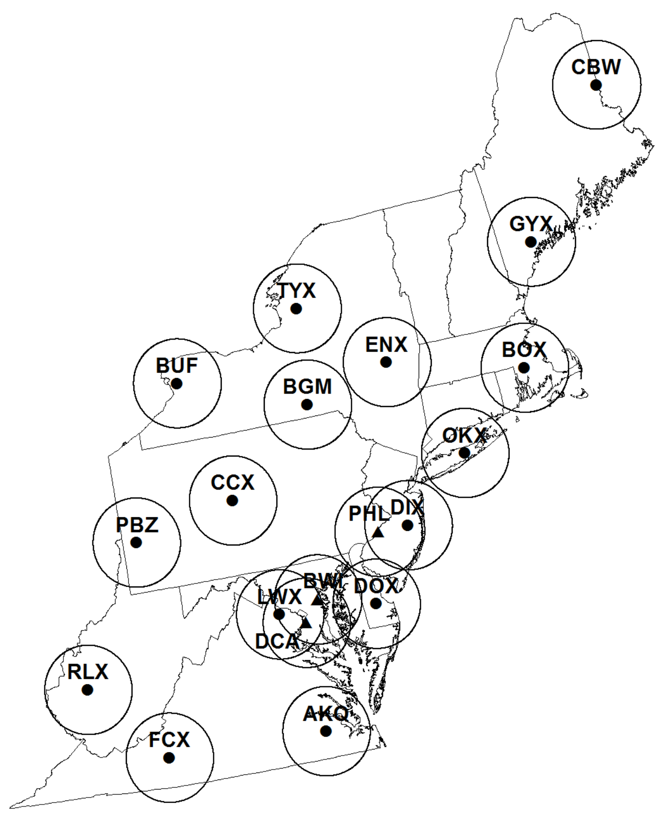

Figure 1. Locations and names of 16 WSR-88D radars (circles) and 3 TDWR (triangles) and their 80-km radius sampling areas.

of migratory bird distributions for 103,043 ha of

201,653 (51%) of the land area among 38 of the 73 (52%) National Wildlife Refuges within the region.

METHODS

WSR operation and data. WSR-88D transmits horizontally-polarized electromagnetic radiation at a wavelength around 10 cm (S band) and a nominal peak power of 750 kW with a half-power beamwidth (3-dB) of 0.95° (Crum and Alberty, 1993). The radar measures the strength of the returned radiation in units of Z (reflectivity) on a logarithmic scale to the nearest half decibel (0.5 dB) from airborne 'targets' (e.g., birds) within a sampled volume of airspace. The radar also measures the mean speed (in knots) of targets relative to the radar (radial velocity). Radar reflectivity is positively correlated to the density of birds in the airspace (Gauthreaux and Belser, 1998, 1999a; Diehl et al., 2003).

The radar makes an individual sampling 'sweep' of the airspace by rotating the antenna 360° from its fixed location at a given tilt angle relative to the horizon (Figure 2). WSR-88D radars make a 'volume scan' of the airspace every six or ten minutes, depending on whether they are set to operate in 'precipitation' or 'clear air' mode; each volume scan is comprised of a set of 5 to 14 sweeps, each collected at a different tilt angle ranging from 0.5° to 19.5° above the horizon. On each sweep, data are measured within 'sample volumes' from 2 to 230 km in range from the radar along each of the 720 radials. We used Level II data for analysis, which has sample volume dimensions of 250 m in range by 0.5° in diameter (i.e., 'super' resolution). However, data from the DOX and TYX radars, operated by the DOD, are archived at the coarser 'legacy' sample volume resolution of 1 km x 1°.

WSR-88D radars provide nearly complete coverage of meteorological phenomena across the U.S., but a stratified and incomplete coverage of biological phenomena (Figure 1). This is because birds and other biological targets fly relatively close to the ground, and the radar beam begins to completely pass over birds embarking on migratory flight at a range of about 80 km. Also, topography and, sometimes, human infrastructure (e.g., tall buildings) can block the radar beam, further limiting the area sampled around some radars. Within a 80-km radius of the radar there are 224,640 sample volumes in a single sweep.

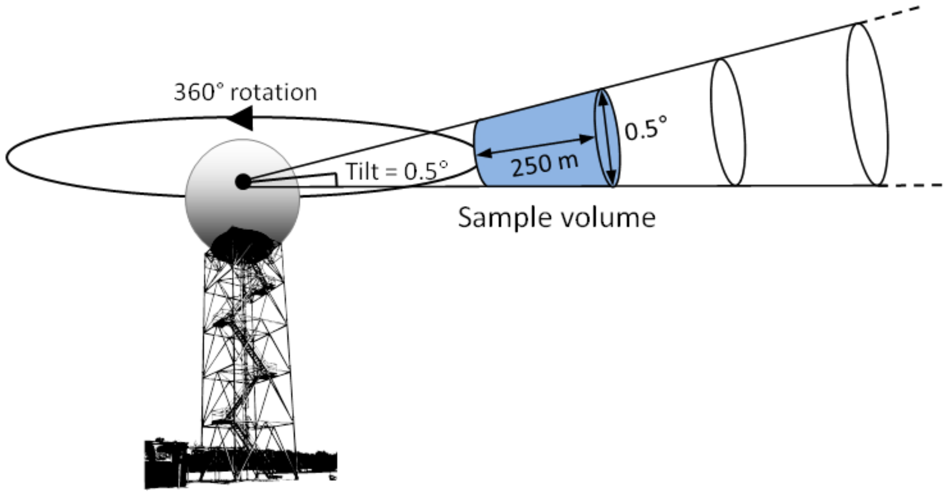

Figure 2. Illustration of operation and individual sample volume of a WSR-88D. Not drawn to scale.

TDWRs transmit radiation at a wavelength of 5 cm (C band) at a nominal peak power of 250 kW. We used the Level III long range base reflectivity scan product (a.k.a. TZL) for analysis, which has sample volume dimensions of 300 m x 0.5°. TZL sweeps are completed every 6 minutes at a tilt angle of 0.6°. Because TDWR operates using a different wavelength than WSR-88D, reflectivity measures from these two radars are not easily directly comparable.

Data screening and selection. We analyzed WSR-88D data collected during the periods of peak autumn landbird migration (15 August to 7 November) in 2008 and 2009 and obtained from the data archive hosted by NOAA's National Climatic Data Center (NCDC). Analysis of data from the three TDWRs was restricted to Fall 2009 because archived data were not available for Fall 2008. We visually screened radar sweeps of the lowest tilt angle to identify days when precipitation was present at dusk or there was extreme refraction of the radar beam toward the ground (a.k.a. anomalous propagation), which can occur under certain atmospheric conditions. These days were excluded from further analysis. For remaining days, we assessed the air speed and direction of movement of radar targets using radar radial velocity data from approximately 3 hours after sunset (i.e., peak of nocturnal migration) to determine whether targets were dominated by migrating birds or insects. For those WSR-88D sites where weather balloons are launched (n = 10), we first obtained upper air sounding data (wind speed and direction) archived by the University of Wyoming. We then estimated mean radar target airspeed from radial velocity data from the 3.5° tilt angle radar sweep, accounting for wind speed and direction using methods outlined by Browning and Wexler (1968). This higher tilt angle sweep has less ambiguity in altitude-specific measures of target speed and direction than lower tilt angle sweeps, and is less affected by beam refraction and blockage. We considered radar sweeps with mean target airspeeds above 5 m/s to be dominated by birds (Larkin, 1991; Gauthreaux and Belser, 1998). For WSR-88D sites without atmospheric sounding data, we obtained surface wind data from the nearest weather station in the NCDC archive. We then visually screened the radial velocity data from the 0.5° tilt angle radar sweep. We categorized sweeps to be dominated by birds if a majority of sample volumes had radial velocities ≥ 5 m/s above the surface wind speed.

Radar base grid and data masking maps. We produced base grid maps for each WSR-88D and TDWR for georeferencing the radar data and extracting landscape characteristics for analyses. Each base grid is a polar grid of 285,120 polygons with spatial resolution of 0.5° x 250 m around the radar out to a distance of 100 km. Polygons of DOX and TYX base grids had a spatial resolution of 0.25° x 1 km. Each polygon corresponds to the two-dimensional boundary of a radar sample volume, the elementary sampling unit of the radar.

We also used base grids to aid in the creation of maps to identify sample volumes to be masked (excluded) from data analyses (Figure 3). Sample volumes were masked if 1) there was partial or complete blockage of the 0.5° tilt angle radar beam due to topography or human infrastructure, 2) they were located over open water, or 3) persistent ground clutter contaminated their reflectivity measures. We used the base grids to determine the mean ground elevation (to the nearest 10 m) underneath sample volumes, using elevation data from the National Elevation Dataset (resolution 1 arc-second) assembled by the U.S. Geological Survey. We then calculated the amount of blockage of the 0.5° tilt angle radar beam due to topography, using the simplified beam interception function described by Bech et al. (2003) assuming standard atmospheric conditions. Radar data from sample volumes with 25% or more of radar

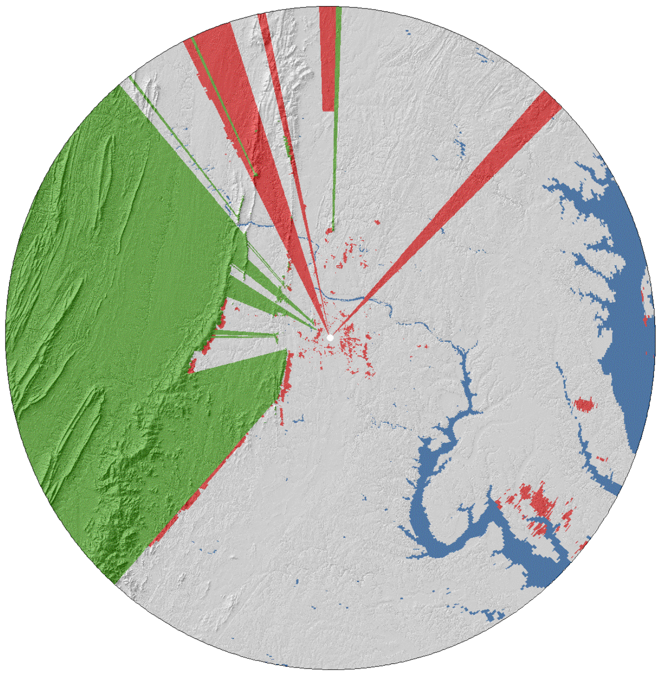

Figure 3. Masking map of the LWX radar in Sterling, VA, showing sample volumes excluded from analyses due to 1) topographic beam blockage (green), 2) dominance of open water (blue), or 3) persistent ground clutter contamination and other sources of beam blockage (red) .

beam blockage were not included in analyses. For radars located in mountainous areas, large portions of the coverage area were masked out due to beam blockage. We also determined the amount of open water beneath sample volumes using data from the National Land Cover Dataset (NLCD 2006; Fry et al., 2011), and excluded from analyses radar data from sample volumes with ≥75% of their associated base grid polygon comprised of water. For radars located in coastal areas, this meant that large portions of the radar coverage area were masked out. Note that we dropped from further consideration radar station CXX, in Burlington, Vermont, which provided little coverage for our purposes due to topographic blockage from the Green and Adirondack Mountains and land coverage by Lake Champlain.

Finally, we produced ‘clutter’ maps to identify sample volumes to exclude from analyses due to 1) persistent ground clutter contamination (i.e., radar echoes caused by highway overpasses, wind farms, tall buildings), 2) partial radar beam blockage caused by human infrastructure (e.g., tall buildings), or 3) chronic data filtering that is part of the radar’s intrinsic clutter suppression algorithm. We identified these sample volumes by analyzing reflectivity measures across ~4,000 daytime volume scans collected during June 2009, when birds were not migrating through the study area. Data were excluded from sample volumes where reflectivity was detected at a high frequency (> 2 standard errors above the mean) and with a mean greater than 30 dBZ (associated with persistent returns from ground targets), or where reflectivity was seldom detected (associated with beam blockage or chronic clutter suppression). Sample volumes with persistent ground clutter contamination were relatively few and typically within 25 km of the radar antenna. Related to this, we excluded data from all sample volumes within 7.5 km of each radar due to unpredictable intermittent ground clutter echoes and unreliable bias-adjusted measures given the low (i.e., close to the ground) and narrow nature of the radar beam near the radar antenna.

Data preprocessing. For suitable days dominated by bird targets, we interpolated reflectivity measures of individual sample volumes to when the sun reached an elevation angle of 5.5° below horizon, using inverse distance weighting of the time differences between the radar volume scans collected immediately before and after the target sun elevation time point. The purpose of the interpolation is to reduce 1) sampling variability among nights due to the relatively coarse sampling rate of WSR-88D, and 2) sampling bias within a radar sweep due to the systematic spatial change in sun elevation along an east-west gradient. The interpolation produces a sample of the abrupt *en masse* exodus of birds at the onset of migratory flight that is standardized in time across the radar-sampled area and across days.

The radar beam spreads as it travels away from the radar antenna and differentially samples the vertical distribution of birds in the airspace. This creates bias in reflectivity measures and precludes the direct comparison of raw radar measures at different ranges and at different ground elevations. To correct for these measurement biases, we adjusted the interpolated radar data using the algorithm of Buler and Diehl (2009) with several refinements. This algorithm characterizes the vertical distribution of birds by determining the mean apparent vertical profile of reflectivity (VPR). When computing VPRs, we improved the weighting of reflectivity measures within the radar beam by using a Gaussian distribution of the power in the beam rather than a uniform power distribution. Additionally, because 25% of radar beam power is outside the 3-dB beam width, we modeled beam characteristics using a wider 6-dB beam width, which incorporates 94% of the radar power. We further improved determination of VPRs by incorporating the variability in mean ground elevation across ranges into beam height calculations and filtering out data from partially blocked beams. Finally, we identified the effective maximum height of birds in the airspace as the maximum beam height of the 0.5° tilt angle beam at the range from the radar where the ratio of the mean reflectivity of the 1.5° beam to the mean reflectivity of the 0.5° beam is ≤ 0.005. This denotes the range at which the 1.5° beam begins to pass completely above the distribution of birds in the airspace. We set any reflectivity values at heights above the effective maximum bird height to zero when determining VPRs. This improvement helped remove contamination in the VPR from occasional reflectivity measures of high altitude non-bird targets (e.g., fog or dust).

Software development. Through joint support from this project and another radar project funded by the USGS National Wetlands Research Center, we developed software to process radar reflectivity data for quantifying bird distributions on the ground. Program BIRDS (Bias Improvement of Radar Data System©; Figure 4) processes data from WSR-88D (both legacy and super resolution) or from TDWR. The software is a system of Java scripts, Python scripts, and Fortran 95 code that runs within a UNIX environment. BIRDS automates data handling and conversion, vastly improves processing time over previous program code developed in SAS® 9.1, and allows for the analysis of radar data without reliance on commercial software. BIRDS converts batched radar reflectivity data (i.e., data from multiple nights at one radar station) to ASCII format, performs the spatio-temporal data interpolation with respect to a specified sun angle, estimates the VPR and partial beam blockage due to topography, adjusts reflectivity measures for measurement bias, and provides summary statistics of adjusted reflectivity for every sample volume across sampling days.

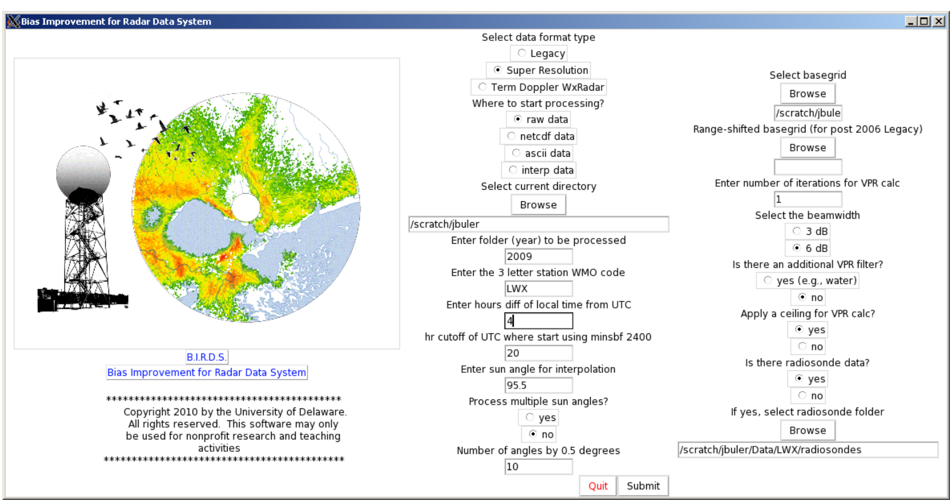

Figure 4. Graphical user interface for the BIRDS software developed at the University of Delaware. BIRDS processes raw radar data from multiple dates at one radar, and summarizes bias-adjusted reflectivity measures from every sample volume in the radar-sampled area.

Data analysis. As the radar beam travels up and away from the radar antenna, it increasingly samples less of the altitudinal distribution of birds in the airspace (i.e., the VPR), invariably reaching a point at which it samples such a small portion of the VPR that bias-adjusted reflectivity measures fall below the limits of reliability for accurate quantification. Accordingly, we censored measures from sample volumes that observed ≤ 10% of the VPR or had a bias-adjustment factor < 0.05 (i.e., adjusted reflectivity is > 20 times raw reflectivity), and considered these as ‘nondetects’. The detection limits of censored values for individual sample volumes varied among days due to the interaction of three main factors. First, different atmospheric conditions among days creates variability in how the beam propagates through the air, ultimately producing variability among days in the sampling heights of the radar beam for a given sample volume. Second, the exact timing of when birds initiate nocturnal migratory flight, and their vertical distribution in the airspace at the time they are sampled, varies among days, creating variability in VPRs. Third, variability among days in the numbers of birds engaging in migratory flight affects the extent of attenuation of the radar beam’s power as the beam passes through target-dense airspace. This creates variability in the sensitivity of the radar for detecting birds. Thus, our radar datasets contain variable detection limits and are called multiply censored datasets.

The semiparametric robust linear regression on order statistics (ROS) method has been evaluated as one of the most reliable procedures for estimating summary statistics of multiply censored data (Lee and Helsel, 2005). The observed uncensored values are combined with modeled censored values (nondetects) to estimate summary statistics of the entire population. ROS is applicable to any dataset that has 0 to 80% of its values censored. However, we conservatively restricted analysis to sample volumes that had < 25% of their values censored. We used the R software (R Development Core Team, 2011) package NADA (Lee and Helsel, 2005) to perform the ROS analyses. For each sampling day, we used the minimum observed reflectivity value among sample volumes at a given range to determine the range-specific censoring limit values for the ROS algorithm. We summarized bias-adjusted reflectivity (hereafter ‘reflectivity’) measures using ROS for each sample volume by pooling radar data across days and years. For each sample volume we estimated the geometric mean reflectivity (MN) as a relative measure of the mean daily stopover density of birds and the coefficient of variation of reflectivity (CV) as a measure of the daily variability in bird stopover density.

We used MN and CV to characterize radar-observed bird use of stopover sites by the magnitude and variation of reflectivity among sample volumes. 'Important' stopover areas are those areas with above-average (MN ≥ 50^{th} percentile) reflectivity, and further categorized as having: 1) consistently high bird stopover density (CV ≤25^{th} percentile and MN ≥85^{th} percentile), or 2) highly variable bird stopover density (CV ≥75^{th} percentile). Stopover classifications of observed data are relative to each radar site since percentile rankings were computed on a radar by radar basis.

Modeling bird distributions. We used five variables that characterize landscape composition and placement for building statistical models to predict MN and CV in portions of Region 5 not observed by the radars (Figure 5). These included the percentages of hardwood forest, agricultural land, and human development within a 5-km radius; mean distance to the nearest major water body; and mean ground elevation. We first created a sampling grid of the entire study region comprised of 637,626 1-km^2 polygons. For each grid polygon that contained radar-observed data (n = 179,348; 28% of all grid polygons), we computed the area-weighted average observed MN and CV from the portions of all radar sample volumes that fell within the boundary of the polygon.

We expected that hardwood forest cover would be informative in explaining variability in bird densities, based on findings of previous radar studies that indicate landbird stopover densities are greater within forest-dominated landscapes (Gauthreaux and Belser, 2003; Bonter et al., 2009; Buler and Moore, 2011). Additionally, Buler et. al. (2007) found that density of migrating forest birds during stopover was most strongly correlated to forest cover measured within a 5-km-radius landscape. Thus, we quantified the percent of land area covered by hardwood forest within 5 km of each grid polygon. We used NLCD 2006 data to determine the extent of hardwood forest cover, considering land cover types (value) Deciduous Forest (41), Mixed Forest (43), and Woody Wetlands (90) as hardwood forest.

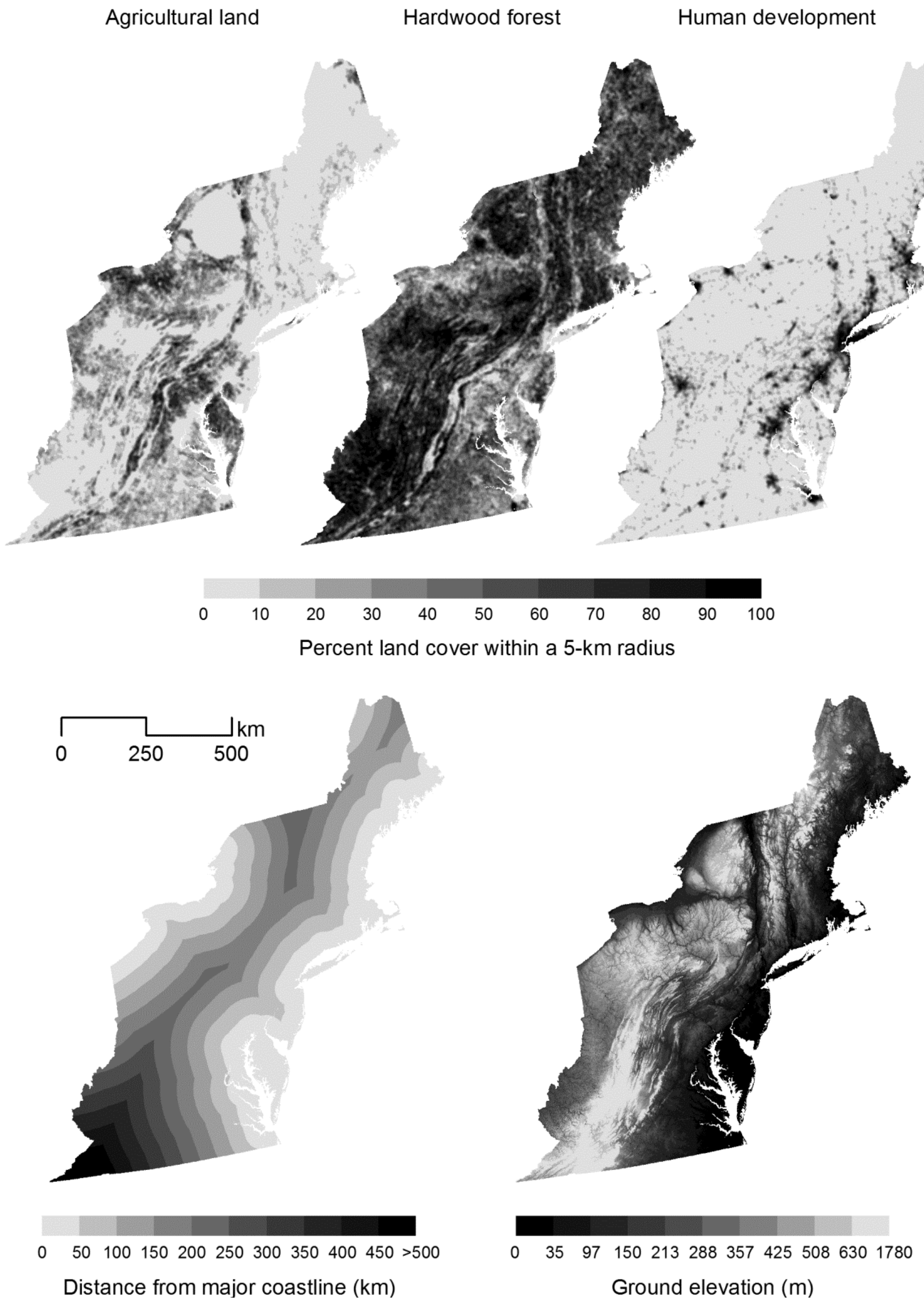

Figure 5. Sampling grid polygon maps of five predictor variables used in modeling bird stopover density within USFWS Region 5: percent area within a 5-km radius of agricultural land, hardwood forest and human development; distance from the nearest major coastline; and mean ground elevation.

We also quantified the percent of land area covered by agricultural land and human development within a 5-km radius around grid polygons. Agricultural lands were comprised of NLCD 2006 land cover types (value) Pasture/Hay (81) and Cultivated Crops (82), and human development was comprised of all Developed classes (21 - 24). We expected that bird densities would be lower within agriculturally-dominated landscapes, as found during the spring migration by Bonter et al. (2009).

The relationship of bird density with human development may be complex. At a regional scale, Bonter et al. (2009) found an overall positive association between human development and bird density during spring migration in the Great Lakes basin. Unfortunately, this association is confounded because human development and bird density both increase with proximity to the coastline, as was found by Buler and Moore (2011) during spring migration along the Gulf of Mexico. Neither study examined the residual relationship of human development with bird density while controlling for the confounding effect of proximity to the coastline. However, Bonter et al. (2009) report qualitatively that relatively few birds depart from heavily developed areas at a smaller spatial scale. This has also been found for areas along the Gulf Coast based on unpublished data from Buler and Moore (2011). Thus, we expected that bird densities at a local landscape scale should be lower in highly developed areas, especially after controlling for coastal proximity, but may exhibit a positive global relationship with development at the regional scale.

The two remaining predictor variables, mean distance to the nearest coastline of a major water body (e.g., Great Lakes, Atlantic Ocean) and mean ground elevation, were metrics of landscape placement. Migrating landbirds tend to concentrate along coastlines of large water bodies before or after crossing them (Gauthreaux, 1971; Gauthreaux and Belser, 1999b; Bonter et al., 2009; Buler and Moore, 2011). Thus, we expected that bird densities would increase with proximity to the coast. We included ground elevation as a predictor variable because it is used in determining the bias-adjustment factor when correcting reflectivity measures. In areas with highly variable topography, the representativeness of the VPR may be poorer and, consequently, elevation may exhibit a negative relationship with bird density as a statistical artifact of the bias-adjustment algorithm. However, there may be an additional biological correlation between bird density and elevation since bottomland forests have been shown to harbor higher densities of migrants than more upland forests (Gauthreaux and Belser, 2003; Buler et al., 2007; Buler and Moore, 2011).

Table 1. Correlation matrix of predictor variables. Values are Pearson correlation coefficients for each variable pair computed using 7,158 1-km^2 polygons. All correlations are significant at $P < 0.01$.

Variable	Longitude	Latitude	Elevation	Distance from coastline	Hardwood forest	Agricultural land
Latitude	0.671					
Elevation	-0.307	0.279				
Distance from coastline	-0.473	-0.082	0.734			
Hardwood forest	-0.122	0.160	0.553	0.491		
Agricultural land	-0.266	-0.188	0.016	0.090	-0.188	
Human development	0.046	-0.201	-0.407	-0.372	-0.551	-0.062

We applied multi-model inference within an information-theoretic approach to estimate the ability of predictor variables to explain variation in MN and CV using ordinary least-squares (OLS) linear regression (Burnham and Anderson, 2002). Data for variables were log-transformed when necessary to help meet assumptions of normality for fitting models. We included latitude and longitude as additional predictor variables for OLS models to assess regional spatial patterns in reflectivity. We fit models using observed radar data from 25 unique subsets of grid polygons that were separated by at least 5 km to ensure spatial independence among landscape composition and reflectivity measures. Modeling results were nearly identical among the data subsets so we present the results from one example subset (n = 7158; Figure 6). Predictor variables for this subset did not exhibit strong multicollinearity (Table 1). Distance to the coastline and elevation had the strongest correlation at 0.734, followed by latitude and longitude at 0.671. We tested all 128 possible combinations of regression models excluding interaction terms. We used Akaike's Information Criterion (Akaike, 1973) to rank models based on their ability to explain the data, and Akaike weights to estimate the relative likelihood of each model given the data. To determine the direction and magnitude of effect sizes for variables, we calculated the mean standardized regression coefficient across all the models containing the variable of interest, and estimated precision using an unconditional variance estimator that incorporates model selection uncertainty (Burnham and Anderson, 2002: p. 162).

Because relationships of landbirds with their environment can vary over space during migratory stopover, even within the area observed by a single radar (e.g., Buler and Moore, 2011), we built predictive models using geographically weighted regression (GWR). As the name implies, GWR implements a geographical weighting scheme that produces localized regression coefficients for individual locations (Fotheringham et al., 2002). By incorporating spatial variability in regression coefficients, GWR can better explain organism-environment relationships than OLS regression, which applies static global regression coefficients (Kupfer and Farris, 2007; Miller and Hanham, 2011). We used the GWR tool within ESRI® ArcMAP™ 9.3.1 to perform the analyses. We used an adaptive spatial extent (the Gaussian kernel) of 100 nearest neighbors (~ 25 km radius) for fitting each local regression among the same subset of grid polygons used to exemplify the global linear regression modeling. We predicted reflectivity measures to the entire 1-km^2 polygon sampling grid, except for 12,119 (2%) grid polygons where local multicollinearity among predictor variables prevented predictions from being calculated. In addition to performing GWR on the subset of data from all radars, we performed GWR among 16 additional data subsets in which we excluded data from one radar in turn among each subset. We then averaged predicted reflectivity measures produced across all 17 datasets. This approach allowed us to reduce the influence of potential sampling bias from any one radar. We characterized bird stopover use from mean predicted reflectivity measures according to the thresholds used for radar-observed data. Note, however, that stopover classifications of predicted data are relative at a regional scale since percentile rankings were computed for the whole of Region 5.

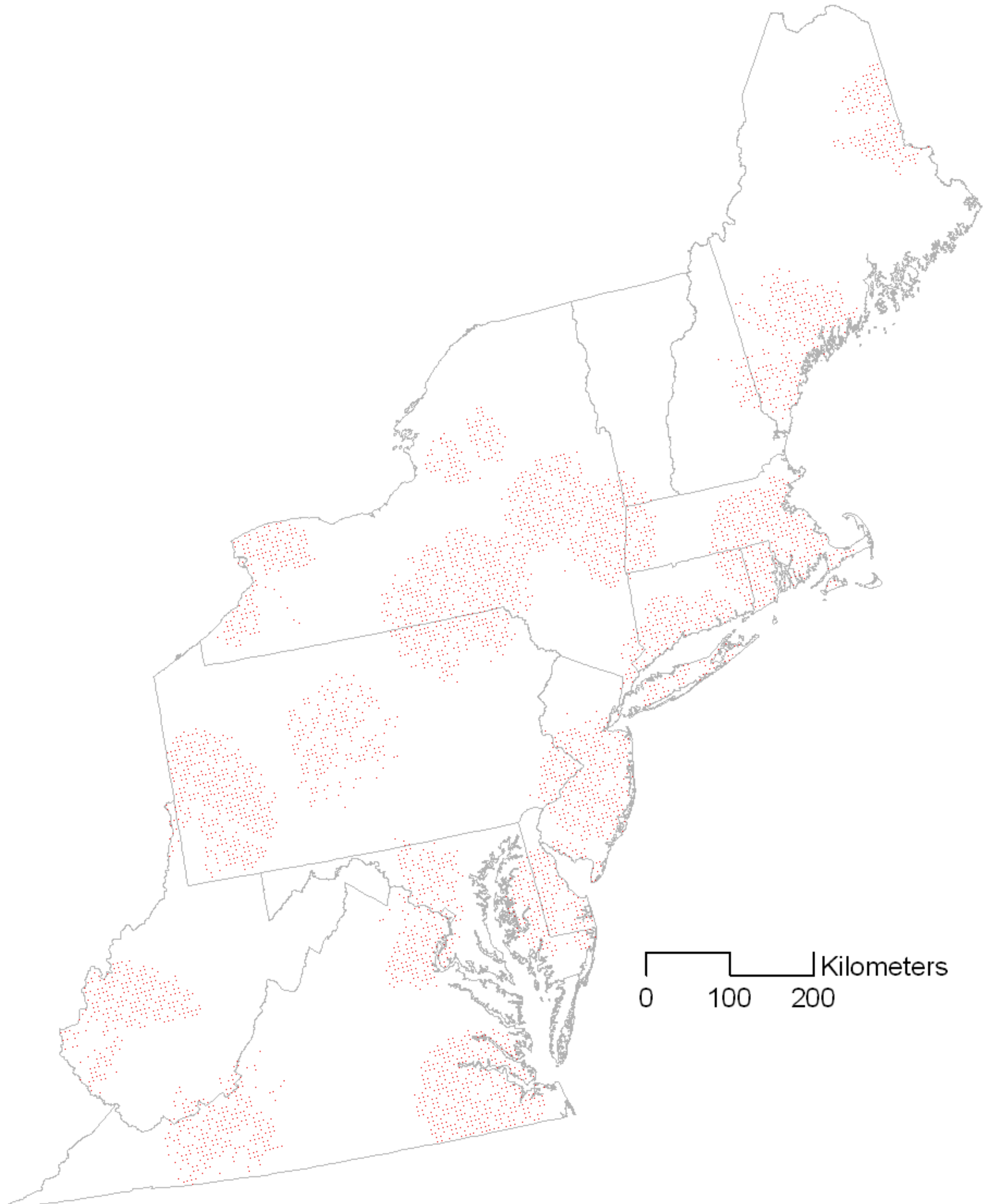

Figure 6. Locations of example sampling grid polygons (red) used for assessing predictive models within USFWS Region 5.

RESULTS

Among all WSR-88D sites and years, we sampled evening migratory flights from 14% of potential days (382 of 2720; see Appendix A); the percentage of potential days used from individual radars ranged from 8% to 23%. Overall, the reasons for excluding days included the presence of precipitation (49%), anomalous propagation of the radar beam (23%), contamination from non-precipitation sources such as insects or clutter from sea breezes (17%), no or weak bird flight activity (8%), or missing or problematic data in the archive (3%). After incorporating masking maps and detection thresholds, individual WSR-88D radars effectively observed bird stopover density for a mean of 12,711 km^2 (range 4,278 to 21,318 km^2) of land throughout fall migration. Collectively, WSR-88D radars effectively sampled 203,386 km^2 (32%) of the land area within Region 5.

Qualitatively, classified observed reflectivity data from individual radars revealed that locally important stopover areas (i.e., consistently high bird stopover density; areas marked in red of Figure 7) coincided with hardwood forests embedded within landscapes dominated by developed and agricultural lands, as well as areas near the shores of major water bodies (see Appendix B for stopover site classification maps of individual radars). Large areas of regionally important stopover use, based on pooled observed data across radars, were located along the coastlines of Long Island Sound, throughout the Delmarva Peninsula, in areas surrounding Baltimore and Washington, along the western edge of the Adirondack Mountains, and within the Appalachian Mountains of southwestern Virginia and West Virginia (Figure 8).

Radars observed bird stopover density at 34 USFWS refuges (see Appendix C for individual refuge maps). Refuges of note that contained locally important areas supporting consistently high bird stopover densities included Bombay Hook, Cape May, Eastern Neck, Edwin Forsythe, Featherstone, Great Dismal Swamp, James River, John H. Chafee, Mason Neck, Occoquan Bay, Patuxent, Presquile, Prime Hook, Rachel Carson, Seatuck, Stewart B. McKinney, and Trustom Pond. Most of the important areas within refuges were associated with forested wetlands. Non-forested wetlands of most refuges harbored low migrant densities.

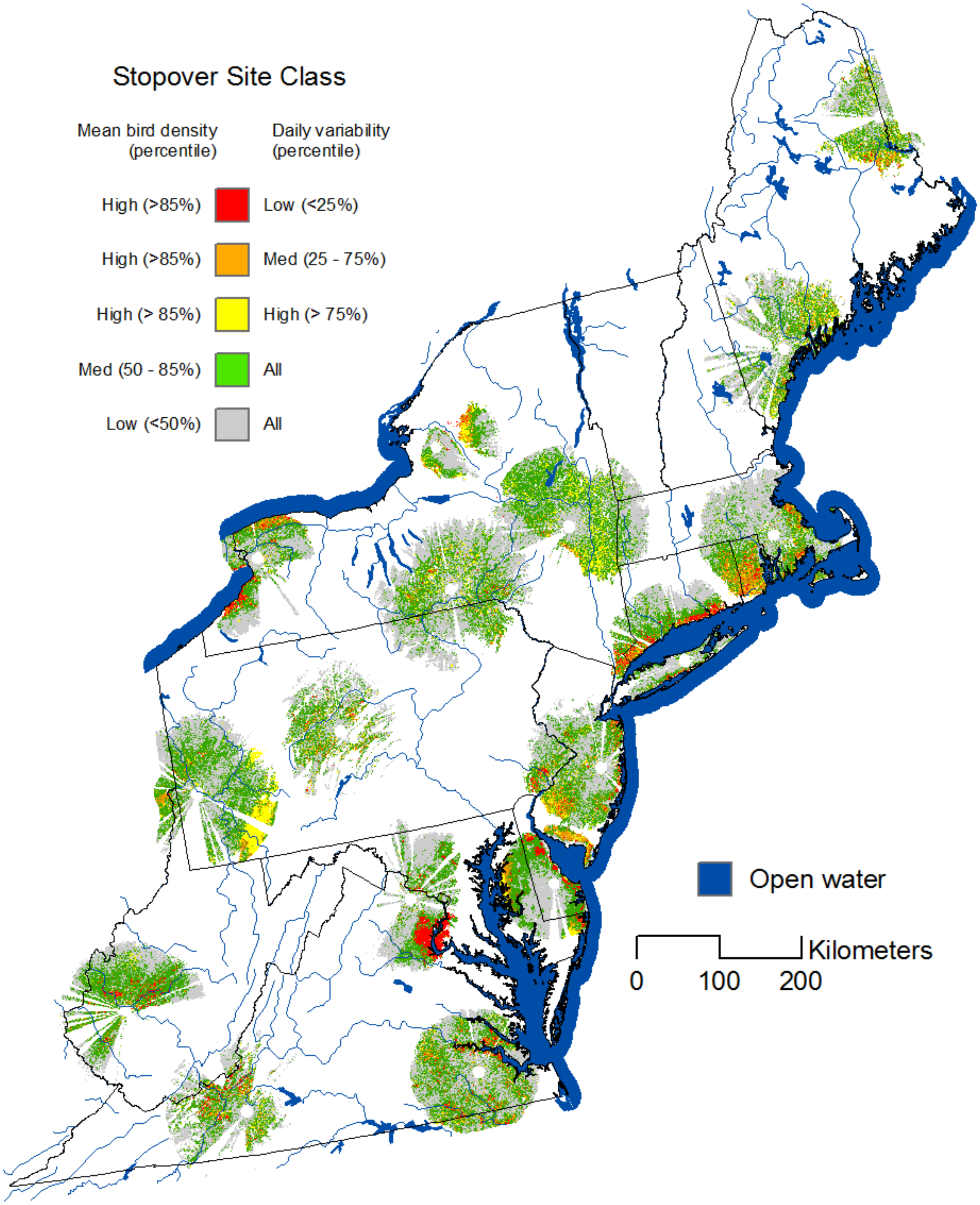

Figure 7. Map of locally-classified (i.e., for each radar separately) radar-observed bird stopover density during Fall 2008 & 2009 for 16 individual WSR-88D sites within USFWS Region 5.

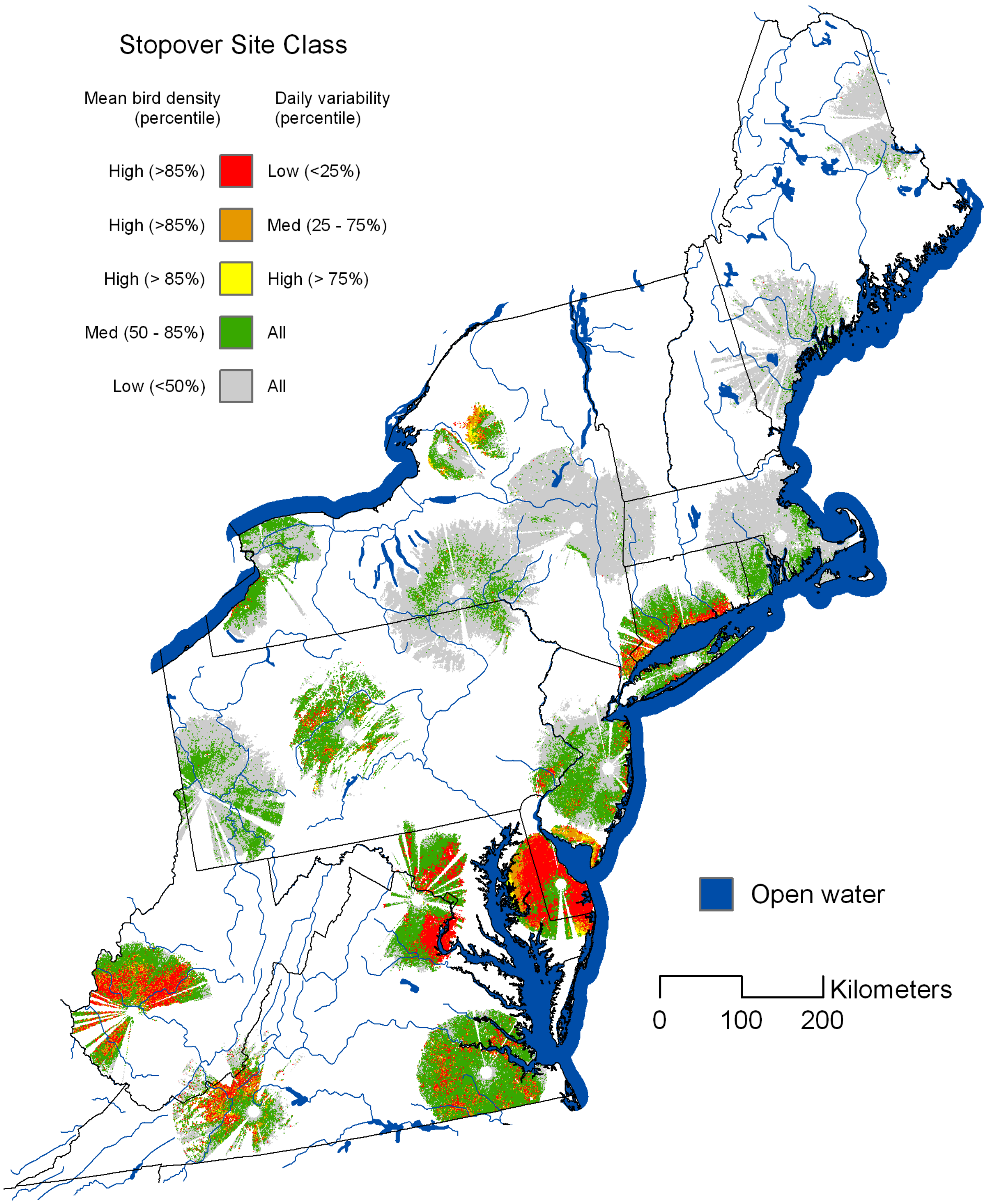

Figure 8. Map of regionally-classified (i.e., data pooled across radars) radar-observed bird stopover density during Fall 2008 & 2009 among 16 WSR-88D sites within USFWS Region 5.

The full OLS model incorporating all predictor variables had the greatest weight of evidence among models and explained nearly half of the variability (unadjusted $R^2 = 0.44$) in MN (Table 2). The strongest effects were associated with longitude, latitude, and distance from a major coastline (Table 3). MN increased to the South and West, and with closer proximity to the coast. Hardwood forest cover within a 5-km radius had a relatively moderate positive effect on MN. Elevation and the amount of human development and agricultural lands within a 5-km radius had weak negative effects on MN.

All predictor variables appeared in the top 3 OLS models that carried most of the weight of evidence, yet explained little of the variability (mean unadjusted $R^2 = 0.16$) in CV (Table 4). The relative effect sizes among individual predictors varied widely. Distance from a major coastline had the strongest effect size such that CV decreased with greater proximity to the coast (Table 3)

. Longitude and latitude had moderate effects, with CV increasing to the North and East. With relatively weak effects, CV also increased with more human development and less hardwood forest cover within a 5-km radius. The effects of agricultural land and elevation on CV were negligible.

Table 2. Summary of top 5 ranked OLS models examining 7 predictor variables affecting the observed mean reflectivity (i.e., relative bird stopover density) during Fall 2008 & 2009 among 16 WSR-88D sites within USFWS Region 5. See Methods for description of predictor variables. We tested 128 models using data from 7,158 1-km^2 polygons. We report the relative difference in AIC compared to the top-ranked model (Δ AIC), the AIC model weight (W), and the number of parameters in the model (K).

Model	Δ AIC	W	K	Rank
All predictors	0	0.767	8	1
All predictors except Agricultural land	2.9	0.201	7	2
All predictors except Agricultural land & Human development	7.6	0.018	6	3
All predictors except Human development	7.9	0.015	7	4
All predictors except Elevation	22.1	0.000	7	5

Table 3. Model-averaged standardized parameter estimates (± unconditional SE) of predictor variables in explaining the observed mean (MN) and coefficient of variation (CV) of reflectivity (i.e., relative bird stopover density) during Fall 2008 & 2009 among 16 WSR-88D sites within USFWS Region 5. See Methods for description of predictor variables. Parameter estimates marked with (ns) have 95% confidence intervals that span zero and are considered not significant.

Variable	MN	CV
Longitude	-0.360 ± 0.017	0.189 ± 0.019
Latitude	-0.388 ± 0.017	0.238 ± 0.018
Elevation	-0.088 ± 0.018	-0.008 ± 0.022 (ns)
Distance from coastline	-0.373 ± 0.015	0.330 ± 0.016
Hardwood forest	0.187 ± 0.015	-0.063 ± 0.016
Agricultural land	-0.022 ± 0.011	-0.018 ± 0.013 (ns)
Human development	-0.034 ± 0.012	0.069 ± 0.014

Table 4. Summary of top 5 ranked OLS models examining 7 predictor variables affecting the observed coefficient of variation of reflectivity (i.e., relative bird stopover density) during Fall 2008 & 2009 among 16 WSR-88D sites within USFWS Region 5. See Methods for description of predictor variables. We tested 128 models using data from 7,158 1-km^2 polygons. We report the relative difference in AIC compared to the top-ranked model (Δ AIC), the AIC model weight (W), and the number of parameters in the model (K).

Model	Δ AIC	W	K	Rank
All predictors except Elevation & Agricultural land	0	0.365	6	1
All predictors except Elevation	0.1	0.351	7	2
All predictors except Agricultural land	1.8	0.146	7	3
All predictors	2.0	0.137	8	4
All predictors except Elevation & Agricultural land & Hardwood forest	14.8	0.000	5	5

The predictive GWR models explained a considerable amount of the variability in MN (unadjusted $R^2 = 0.81$) and a moderate amount of the variability in CV (unadjusted $R^2 = 0.43$). An examination of maps of the predictor variable coefficients for GWR models of MN and CV revealed that the direction and magnitude of all predictor variable coefficients varied locally throughout the study region (see Figure for coefficient maps for the MN model). Additionally, each predictor variable was locally uninformative (i.e., not significantly different from zero) for about half of the region. Mean bird density tended to increase with greater amount of hardwood forest cover in the landscape. This is based on an evidence ratio equal to 5.1 of the number of significantly positive local coefficients to significantly negative local coefficients. Mean bird density also tended to increase with lower elevation (evidence ratio = 3.4), closer proximity to a major coastline (evidence ratio = 1.8), and lower amount of human development in the landscape (evidence ratio = 1.3). Mean bird density showed nearly equal directional response to the amount of agricultural land in the landscape (evidence ratio = 1.03). The CV of bird density tended to increase with increasing distance from a major coastline (evidence ratio = 2.3), greater amount of human development in the landscape (evidence ratio = 1.6), and lower amounts of agricultural lands (evidence ratio = 1.5) and hardwood forest (evidence ratio = 1.3) in the landscape. The CV of bird density showed nearly equal directional response to elevation (evidence ratio = 1.1).

The classified map of predicted reflectivity revealed several regionally important stopover areas, including areas within 50 km of the coastlines of Lake Erie, Lake Ontario, Long Island Sound, Chesapeake Bay, and Delaware Bay, and within 100 km of the Gulf of St. Lawrence (Figure 10). Other regionally important stopover areas included forested landscapes within the Ohio Hills and Northern Cumberland Plateau physiographic areas in West Virginia, the Mid-Atlantic Ridge and Valley of Virginia, the Allegheny Plateau of Pennsylvania and New York, and the Northern Piedmont of Pennsylvania (Figure 10).

The mean migratory flight direction among 10 radars analyzed was to the south-southwest (Figure 11). For four coastal radars (BUF, DOX, GYX, and OKX), mean migratory flight direction was parallel to the orientation of the coastline. Mean migratory flight direction at BOX (165° ± 18°) was remarkable in that it was more easterly than other radars, and was perpendicular to the orientation of the southern coastline of Massachusetts (~255°). However, the flight direction was parallel to the eastern coastline of Massachusetts (~155°), which some migrants encounter prior to reaching the southern coast.

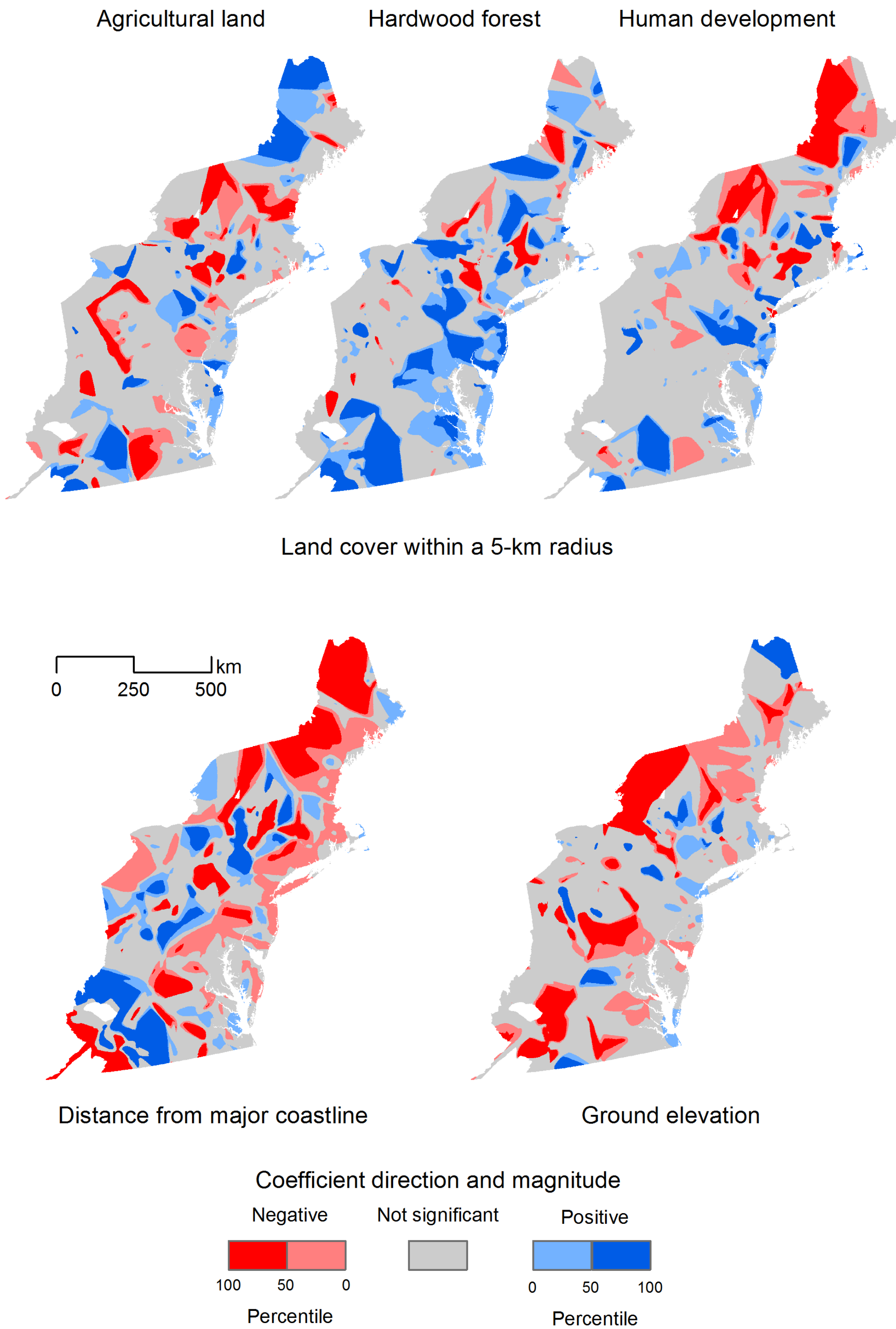

Figure 9. Maps of local predictor variable coefficients explaining mean reflectivity output from GWR analysis of dataset incorporating observed data from all radars.

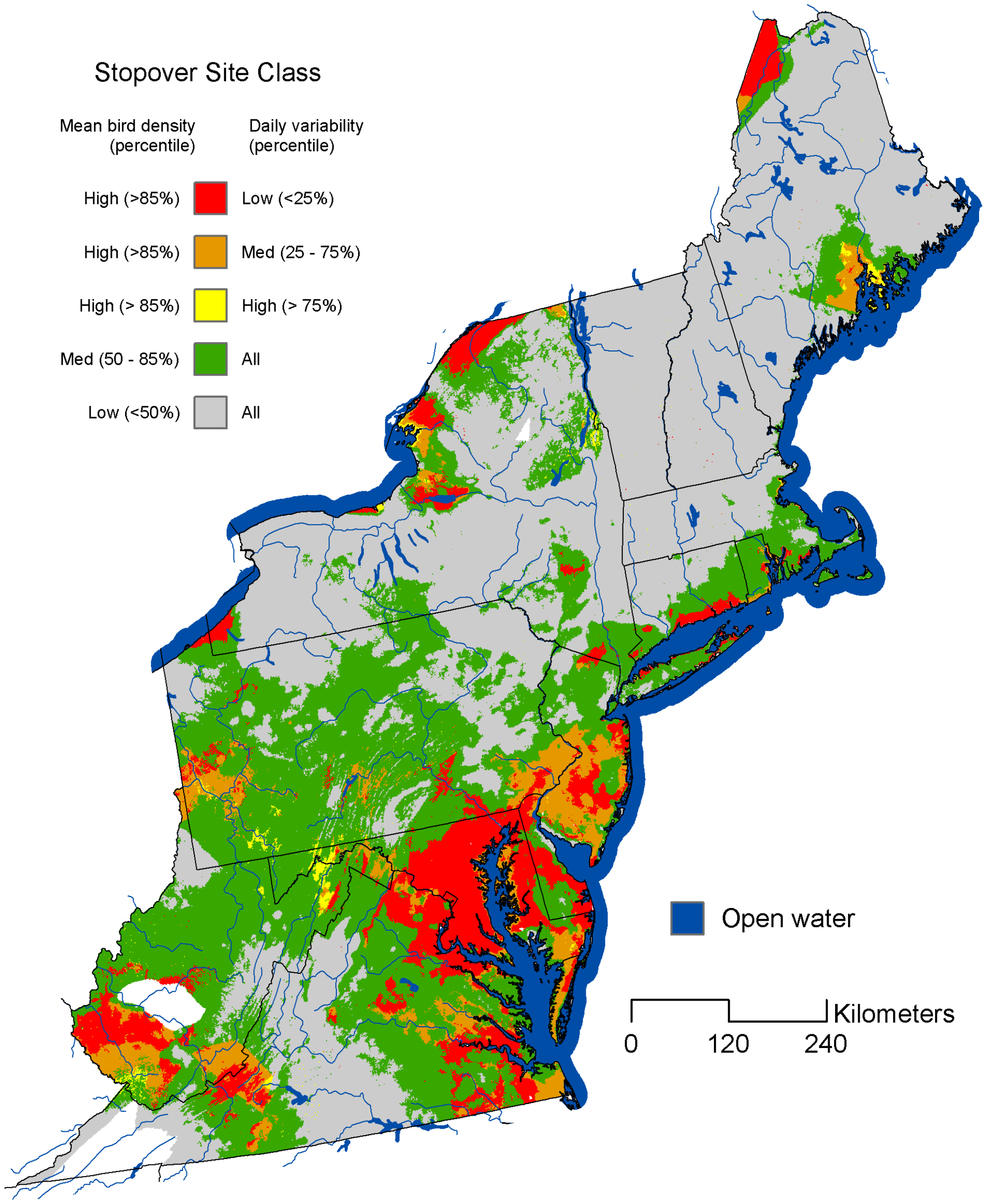

Figure 10. Map of regionally-classified (i.e., data pooled across 16 WSR-88D sites) mean GWR-predicted bird stopover density during Fall 2008 & 2009 within USFWS Region 5.

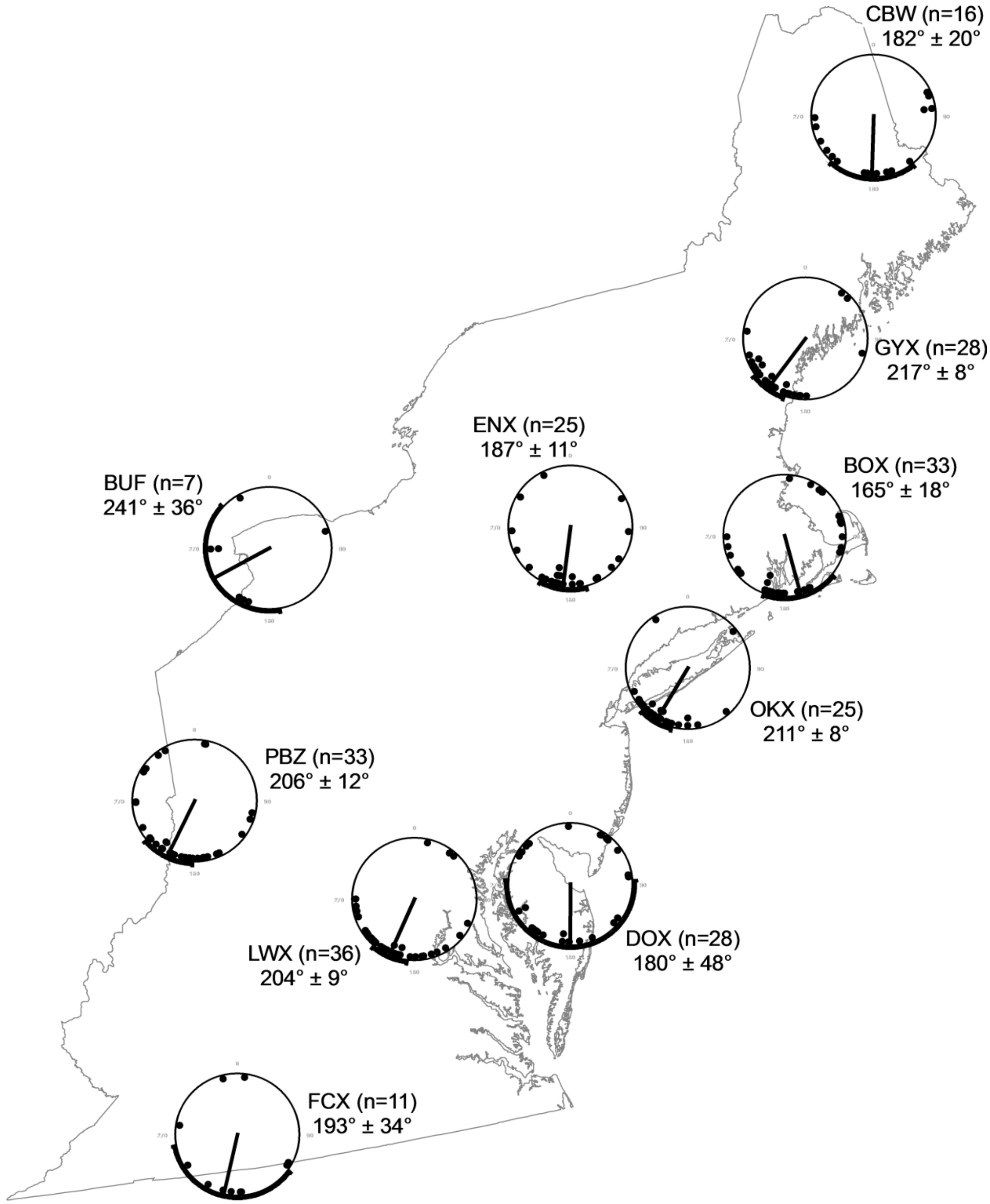

Figure 11. Overall mean ± SE flight direction of birds during Fall migration 2008 & 2009 at 10 WSR-88D sites within USFWS Region 5. Names of WSR-88D sites and number of sampling nights are shown. Circular plots denote the location of WSR-88D site (center), mean flight direction within individual nights (dots), and overall mean (line) and SE (error bars) of flight direction among nights.

DISCUSSION

Landbirds are known to stop over at almost any conceivable shelter, ranging from offshore oil platforms to urban parks to forests. During fall migration, we found that landbirds are ubiquitous throughout the northeastern U.S., being detected within essentially all radar sample volumes over land among all of the radars at some point during the migration season. However, not all stopover sites are used by migrants in equal densities or consistently throughout the migration season. The magnitude and variance in bird density can be used to help identify important stopover areas where scarce conservation resources can be invested most efficiently (Mehlman et al., 2005). Accordingly, sites that are consistently used in relatively high densities may be the best targets for conservation due to their high intrinsic (e.g., relatively abundant food resources) and/or extrinsic (e.g., proximity to a geographical barrier) value.

In general, we found that the most consistent and highest bird stopover densities occurred primarily in 1) areas in close proximity to the shores of major water bodies, 2) hardwood forest patches, particularly narrow floodplain forests of rivers and streams, embedded within landscapes dominated by developed and agricultural lands, and 3) hardwood forests within forest-dominated landscapes of the southwestern portion of the region (i.e., Ohio Hills and Northern Cumberland Plateau of West Virginia and Virginia). These patterns are consistent with other radar studies of landbird distribution patterns during migratory periods. Bonter et al. (2009) analyzed spring bird stopover within the Great Lakes basin and found that areas of high bird density were associated with near-shore areas and forest fragments in highly developed landscapes. Additionally, radar-observed bird stopover densities are greater in near-coastal areas and hardwood forests along the Atlantic and Gulf coasts (Diehl et al., 2003; Gauthreaux and Belser, 2003; Buler and Moore, 2011). Extensive ground surveys within the region also provide evidence that migrant birds often concentrate along the Lake Ontario shoreline in New York (Strobl, 2010) and along the Chesapeake Bay and Atlantic Ocean coasts of the Delmarva Peninsula (Watts and Mabey, 1994). Additionally, Strobl (2010) found that abundance of migrants was greater in forest patches within agriculture-dominated landscapes than in forest patches in more forested landscapes.

Extrinsic physiographic features have an important influence on bird distributions during migratory stopover by shaping the direction of bird movements and concentrating birds in areas along geographical barriers. Among the coastal radar sites we analyzed, migrants tended to move parallel to coastlines, suggesting that major coastlines influence the direction of migratory flight. Others have found that migrants track the direction of coastlines (Able, 1972; Gagnon et al., 2011) and other physiographic features such as mountain ranges (Bruderer and Jenni, 1990) and rivers (Bingman et al., 1982).

Across the northeastern U.S., proximity to a major coastline had a strong effect in explaining bird stopover densities. We observed that migrant birds are consistently concentrated into near shore areas of large water bodies in general. This is probably because coastal areas provide much-needed resting or landing places for migrating landbirds before or after overwater crossings (Diehl et al., 2003). Along the Atlantic Ocean, coastlines oriented perpendicular to the generally southerly direction of migrant flight (e.g., Connecticut coast) exhibited more-extensive concentrations of migrants than more parallel-oriented coastlines (e.g., New Jersey coast, eastern coast of Massachusetts). Additionally, we observed that migrants tended to concentrate to a greater extent on the down-migration side of some more inland coastlines (e.g., Delaware coast of Delaware Bay, southern coasts of eastern Lake Erie and James River) than on the up-migration side (e.g., New Jersey coast of Delaware Bay, northern coasts of eastern Lake Erie and James River).

The region-wide gradient of increased bird density to the south and west is another extrinsic factor that had a strong effect on bird distributions. We propose two possible explanations for this pattern. First, the gradient may reflect a temporal sampling bias. Peak passage of migrants occurs earlier to the north and may not have been sampled as well as migration through more southern areas, which may explain the latitudinal change in bird densities. However, we used a wide sampling window (mid-August through early November) to capture the bulk of migration throughout the entire region and found no correlation between mean sampling day and latitude or longitude. More likely, the gradient of increased bird density may reflect the ever growing numbers of migrants that pass through the region to the southwest, the general migratory direction, through the course of the season. That is, fewer birds may migrate through (and stop over in) the more northeasterly areas of the region, which could explain the lower seasonal mean bird densities to the northeast.

It is not surprising that intrinsic factors related to habitat composition had weaker effects than extrinsic factors in explaining bird stopover distributions across such a broad geographic area. Intrinsic factors generally operate at smaller spatial scales (Hutto, 1985; Wiens, 1989). Unfortunately, the resolution of the radar data is not fine enough to measure airspace over pure land cover types and resolve fine-scale patterns in habitat use. For example, only 3% of sample volumes over hardwood forests at DIX are pure hardwood forest. Thus, there is noise in the data from sampling of mixed habitat types.

The consistently high bird densities associated with hardwood forests is likely due to a combination of intrinsic habitat qualities, including habitat structural diversity, abundant food resources, and similarity to migrant breeding habitat. In general, tall and structurally diverse habitats like forests support greater numbers of migratory bird species than habitats of low stature or simple structure (Petit, 2000 and references therein; Rodewald and Matthews, 2005). Additionally, bird stopover density has been positively related to food abundance among and within habitats (e.g., Hutto, 1985; Martin and Karr, 1986; Rodewald and Brittingham, 2004; Buler et al., 2007). Moreover, most of the landbirds migrating through the region are forest-breeding birds of the northeastern U.S. and Canada, and the habitats they select during migration may resemble the habitats used during the breeding season (Parnell, 1969; Hutto, 1985; Petit, 2000; Rodewald and Brittingham, 2004).

Radar observations clearly demonstrated that forest patches in highly developed landscapes support high densities of migrating landbirds, likely because they concentrate more where suitable habitat is sparse than in forested landscapes, where migrants can distribute throughout. GWR modeling indicated that the strongest positive relationships between bird density and forest cover occurred in areas with low amounts of forest cover in the landscape. These results also support the idea that birds migrate along a broad front and exhibit limited reorganization in their distributions in the landscape. Preserving islands of natural habitat in developed and agricultural landscapes should be a priority for conservation plans addressing the stopover requirements of migratory landbirds.

Across Region 5, bird density was weakly negatively related to human development, but the magnitude and direction of this relationship varied locally based on GWR modeling. The strongest negative relationships occurred within the forest-dominated landscapes of the northeastern portion of the region (New York, New England states, and Maine). In these areas, the matrix is comprised of forest and other natural habitats with a paucity of developed areas. Thus, it is much easier for migrants to find suitable stopover sites and avoid developed areas than for those migrants stopping over in heavily developed areas along the Mid Atlantic coastline that exhibited positive relationships between bird density and human development. Similarly, Bonter et al. (2009) found a positive relationship between bird density and the amount of human development in coastal areas of the Great Lakes, which they attribute to a confounding correlation between the amount of development and proximity to the coast. However, this confound was accounted for in the positive relationship with development that we found. In the areas where bird density was positively related to development, the matrix is comprised of agricultural and developed land uses with a paucity of forest or natural habitats. Thus, we concur with the alternative explanation offered by Bonter et al. (2009) that birds may concentrate into small forest fragments or the tree and shrub cover that exist in parks, gardens, and yards of residential areas, which may provide the most suitable stopover habitat in landscapes with little natural vegetation.

Although we developed improvements in data quality control and reduction of radar measurement biases for this study, there remain challenges for the use of weather radar data for analyzing bird stopover distributions. Major challenges include contamination of radar measures by non-bird targets, inability to identify targets to species, spatial displacement of birds from their true stopover locations, and coarse data resolution (Diehl and Larkin, 2005; Ruth et al., 2008). Ongoing and future technological improvements will address some of these limitations (e.g., use of dual-polarized radars to discern birds from insects; Bachmann and Zrnić, 2007). However, the combined effects of current limitations prevent adequate assessment of bird use of spatially restricted or rare habitats. For example, there are undoubtedly tidal wetlands that are critically important stopover areas for some bird species, and variability in bird density among different wetland areas. However, weather radar is poor at discerning these patterns because birds emerging from narrow or small habitat patches may be spatially displaced from them by the time they are sampled by the radar, and birds emerging from adjacent habitats contaminate the airspace over the small habitats, adding considerable noise to radar measures. Similarly, the scrub/shrub habitat type, of particular interest to refuge biologists, generally occurs in patches too small to explicitly assess its value as stopover habitat or to use this cover type for predictive modeling. Note also that an assessment of stopover use by particular bird species or species groups will require that the dates and locations examined be tailored to fit their natural history.

Areas with high topographic relief also pose challenges in using radar for mapping bird distributions. There is increased uncertainty in the accuracy of altitudinal distributions of birds, modeled beam propagation and blockage, and, consequently, adjusted radar measures in these areas. For example, there is the yet-untested possibility of localized variability in the altitudinal distributions of birds based on differences in the timing of migratory flight initiation or ascent rate depending on whether birds emerge from ridge or valley locations. A close visual inspection of adjusted radar measures often shows increased reflectivity within valleys which may be due in part to an artifact of the adjustment algorithm rather than to truly greater bird density in low-lying areas in mountainous terrain. This is why we included elevation as a covariate in the regression models. Conversely, reflectivity measures can be inflated by radar energy reflected back from the beam striking the ground at higher elevations.

It's important to keep in mind that our maps of discretely classified migrant stopover density can be powerfully effective at focusing conservation efforts, but can also oversimplify the dynamics of bird migration and the function of any particular area for stopover. Our classification scheme was coarse by having only a few categories to characterize seasonal patterns in bird use. The unclassified data include more precise measures of migrant stopover density at finer temporal scales and are available upon request to better elucidate dynamics of bird use. Additionally, the function of particular stopover areas may not be closely tied to the density of bird use and likely varies among migrants at a site within and among days.

We caution against relying too heavily on our region-wide predictive map (Figure 10) to assess the relative importance of sites outside of radar-sampled areas. The predicted bird densities within radar-sampled areas agreed quite well with radar-observed densities, but the accuracy of predicted bird densities elsewhere remains unvalidated. Thus, the region-wide map should be viewed as a coarse and preliminary guide for conservation purposes. Confidence in the predictive model can be improved with further evaluation and testing, either through field surveys to ground-truth the predicted patterns or consideration of alternative predictive modeling approaches. Moreover, the maps we generated were based on two years of data, and we are uncertain as to how representative the data are of migratory patterns over a longer time span or into the future.

Our results emphasize that complex interactions among factors extrinsic and intrinsic to specific stopover sites influence migrant distributions across multiple spatial scales (Hutto, 1985; Kelly et al., 1999; Moore et al., 2005; Buler et al., 2007; Buler and Moore, 2011). At a broad geographic scale, migrants occurred at greater density along latitudinal and longitudinal gradients to the south and west, and in closer proximity to coastlines. At a finer scale, migrant densities were related to land cover composition, but these relationships were not stationary in magnitude and direction and appear to vary according to broader-scale landscape context.

Our results support the idea that preserving existing patches of natural habitats, particularly forests, in developed and agricultural landscapes and in coastal areas should be a conservation priority to address the stopover requirements of migrant landbirds (Bonter et al., 2009). Mehlman et al. (2005) argue that conservation of fire escape and convenience store sites, which these habitat patches appear to represent, should take priority over full-service hotel sites because 1) they are otherwise unlikely to be identified and managed for conservation, 2) there are few remaining opportunities to protect them, and 3) they are at greater risk of being destroyed or degraded. Additionally, full-service hotel sites are likely already under protection or targeted for conservation given their large extent or importance for other taxa.

WSR data are useful in elucidating migrant distributions at a rather fine grain (on the order of 10 ha) across broad geographic areas to assess the relative importance of stopover sites based solely on migrant use. From an ecological perspective, however, identification of important sites requires a better understanding of the function of sites for migratory birds beyond simple quantification of bird densities.

We suggest that our bird stopover density maps should be complemented and integrated with studies of the intrinsic characteristics of specific sites or habitats (e.g., food resources, plant composition, vegetation structure) and the stopover behavior and ecology of birds using them (e.g., bird mass change, stopover duration, movement, mortality) before conclusions can be drawn about the quality or function of particular sites or habitats.

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[Appendices in separate documents]

APPENDIX A. Sampling days (gray) used for mapping bird stopover density by date and WSR-88D station. Unused days are classified by exclusion type*.

Date	AKQ	BGM	BOX	BUF	CBW	CCX	DIX	DOX	ENX	FCX	GYX	LWX	OKX	PBZ	RLX	TYX
08/15/08	P	P	P	P	I	P	P	P	P	P	P	P	P		CL	AP
08/16/08	CL	P	P	AP	P	AP	I	I	P	CL	P	AP		I	I	P
08/17/08	AP	ND	NM	P	CL	P		AP	P	NM	P	AP	ND	I		NM
08/18/08	CL	P	NM	P	P	AP	P	AP	P	NM	P	CL	AP	I	AP	P
08/19/08	AP	AP		CL	P			AP	AP	CL	AP	AP	CL	AP	P	P
08/20/08	I		AP	AP		CL	CL				I		I	AP	AP	
08/21/08	I		NM	AP	AP	AP	CL		AP	I	P	CL	I			P
08/22/08	P	CL	NM	AP	AP	I	AP	P	I	I	P	I	AP	AP		NM
08/23/08	AP		CL	NM	AP	I	I	P	I	I	P	P	I		CL	AP
08/24/08	CL	P		P	AP	ND	AP	ND	I	I	P	I	I	P	I	P
08/25/08	P	ND	P	AP	P	ND	AP	ND		P		P	P	AP	P	DP
08/26/08	P	ND		AP	P	AP	AP			P					P	
08/27/08	P	ND		P	I	P	AP	P	I	P	AP	P	ND	P	P	
08/28/08	P	ND		P		P	P	P		P	AP	P	AP	P	P	P
08/29/08	P	ND		I	CL	AP	P	P	P		I	P	P	AP	AP	P
08/30/08	P	ND	P	AP	P	AP	P	CL	P	CL	P	P	P			P
08/31/08	AP	ND		AP	P	CL	CL	AP		AP	AP	AP			P	AP
09/01/08	CL	ND		AP	P		CL	AP	CL	I	AP		AP	AP		
09/02/08	ND	ND		AP		AP	AP	AP	AP	AP	AP	I	P	AP		CL
09/03/08	ND	ND	AP	AP	P	CL		AP	P	AP	I	I	P			P
09/04/08	ND	ND	I		P	I	AP	AP	CL	CL	AP	I	P	AP	AP	AP
09/05/08	P	ND	CL	P	CL	NM	P	P	NM	P	I	P	I	P	AP	P
09/06/08	CL	P	P	CL	P	P	P	P	P	AP	P	P	P	AP	AP	P
09/07/08		P	AP	P	P	ND			P		AP	AP		I		P
09/08/08	AP	DP		P	I	P		AP	I	P	AP	I	AP	AP		P
09/09/08	P	ND	P	P	P	P	AP	AP	AP	P	P	P	P	AP	P	P
09/10/08	P	AP			AP		CL	P	AP	P	AP	AP		AP	P	DP
09/11/08	I	P		CL	AP	AP					I	P	I	NM	P	AP
09/12/08	AP	P	P	P	P	P	ND	P	P	AP	P	P	P	P	P	P
09/13/08	I	P		P	AP	P	ND	P	P	AP	AP	P	P	P		P
09/14/08		P		P	P	P			AP	P	NM		AP	P	P	P
09/15/08	AP	P	CL	CL	P	CL	AP		P	AP	AP	AP	AP		AP	P
09/16/08	P	AP	CL		AP	CL	AP	P	AP	AP	AP	AP		AP	CL	CL
09/17/08			AP	P	P		AP	I		AP	AP		AP	AP	CL	
09/18/08		AP	AP	AP	AP	P	AP	CL	CL	P		CL	AP	AP	CL	CL
09/19/08			I	AP	NM	AP	CL		I	I	I	I	I	AP	AP	
09/20/08	P	P	CL	CL		CL	I	I		AP		AP	CL	CL	CL	CL
09/21/08	P	P	P		AP	P	AP	AP	P	AP	P	AP	AP	CL	CL	CL
09/22/08	AP	AP	I	AP	AP	AP	AP	CL	AP		AP	P	AP		P	AP
09/23/08	ND	AP	AP	AP	NM	ND	ND	CL	I	ND	I	I		ND	ND	ND
09/24/08	DP		I	AP	AP		AP	CL		DP	AP		I			DP
09/25/08	P		CL	CL	NM		P	P		P	AP	P	P	I	CL	CL
09/26/08	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
09/27/08	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
09/28/08	P	P	P	P	P	P	P	P	P	P	P	P	P	AP	AP	P
09/29/08	AP	AP	P			AP	CL	CL	P	AP	P	AP	AP	AP	AP	CL
09/30/08	P	P	P	P		P	P	P	P	P	P	P	AP	P		P
10/01/08	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
10/02/08		P	P	P	P	P			P	AP	P	I	P	P		P
10/03/08		DP	I	P	NM	AP			AP		I	CL	I	AP		P
10/04/08	AP				P	AP				CL	P	CL			CL	P
10/05/08	AP		P		P		AP	AP	P		P	CL		AP	CL	P
10/06/08	AP		CL		P	CL	CL	CL		AP		AP		ND		AP
10/07/08			CL	AP	P	NM					CL		AP		I	ND
10/08/08		P		P	NM	P	P	I	P	P	P	P	I		P	P
10/09/08	P		I	AP	P		ND		NM	P	AP		I		CL	NM
10/10/08	CL	CL	AP	P	P		AP	AP		CL		CL	AP	AP	AP	AP
10/11/08	CL		AP	AP	P	CL	AP	AP		AP	AP	AP		AP	CL	
10/12/08	CL		I	AP		NM	AP	AP	I	I	P	AP		NM	CL	I
10/13/08	CL			AP	CL	AP	AP	CL	I	AP	AP	AP	CL	NM		AP
10/14/08		P	NM	P	P	P	P	AP	P	AP	NM	AP	NM	P	P	P
10/15/08	AP	P	CL	P	P	P	AP	CL	DP	AP	AP	AP	CL	NM	CL	P
10/16/08	P	CL	P	P	P	P	P	P	AP	P	P	P	P	AP	P	AP
10/17/08	P	DP	AP		AP	CL	P	P	CL	P		P	AP		AP	AP
10/18/08	P	P	CL		AP	P	AP	P	AP	P	AP	P	DP		CL	AP
10/19/08			I	CL	NM	NM	AP	I	NM			NM	CL	NM		I
10/20/08		NM		P	NM	NM			NM			NM	AP	NM	P	ND
10/21/08	AP	P	P	P	P	P	P	CL	P	CL	P	CL	P	P	CL	P
10/22/08		P	P	P	P	AP	AP	AP	NM		P	AP	AP	AP		CL
10/23/08		CL	AP		DP	NM	AP	CL	I	AP	AP	NM	AP	NM	NM	CL
10/24/08	P	NM	NM	P	NM	P	NM	I	NM	P	NM	NM	NM	P	P	NM
10/25/08	P	P	P	P	NM	AP	P	P	P	AP	P	P	P	NM		P
10/26/08		NM	AP	P	P	P	I	I	NM	P	AP	NM	NM	P	NM	P
10/27/08	P	P	AP	P	P	P	P	P	P	P	P	P	AP	NM	P	P
10/28/08		P	P	AP	P	P	P	P	P	P	P	P	P	P	P	P
10/29/08	CL	P	P	P	P	P	P	P	P	AP	P	P	NM	P	P	P
10/30/08	AP	ND	AP	AP	P	AP	CL	AP	AP	CL	AP	CL	AP	NM	AP	AP
10/31/08	P	NM	NM	I	NM	NM	NM	NM	NM	P	AP	NM	NM	NM	AP	AP
11/01/08	P	AP	AP	AP	DP	P	CL	AP	AP	P		AP	AP	P	AP	CL
11/02/08	P	NM	AP	CL	NM	NM	AP	AP	I	AP	AP	P	CL	P	CL	NM
11/03/08	P	NM	NM	P	NM	P	CL	CL	NM	AP	NM	NM	NM	P	CL	NM
11/04/08	P	P	NM	AP	NM	P	P	P	NM	P	NM	P	NM	NM	CL	NM
11/05/08	P	P	P	AP	NM	AP	P	P	P	AP	NM	P	P	NM	AP	AP
11/06/08	CL	P	P	AP	P	AP	P	P	P	AP	P	P	P	AP	AP	P
11/07/08	NM	NM	NM	P	P	NM	CL	AP	P	NM	NM	AP	NM	P	P	P
Total sample	16	16	18	11	7	9	12	14	15	11	10	8	12	16	19	7

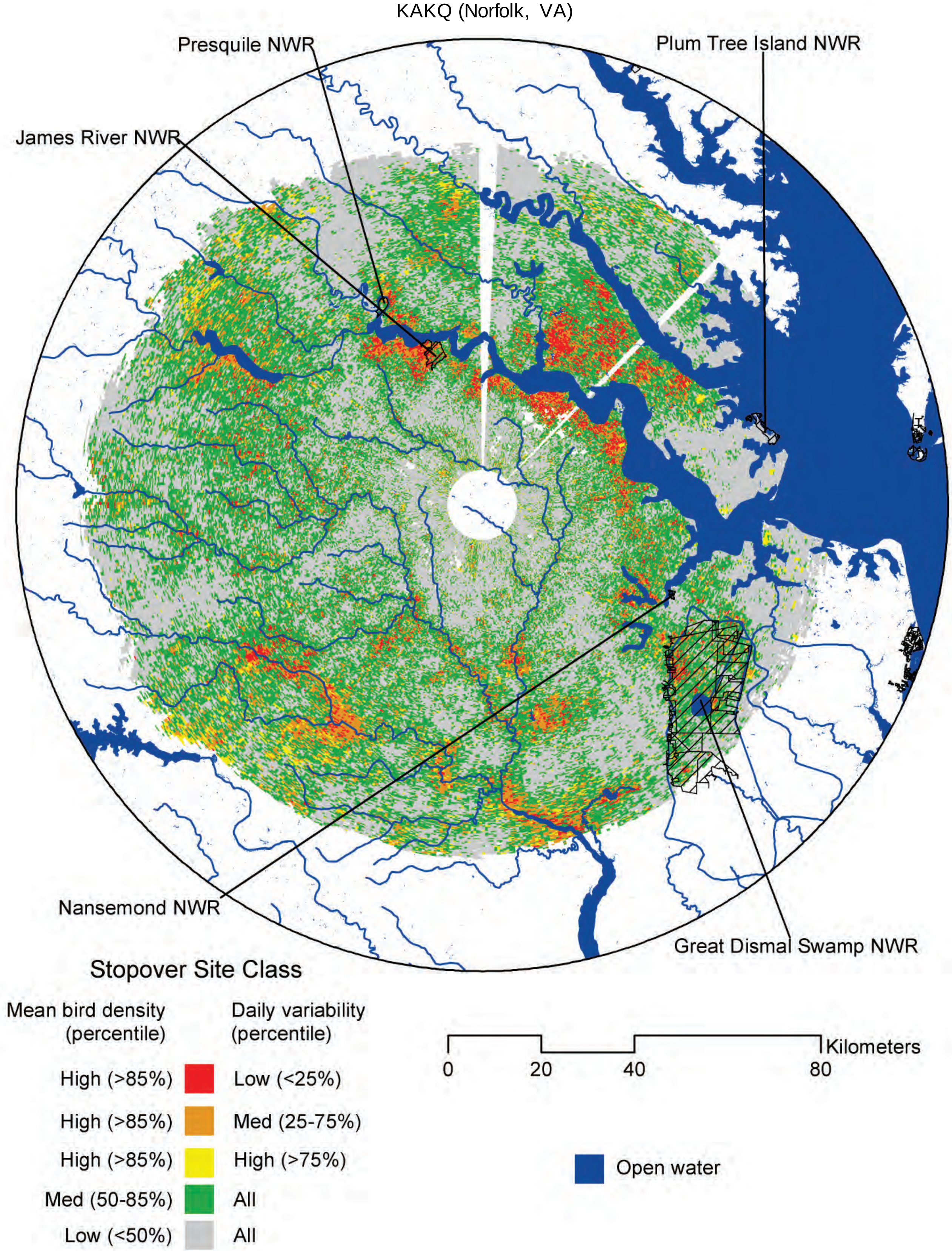
* P = precipitation, AP = anomalous beam propagation, CL = clutter, I = insects, ND = missing data, NM = no or weak bird migration, DP = data processing problem

Appendix A (continued). Sampling days (gray) used for mapping bird stopover density by date and WSR-88D station. Unused days are classified by exclusion type*.

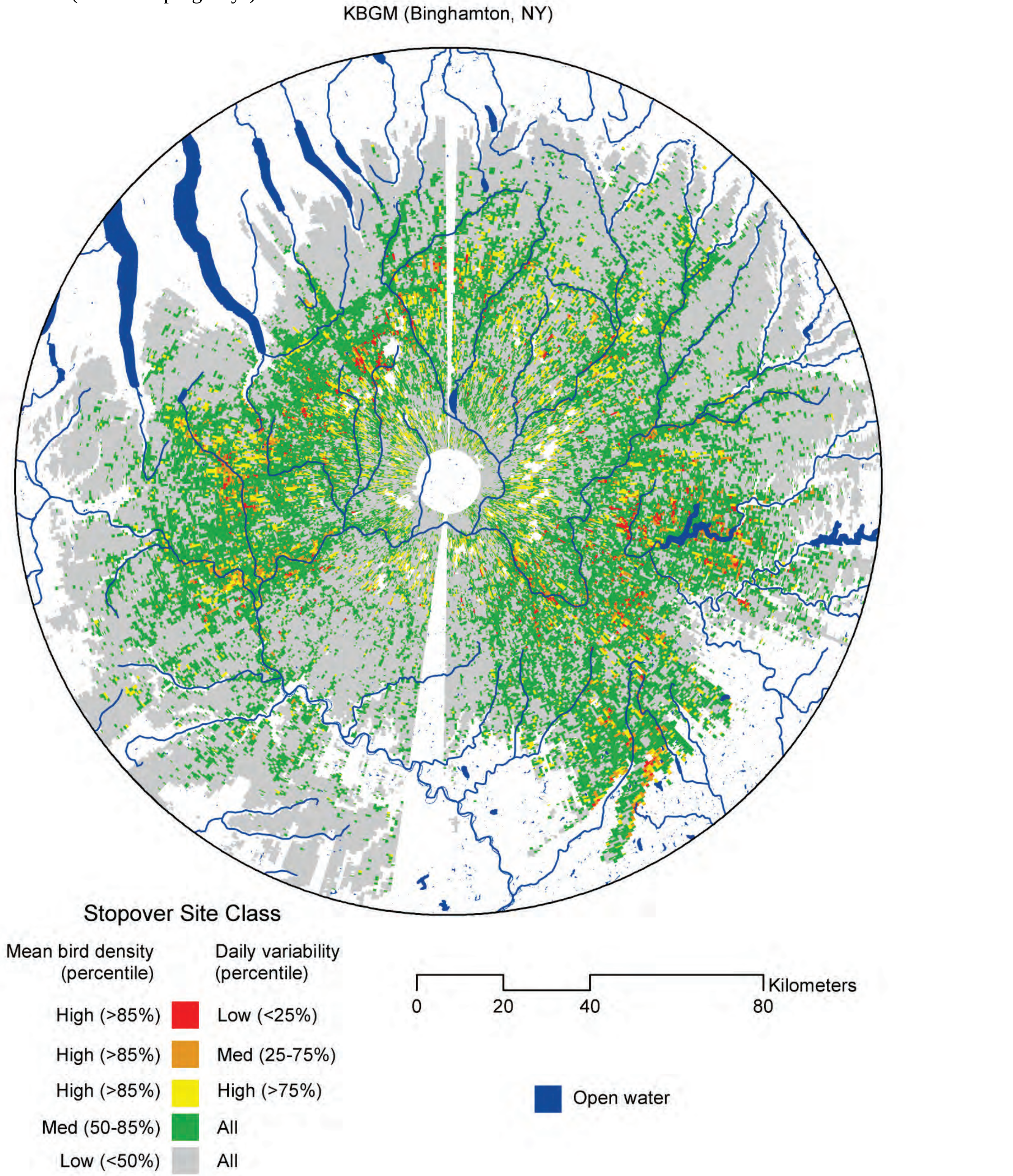
Date	AKQ	BGM	BOX	BUF	CBW	CCX	DIX	DOX	ENX	FCX	GYX	LWX	OKX	PBZ	RLX	TYX
08/15/09	P	ND	P	ND	NM	ND	AP	AP	P	ND	AP		AP	I	AP	I
08/16/09	AP	CL	NM	AP	P	NM	AP	P	P	P	AP	I	AP	AP	AP	I
08/17/09	AP	P	P	NM	NM	P	AP	AP	P	P	I	P	AP	P	P	P
08/18/09	I	P	NM	I	P	P	P	P	P	P	AP	P	P	P	P	P
08/19/09	P	I		P	CL	P	P	P	P	P	P	P	P	DP	P	AP
08/20/09	I	I	I	P	P	P	CL		P	P	I	P		P	P	I
08/21/09	P	I	P	P	P	P	P	P	P	P	P	P	P	I	P	P
08/22/09	P	P	P	P	P	P	P	P	P	AP	P	P	P		P	P
08/23/09	P	P	P	P	I	P	P	P	P	P	P	P	P	I	CL	P
08/24/09	P		P		P		AP	AP	CL	P	P	AP	AP	DP	CL	
08/25/09	ND	AP		AP	I	AP	AP	CL		P	I	AP	P			CL
08/26/09	ND	P	P		DP	P	P	I	P	P	P	AP	P	P	CL	CL
08/27/09	P	AP		AP	AP	P	P		I	I		P		AP	P	
08/28/09	P	AP	P	P	AP	P	P	P	P	P	AP	P	P	P	P	P
08/29/09	P	P	P	P	P	P	P	AP	P	P	P	P	P	AP	CL	P
08/30/09	AP	P		P	P	P	AP	P	P	DP	P	P	AP	P	CL	P
08/31/09	P	AP				AP	AP			DP	AP		CL	AP	CL	
09/01/09	CL		CL	AP	AP		AP	CL		AP				DP	CL	AP
09/02/09	I		CL		AP		AP	I		AP	P	I	AP			AP
09/03/09	P		P	AP	I	AP	P	P	AP	AP	AP		AP	AP		AP
09/04/09	AP	AP	I	AP	CL	CL	AP	P	CL	P	AP		AP	AP		P
09/05/09	AP	AP	CL		AP	CL	AP	AP	CL	P	AP	CL	P		CL	
09/06/09	P	CL	I		AP	P	CL	I	I	P	I	P	CL	P	P	CL
09/07/09	P	P	AP	P	I	P	CL	P		P		P	CL	P	P	P
09/08/09	P	P	AP	P	AP	P	P	P	P	P	AP	I	CL	P	P	CL
09/09/09	P	P	I	AP	AP	P	P	P	P	P	AP	P		AP	P	
09/10/09	P	P	NM	P	AP		P	P		P	I	P	P	I	P	CL
09/11/09		P	P	P	AP	P	P	P	P	P	P	P	P	P	CL	P
09/12/09	P	AP	P	AP		P	P	P	P	I	P	P	P			P
09/13/09	AP	P	P	AP	P	AP	P	CL		AP		AP	AP		CL	CL
09/14/09		CL		AP	P		AP			AP	P		AP	I		
09/15/09	AP		CL	P	AP	P	P	P	CL	P	CL	P	P		P	
09/16/09	P	P	P	P	AP	P	P	P	P	P	AP	P	P	AP	CL	P
09/17/09	P	CL	P	P		NM		I	P	P	AP	P	CL	AP		
09/18/09		CL	P	P	P		AP		CL	P	P		AP		P	CL
09/19/09	AP					AP	AP	AP		P	AP	AP	CL			AP
09/20/09		CL	I	AP		I	CL	AP	I	I	AP	I	AP	P	P	
09/21/09	I	P	I	P	I	P			P	P	AP	I	AP	P	P	P
09/22/09	P	P	P	AP	P	P	I	I	P	P	I	P	AP	AP	P	P
09/23/09	P	P	NM	P	P	P	CL		P	AP	P	P	P	P	P	P
09/24/09	P	AP	P	P	P		AP	CL	AP	P			CL	P	P	AP
09/25/09	P		CL	AP	AP		AP	CL		P		AP	CL	I	P	
09/26/09	P	P	I	P		P	P	P	P	P	I	P	CL	P	P	P
09/27/09	CL	P	P	P	P	P	P	P	P	AP	P		P			P
09/28/09	P	P	P	P	AP	P	P	P	P	AP	P		P	P		P
09/29/09		P	NM	P	NM	P			P	P	P		CL	P	P	P
09/30/09	ND	P		P	P	P		P	P	AP	P	AP	AP		P	P
10/01/09	CL	P	P	P	P		P		P	AP	P		P		P	P
10/02/09	P	P	P	P	P	P			P	P	P	P	AP	P	P	P
10/03/09	AP		P	P	P	I	P	I	P	AP	P		P			I
10/04/09		P	AP	P	P	P	AP		P	AP	P	AP	P			P
10/05/09	AP	P	I	P	P	P		AP	P	AP	P	AP	P		CL	P
10/06/09	AP	P	I	P	P	P	AP		I	P	CL	P	CL	P	P	P
10/07/09	CL	P	P	P	P	P		I	P	CL	P	I	AP			P
10/08/09			CL	P	P	P	P		AP	P	AP	P		P	P	
10/09/09	CL	P	P	P	P	P	AP	I	P	P	P	P	P	P	P	P
10/10/09	CL	AP		P	P		AP		DP							CL
10/11/09	AP	AP	AP	AP	NM		AP		P	AP	P				CL	P
10/12/09	P	P	P	P		P	P	P	P	P	AP	I	P	P	P	P
10/13/09	CL	P	P	I	P	P	CL		P	CL	P	CL	P	P	CL	P
10/14/09	P	P		P	P	P	P	P		P	P	P		P	P	CL
10/15/09	P	P	P	P		P	P	P	P	P	AP	P	P	P	CL	P
10/16/09	P	P	CL	P	AP	P	P	P	P	P	P	P	P	P	P	AP
10/17/09	P	P	P	P	I	P	P	P	P	P	P	P	P	P	P	P
10/18/09	P	AP	P	AP	P	AP	P	P	P	AP	P	AP	P	AP		
10/19/09		AP	I	ND	AP	AP	AP	AP	I			AP	CL	NM		NM
10/20/09			CL	P	P	NM	I	I		AP	NM	I	AP	NM	P	P
10/21/09	CL	P	I	P	CL		AP	AP	NM	CL		NM	P	NM		P
10/22/09	DP	P	NM	P	P	AP	AP		P	NM	P	AP	NM			P
10/23/09	P	P	P	P	NM	P	P	P	P	P	P	P	P	P	P	P
10/24/09	P	P	P	P	P	P	P	P	P	CL	P	P	P	P	P	P
10/25/09	AP	CL	CL	AP	NM	AP	AP	AP	AP	AP	I	AP	CL		CL	CL
10/26/09	P	CL	AP	AP	NM	NM	AP	I	I	P	AP	AP	CL	NM	CL	AP
10/27/09	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	AP
10/28/09	CL	P	P	P	NM	P	CL	CL	P	AP	P	I	P	AP	CL	P
10/29/09	P	CL	CL	NM	NM	AP	AP	AP	AP	NM		CL	CL		CL	P
10/30/09	P	AP	NM	NM	NM	NM	NM	CL	P	P	NM	NM	NM	NM	NM	P
10/31/09	P	P	P	P	NM	P	P	P	P	P	P	P	P	P	P	P
11/01/09	P	I	AP	AP	NM	AP	P	P	AP	P	AP	P	CL	AP	CL	CL
11/02/09	CL	NM	NM	P	NM	NM	AP	P	I	AP	NM	AP	AP	NM		NM
11/03/09	AP	P	NM	P	P	P	AP	CL	P	AP	P	ND	P	AP	CL	P
11/04/09	NM	P	NM	P	NM	P	P	P	P	P	NM	P	NM	P	P	P
11/05/09	AP	P	P	P	P	P	P	P	P	CL	P	P	NM	P		P
11/06/09	AP	AP	CL		NM	AP	AP	AP	P	AP	NM	AP	CL	AP	CL	P
11/07/09	NM	NM	NM	NM	P	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
Total sample	9	10	10	8	8	12	7	17	12	2	10	15	8	21	20	12

* P = precipitation, AP = anomalous beam propagation, CL = clutter, I = insects, ND = missing data, NM = no or weak bird migration, DP = data processing problem

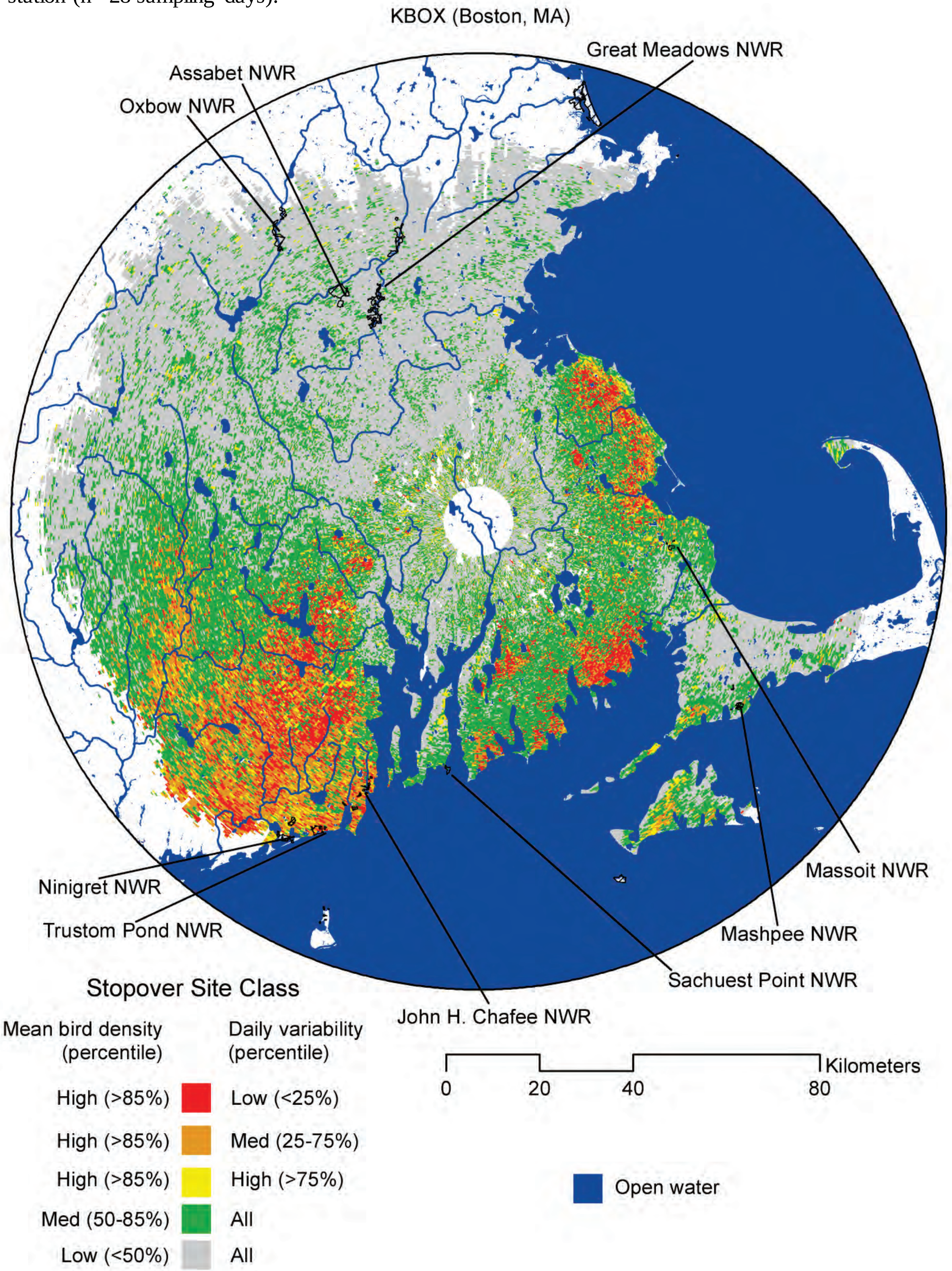
APPENDIX B. Classified bird stopover density during fall 2008 & 2009 from the KAKQ station (n= 25 sampling days).



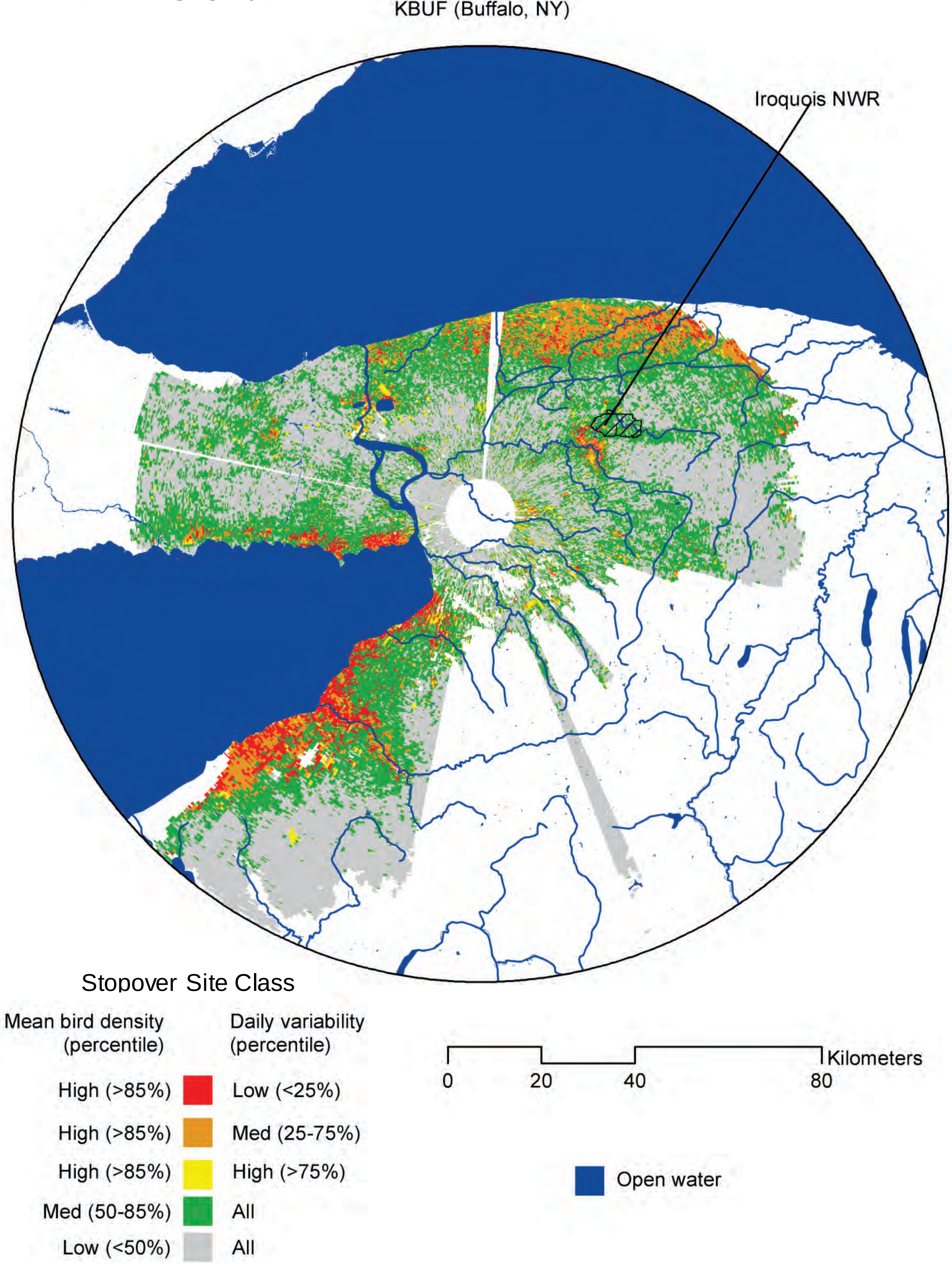
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KBGM station (n= 26 sampling days).



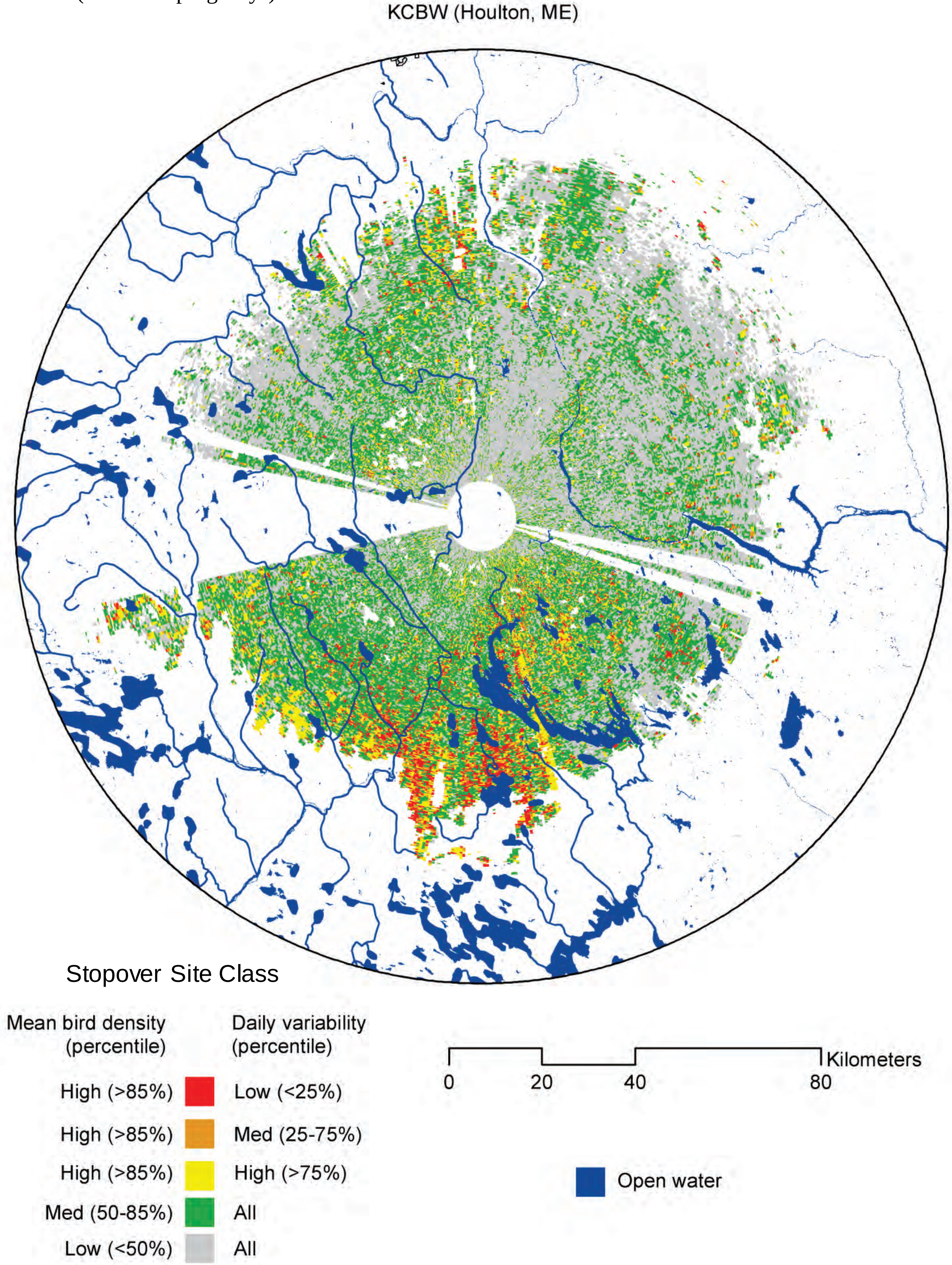
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KBOX station (n= 28 sampling days).



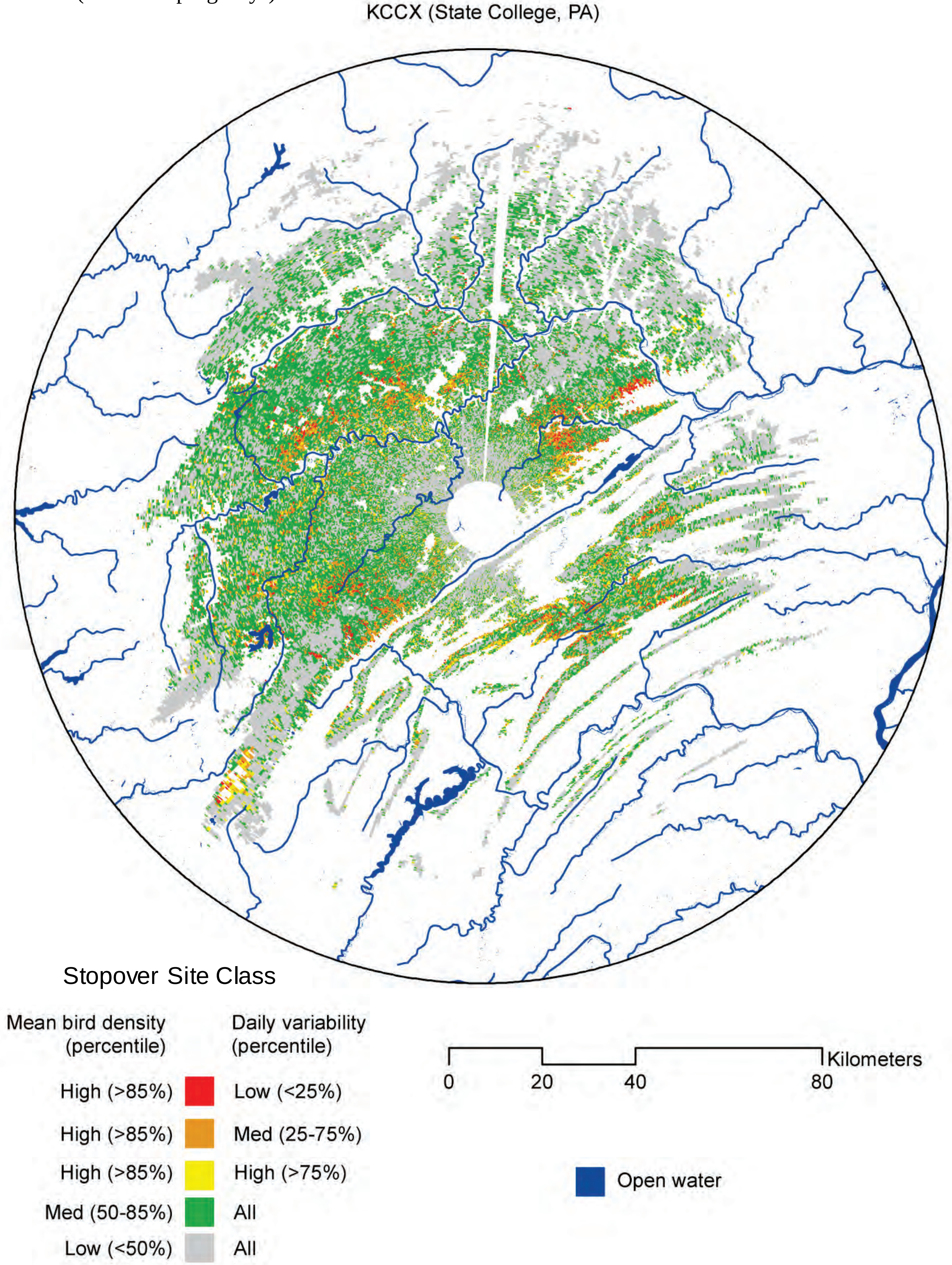
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KBUF station (n= 19 sampling days).



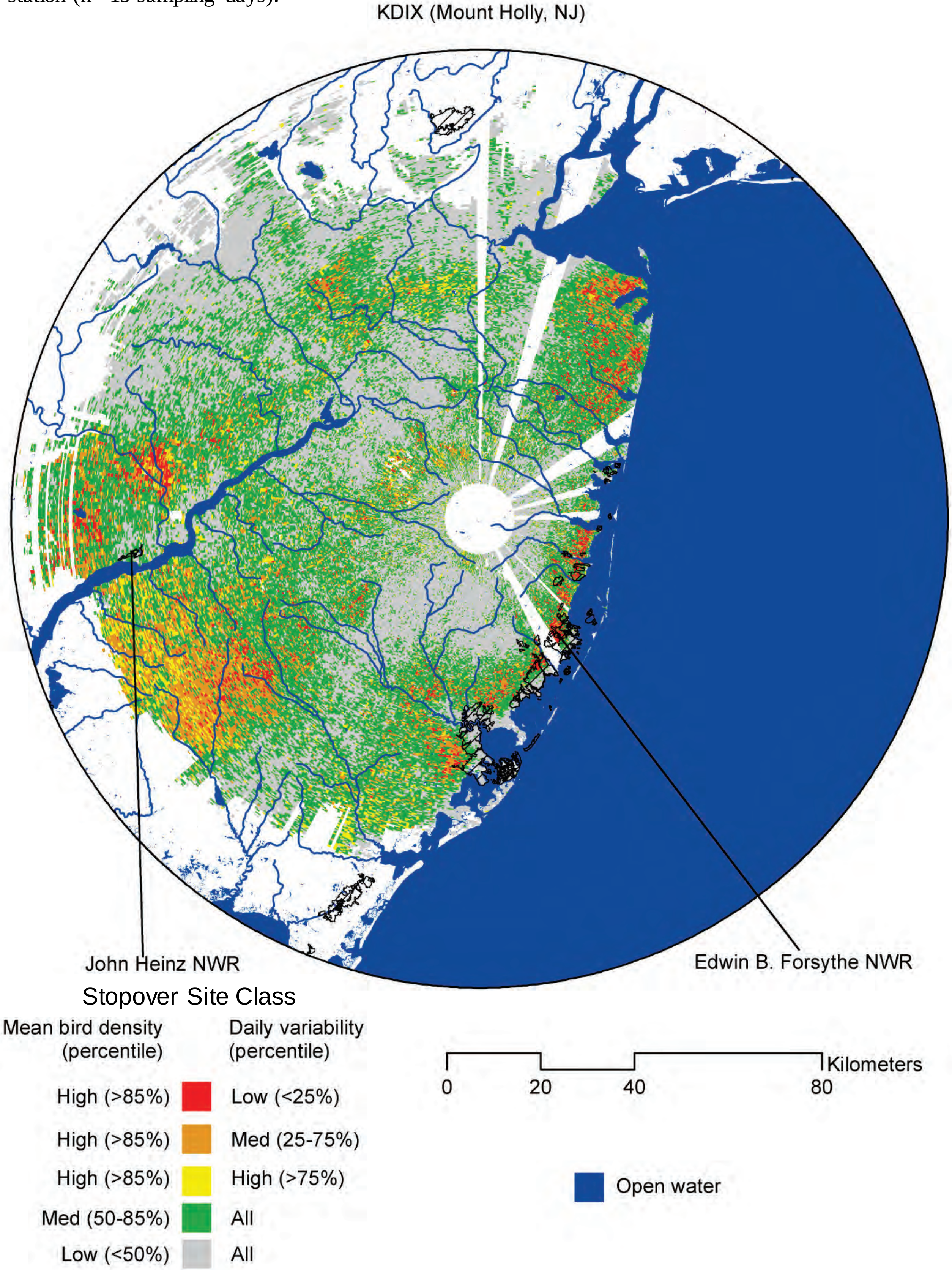
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KCBW station (n= 15 sampling days).



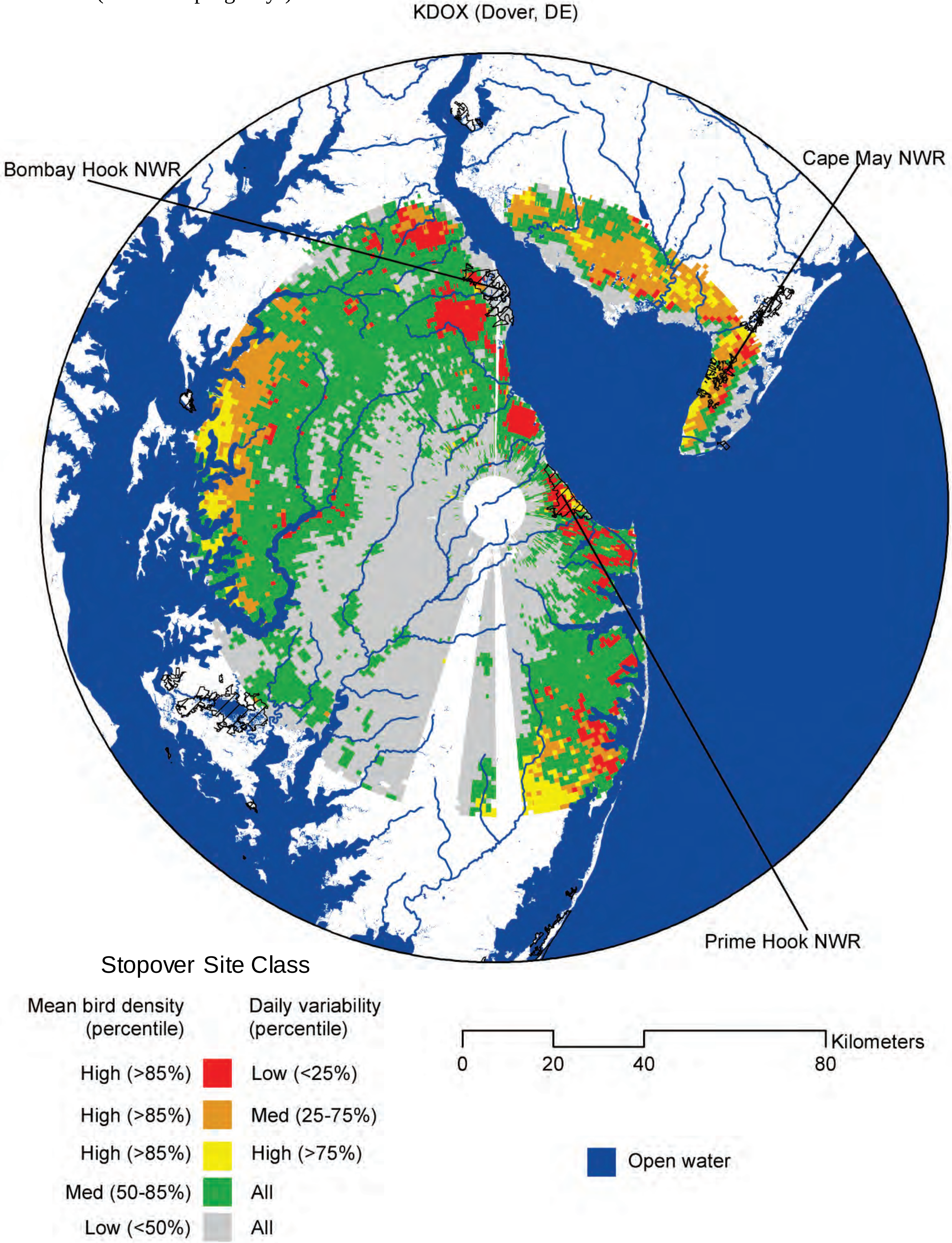
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KCCX station (n= 21 sampling days).



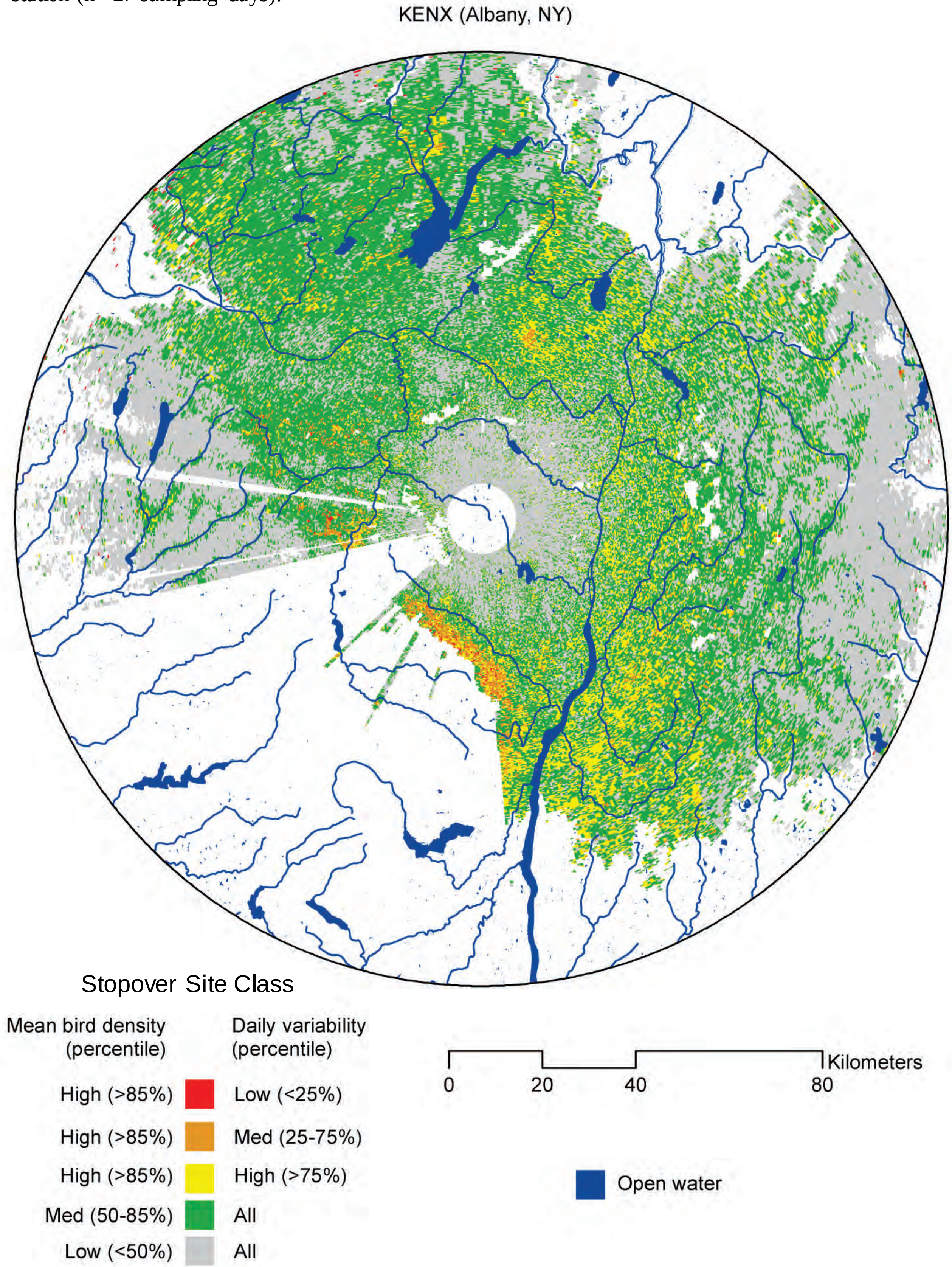
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KDIX station (n= 19 sampling days).



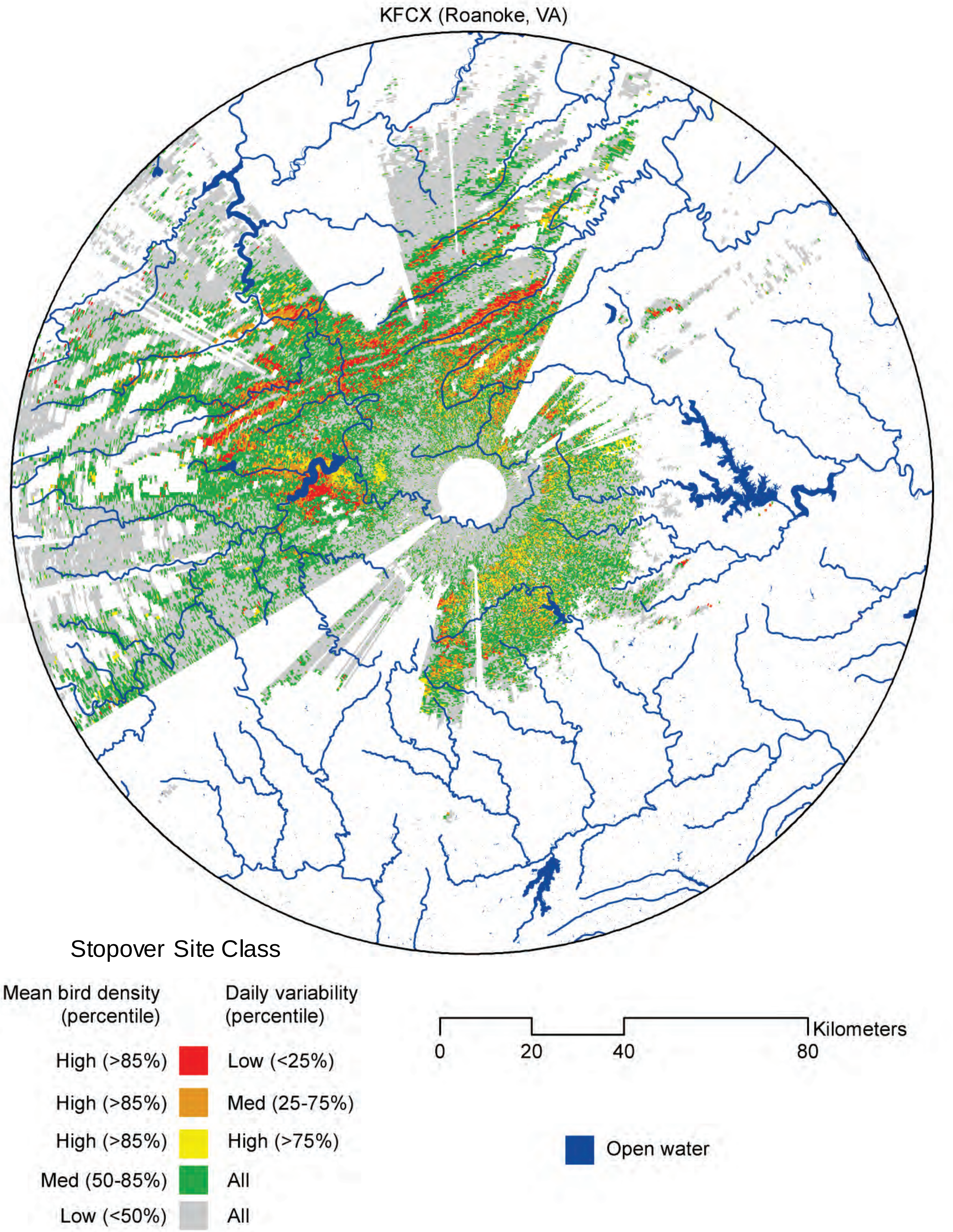
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KDOX station (n= 30 sampling days).



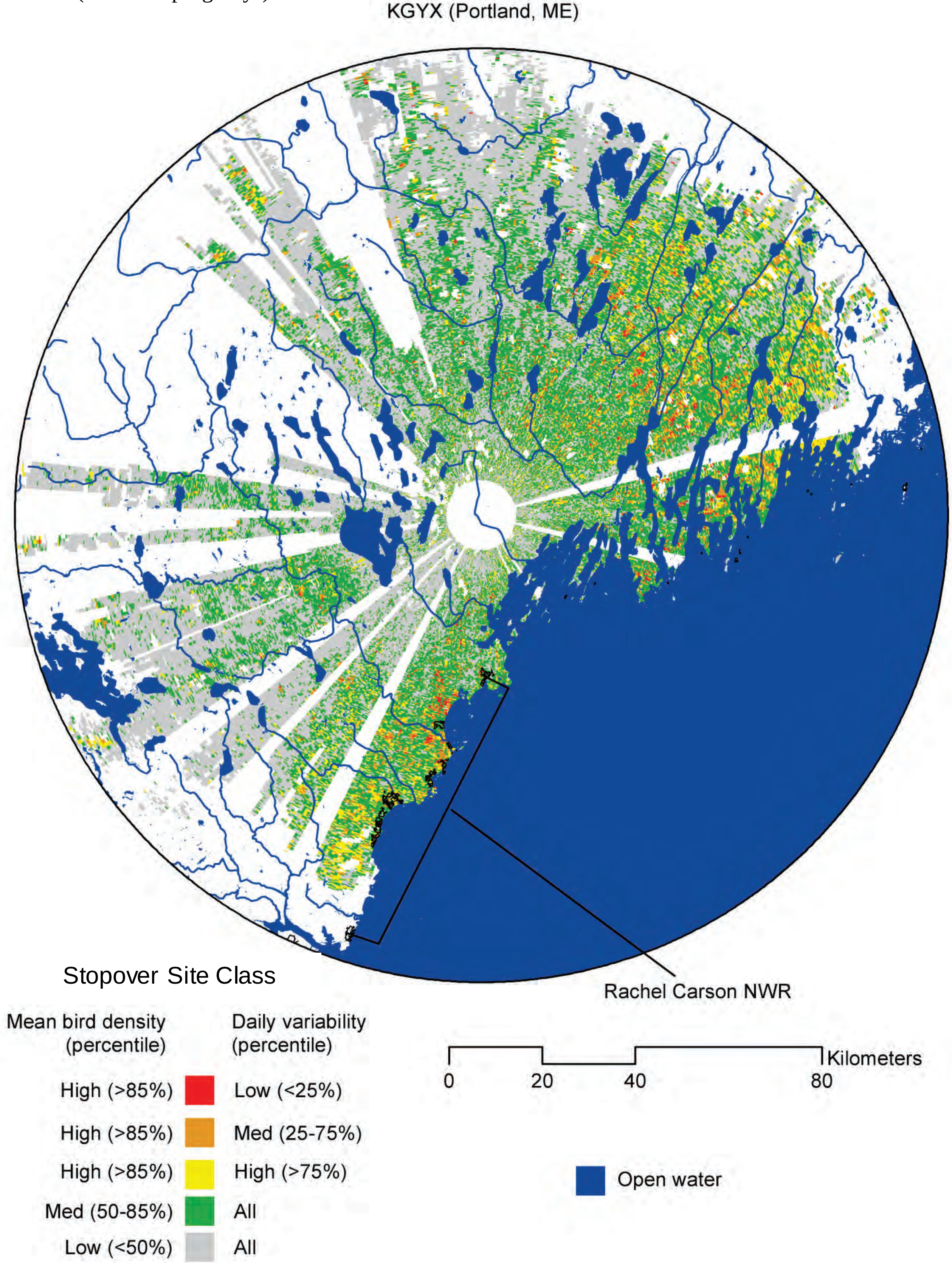
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KENX station (n= 27 sampling days).



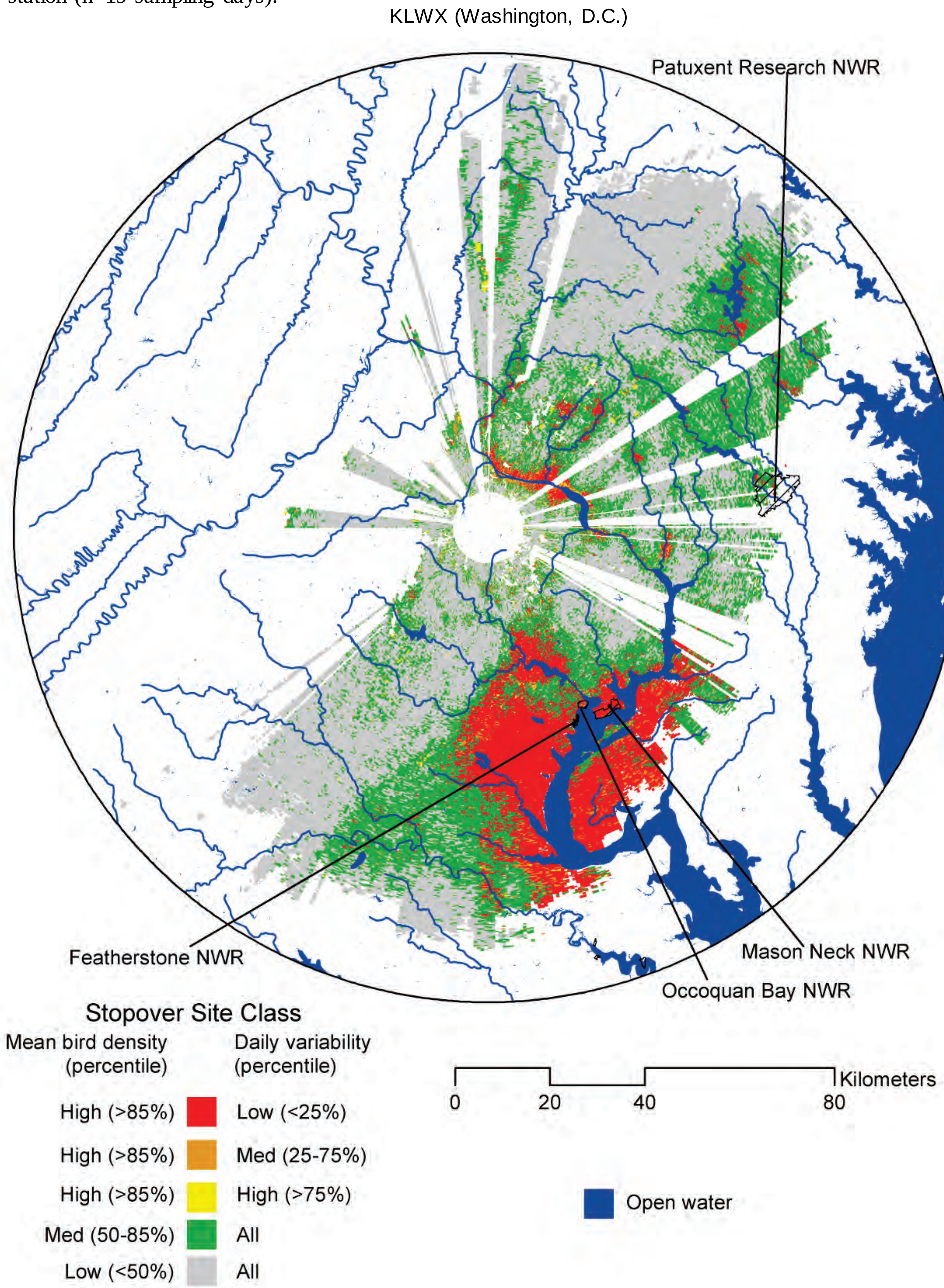
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KFCX station (n=13 sampling days).



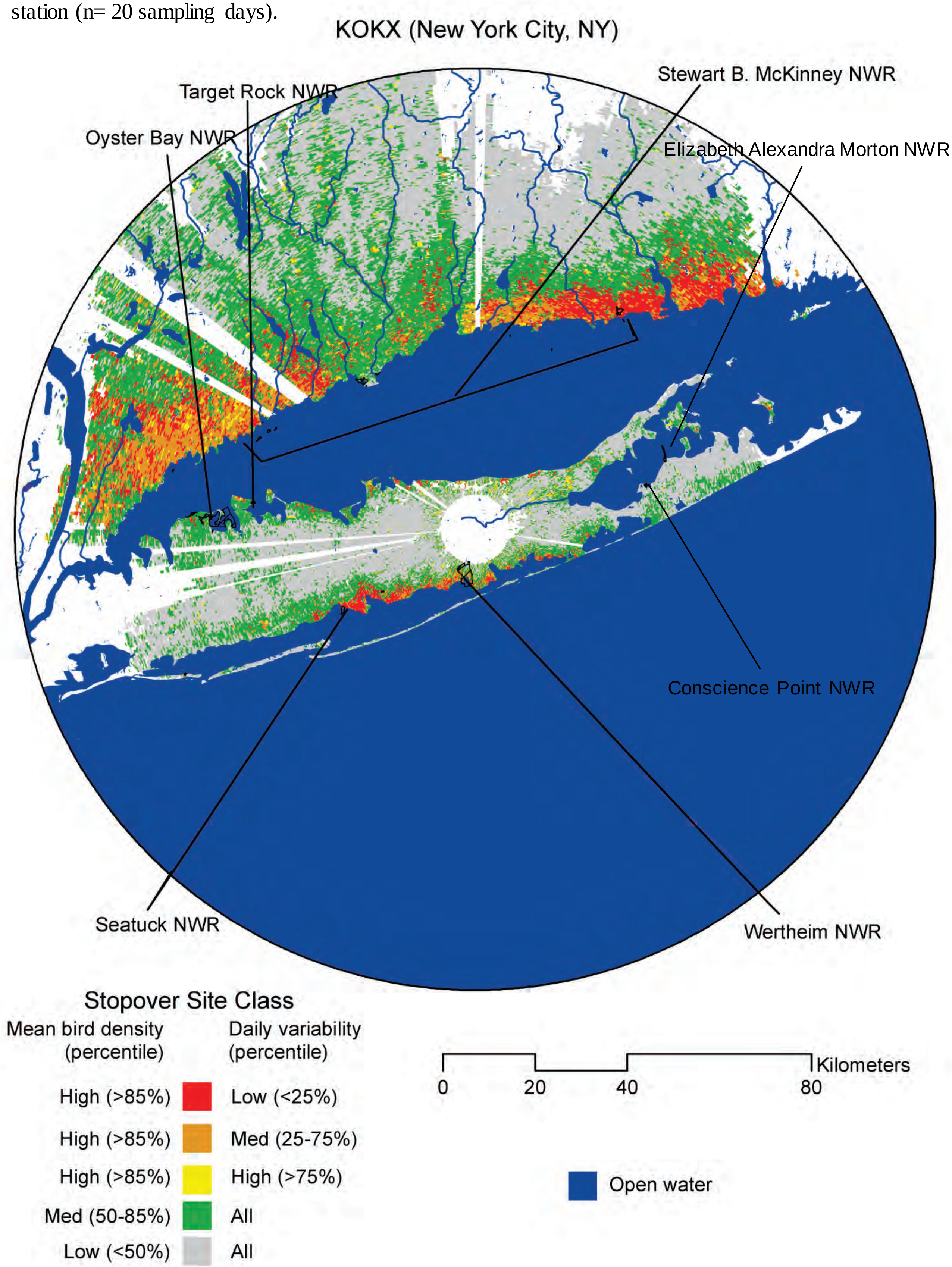
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KGYX station (n=20 sampling days).



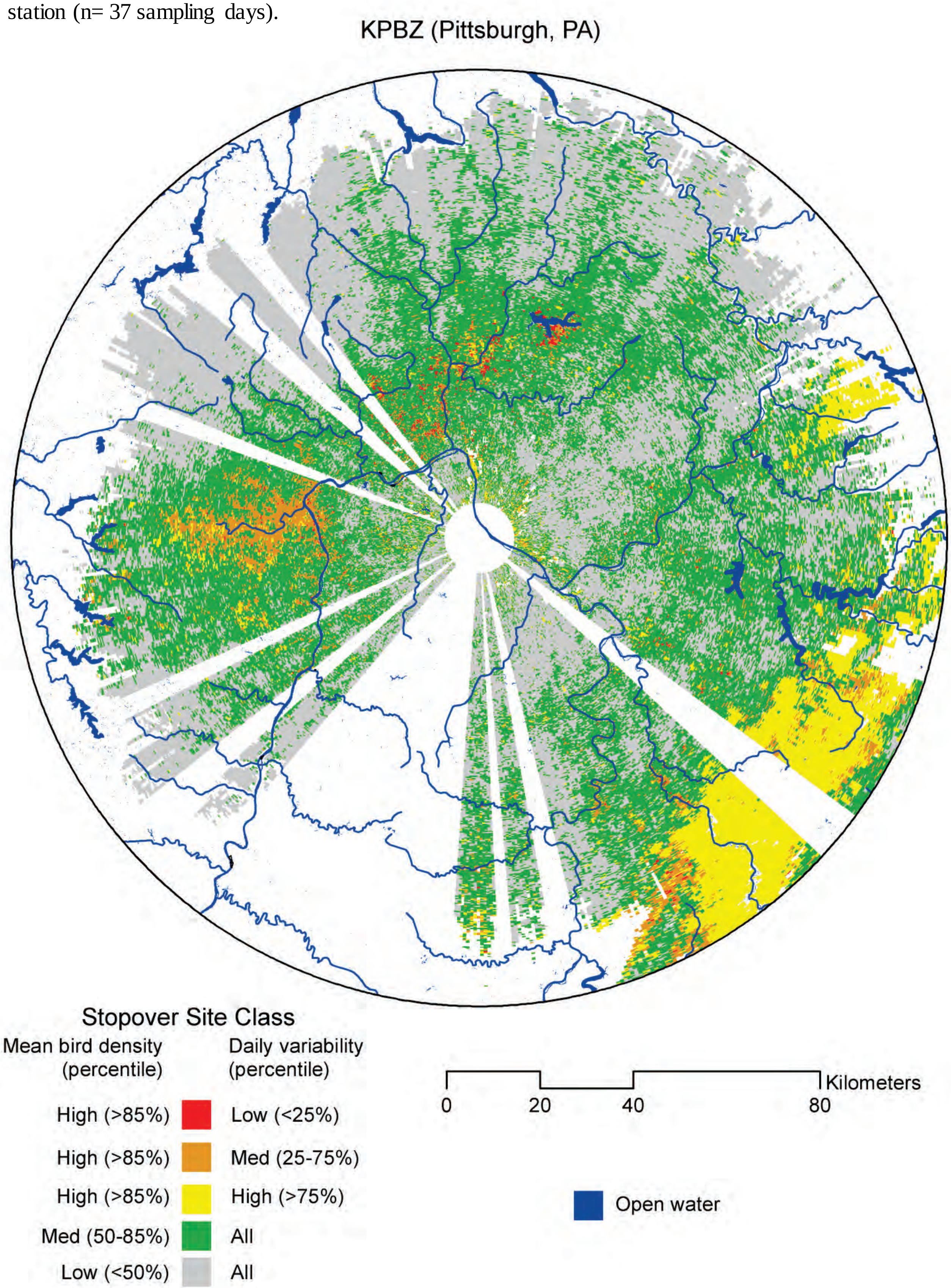
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KLWX station (n=19 sampling days).



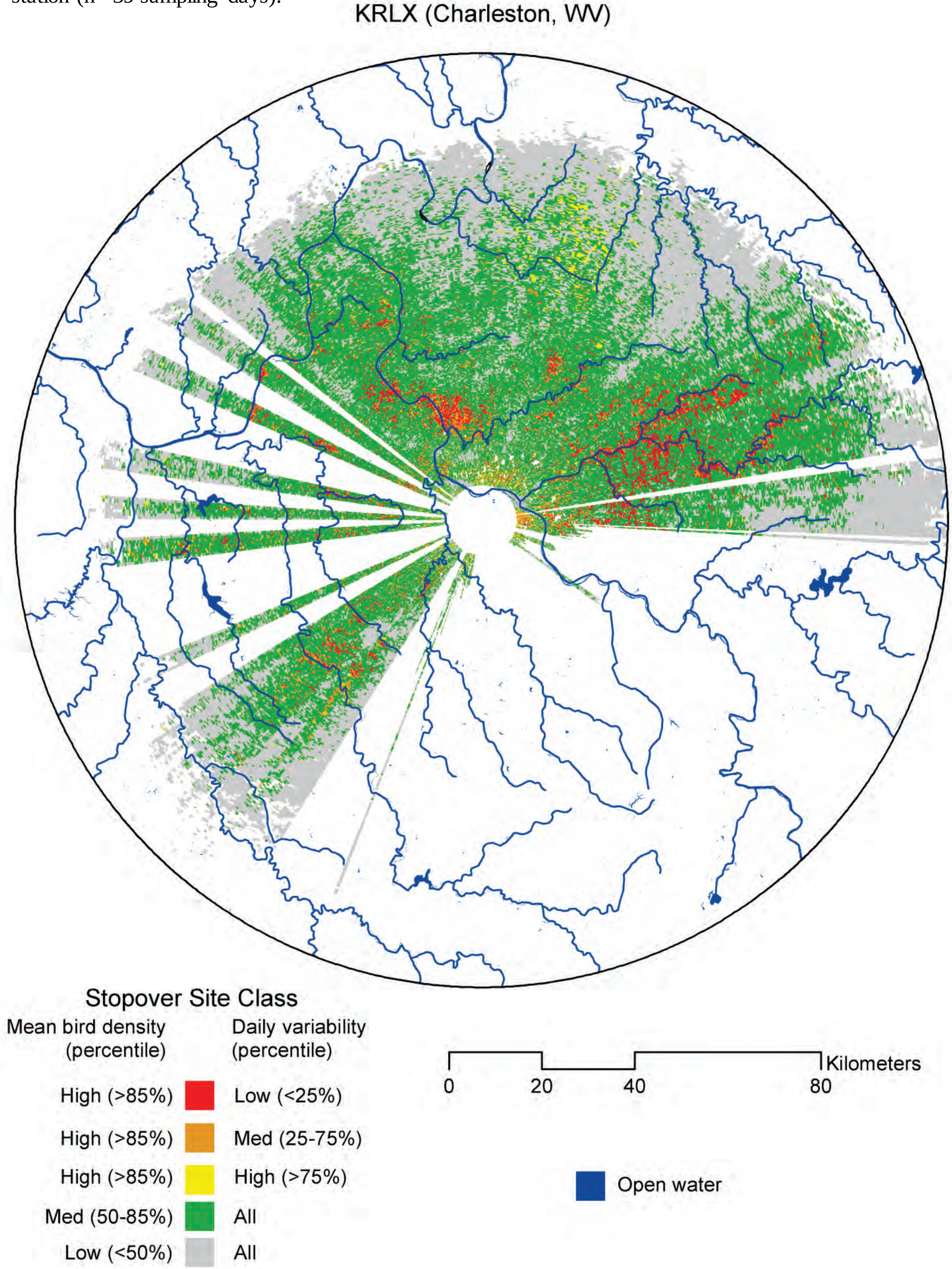
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KOKX station (n= 20 sampling days).



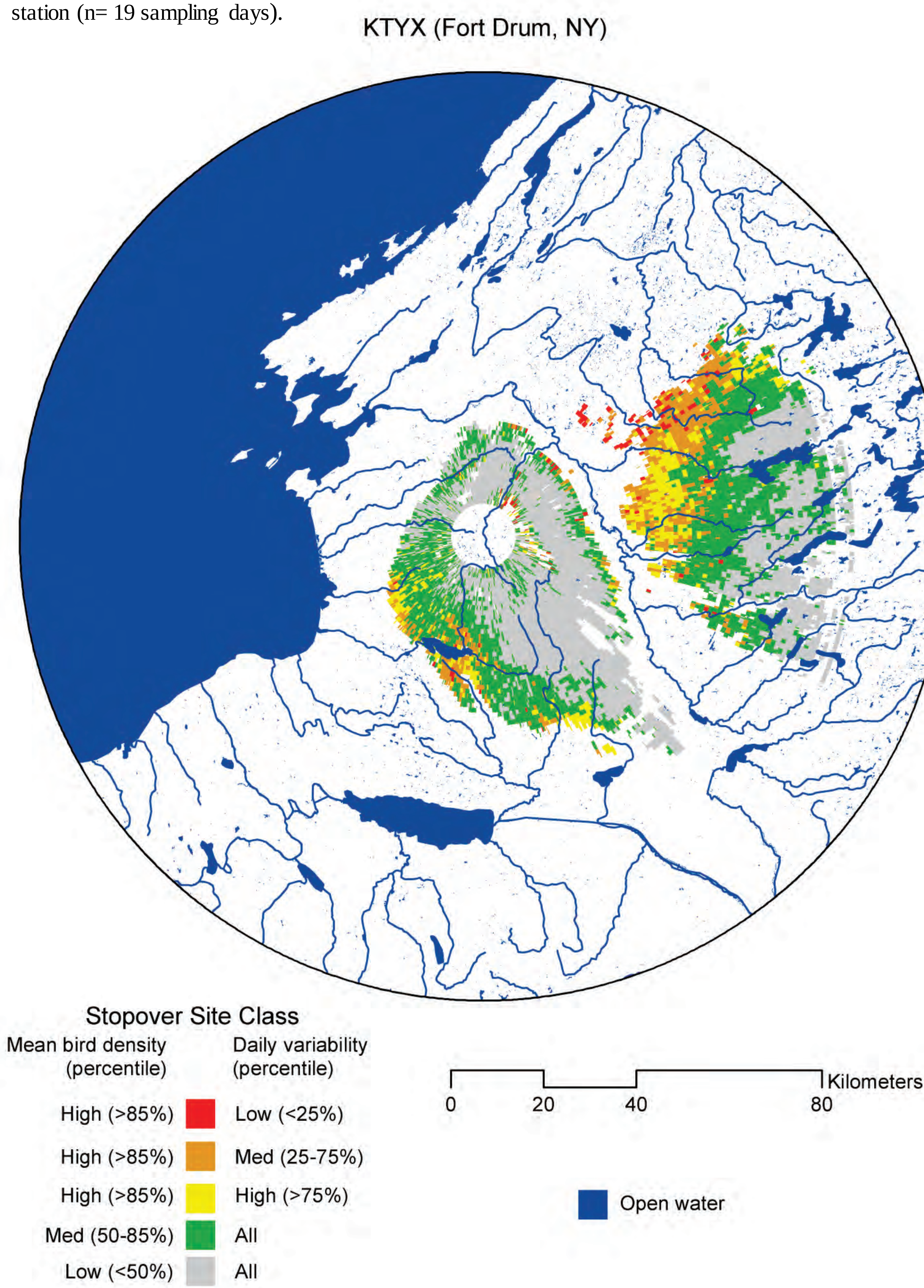
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KPBZ station (n= 37 sampling days).



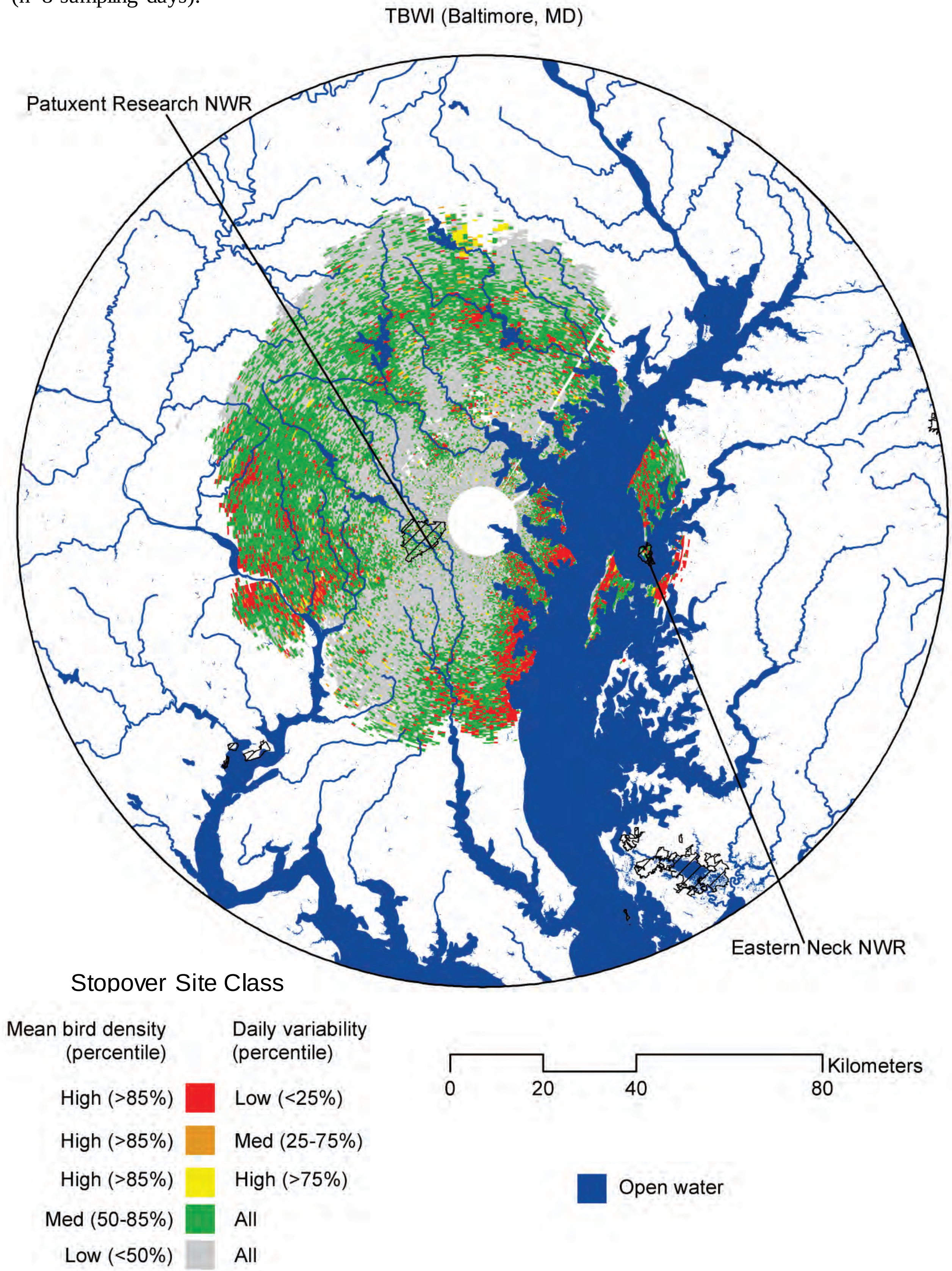
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KRLX station (n= 39 sampling days).



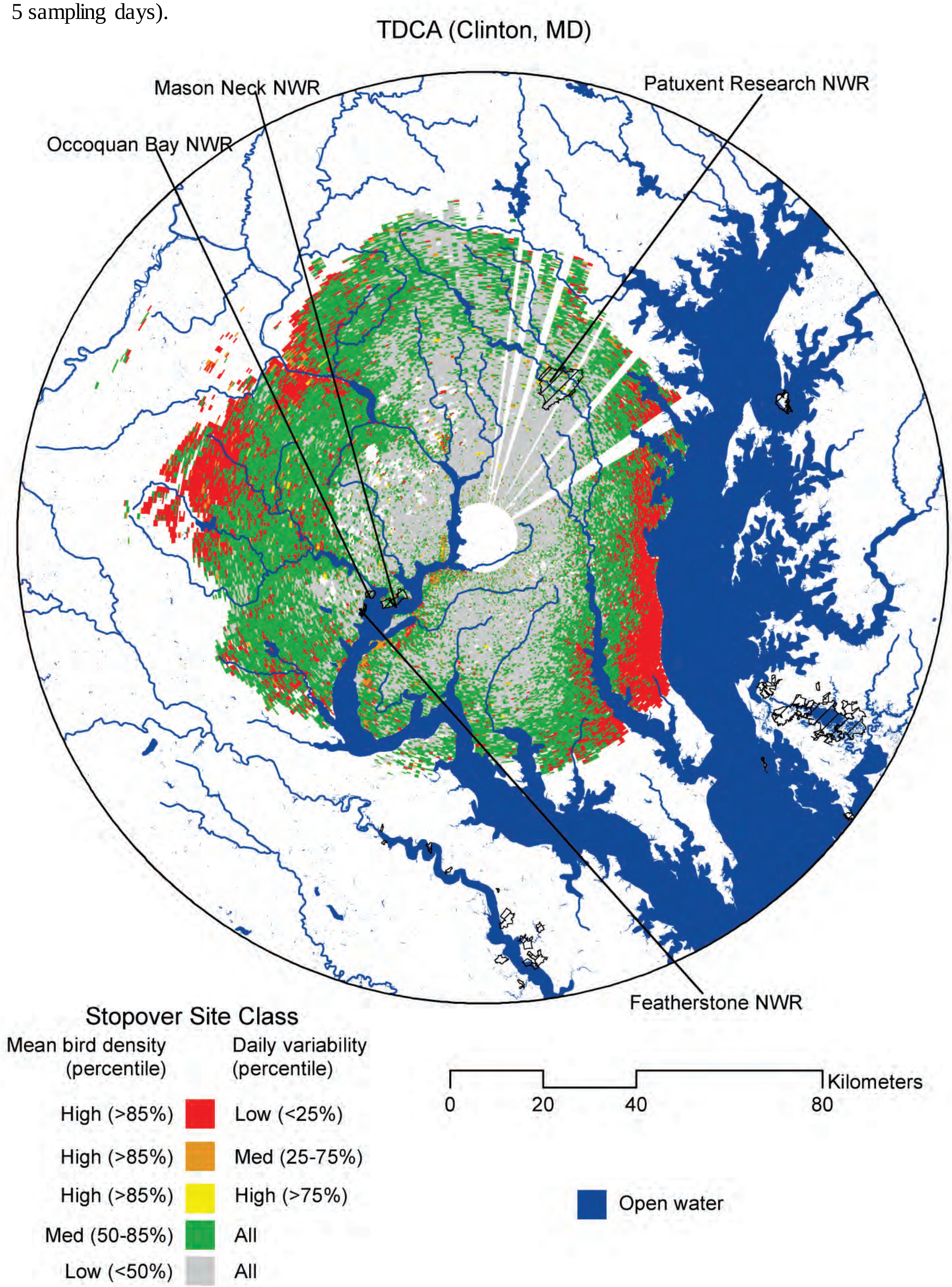
Appendix B (continued). Classified bird stopover density during fall 2008 & 2009 from the KTYX station (n= 19 sampling days).



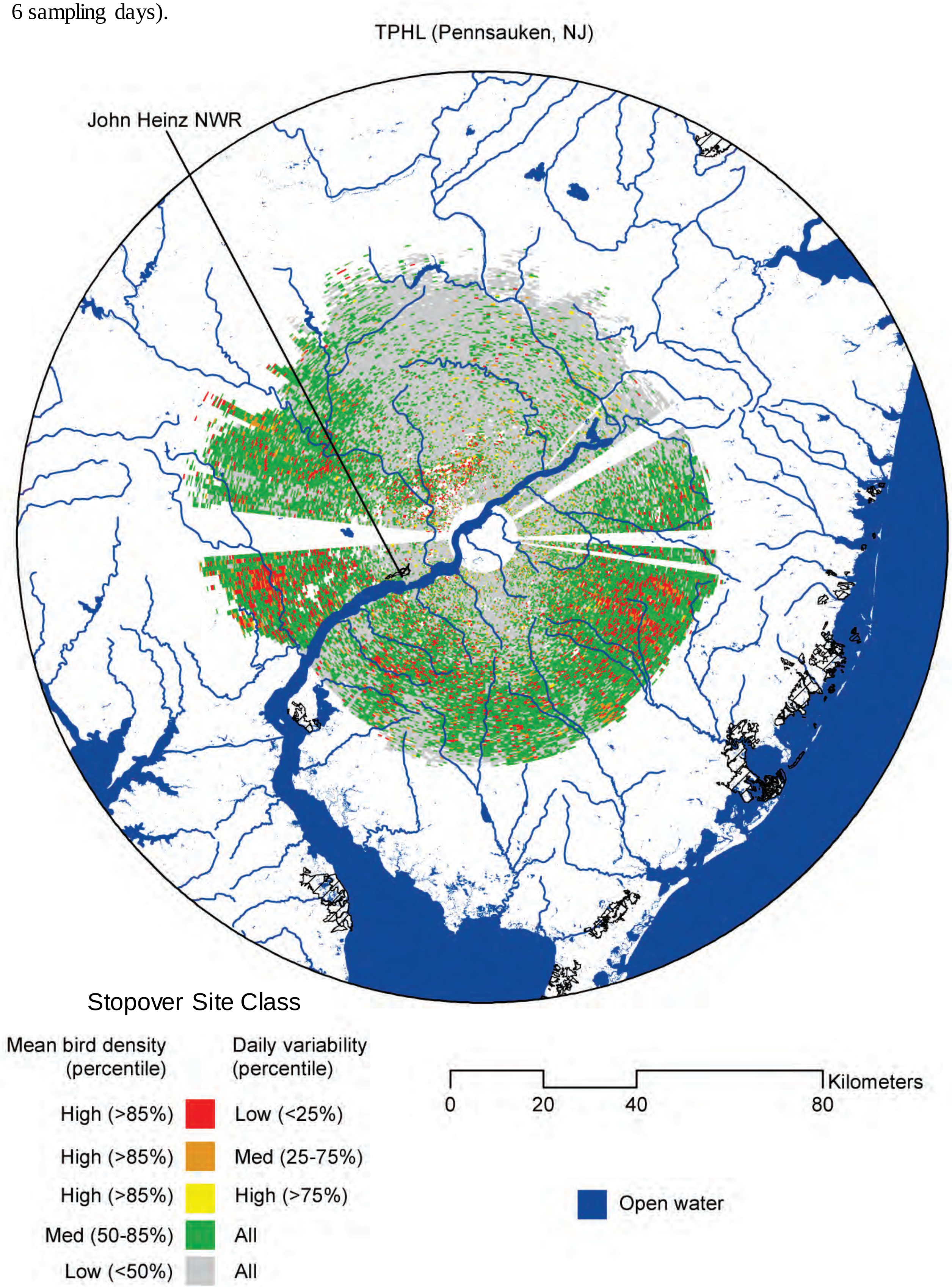
Appendix B (continued). Classified bird stopover density during fall 2009 from the TBWI station (n=8 sampling days).



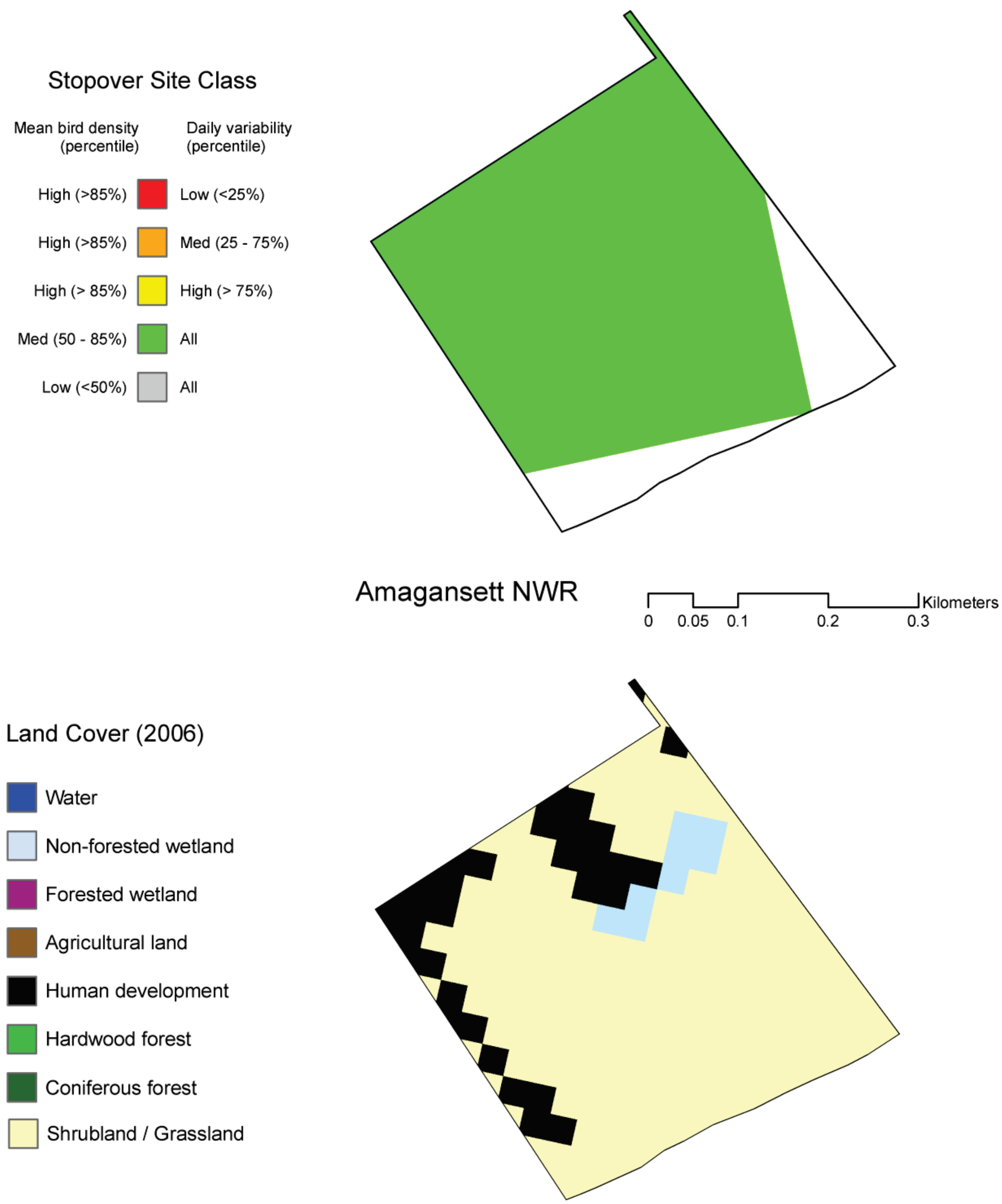
Appendix B (continued). Classified bird stopover density during fall 2009 from the TDCA station (n= 5 sampling days).



Appendix B (continued). Classified bird stopover density during fall 2009 from the TPHL station (n= 6 sampling days).

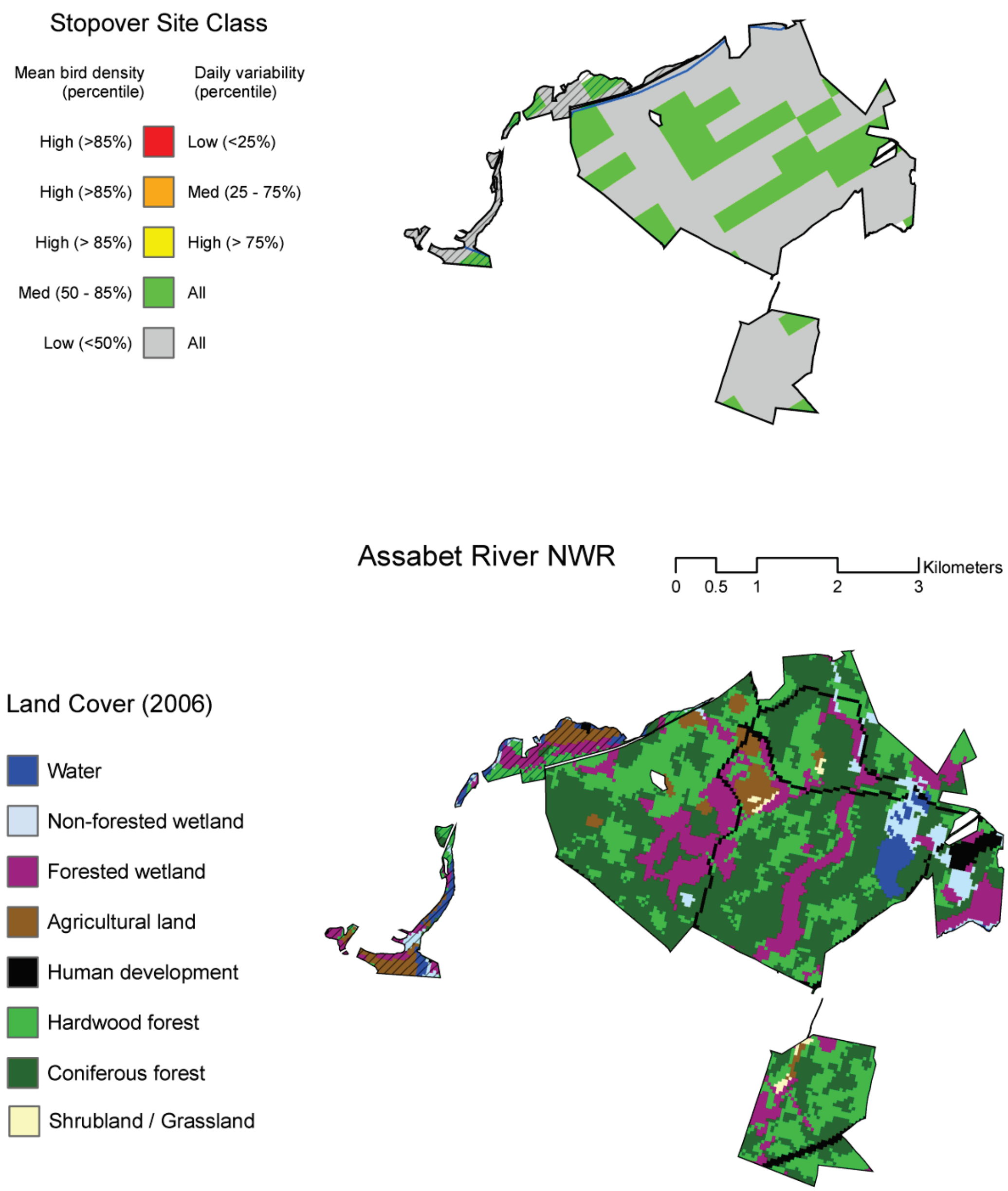


APPENDIX C. Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



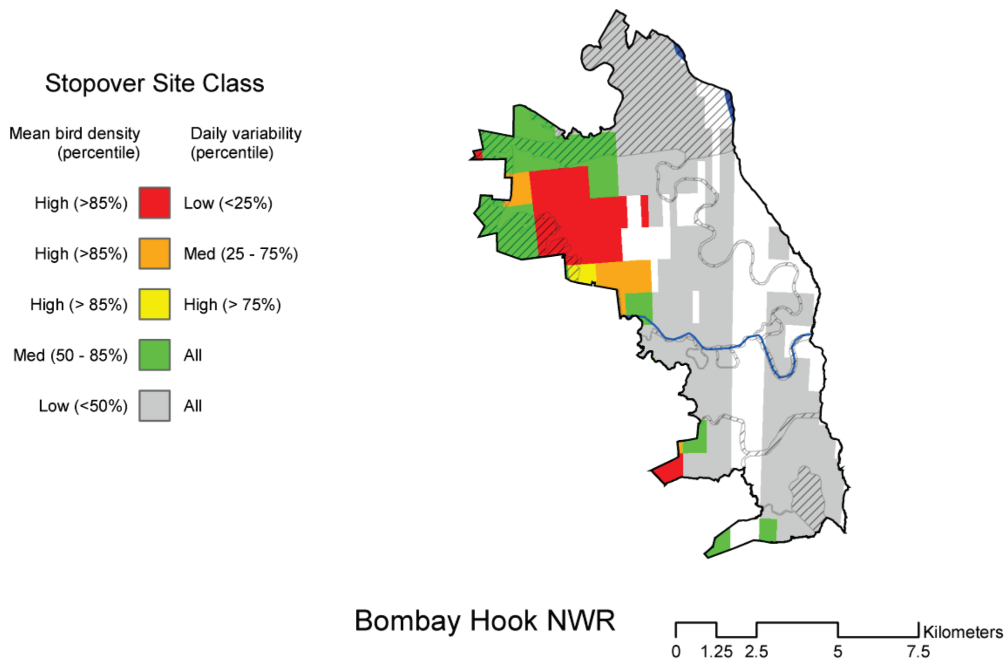
* Stopover site classification for the Amagansett NWR in Amagansett, NY is based on 20 sampling days of weather radar data from the KOKX station, New York City, NY.

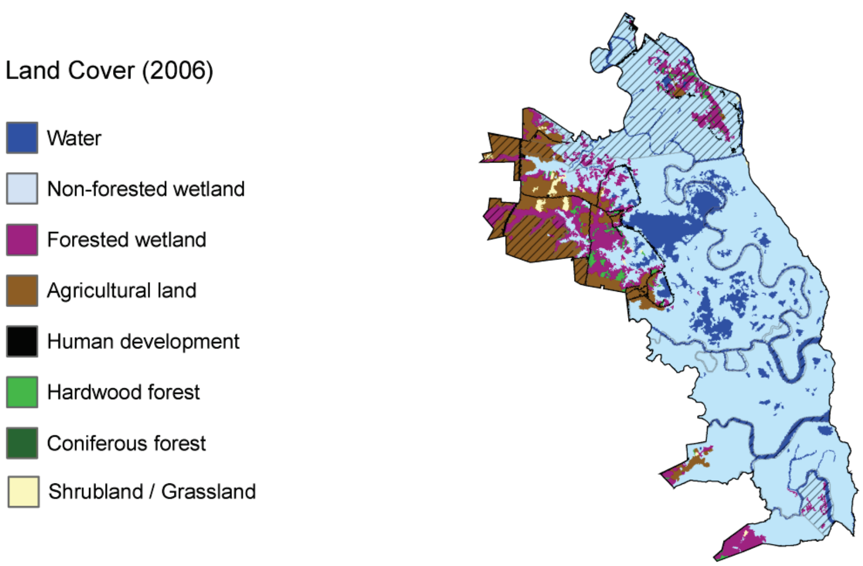
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



* Stopover site classification for the Assabet River NWR in Sudbury, MA is based on 28 sampling days of weather radar data from the KBOX station, Boston, MA.

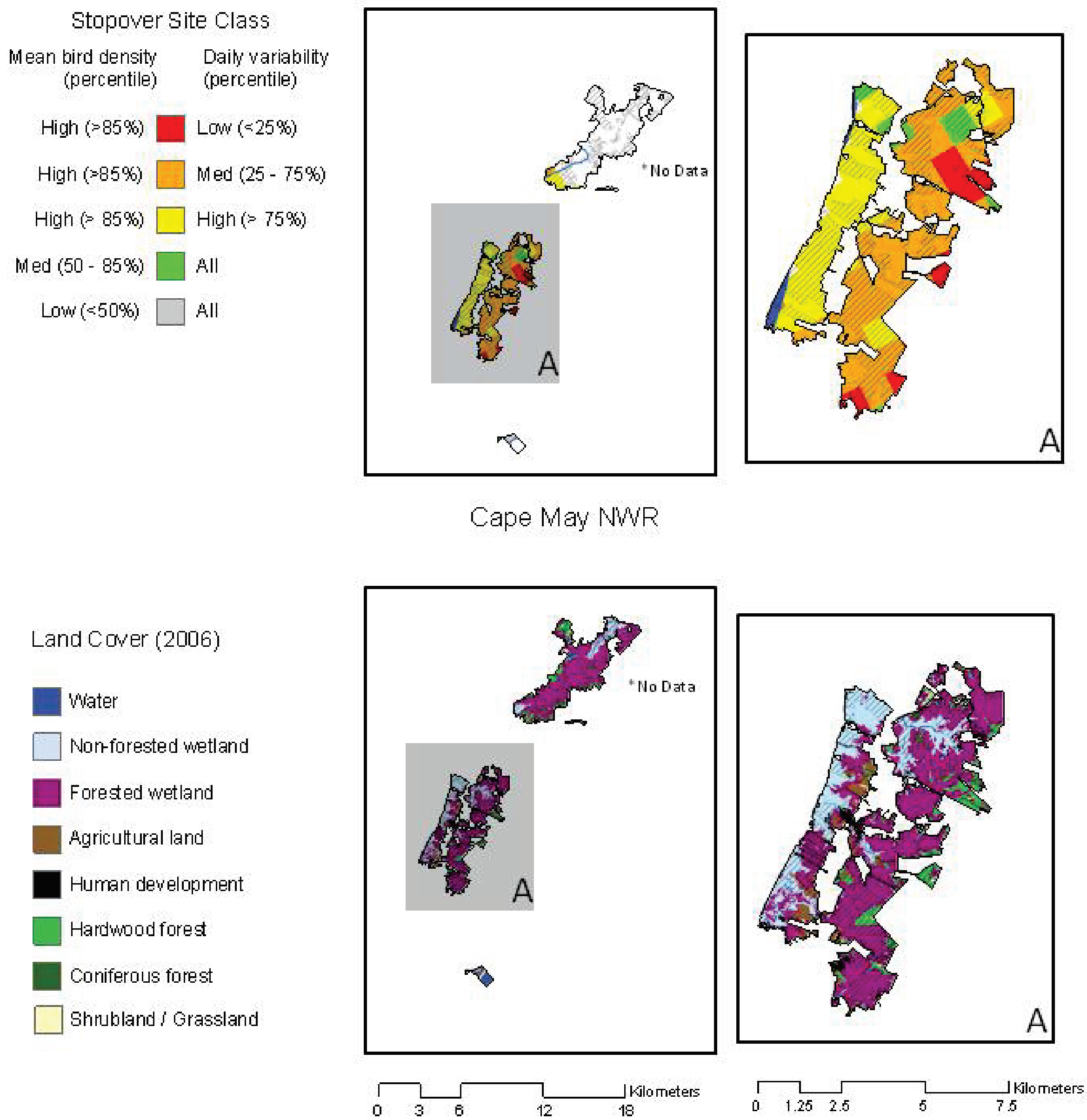
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.





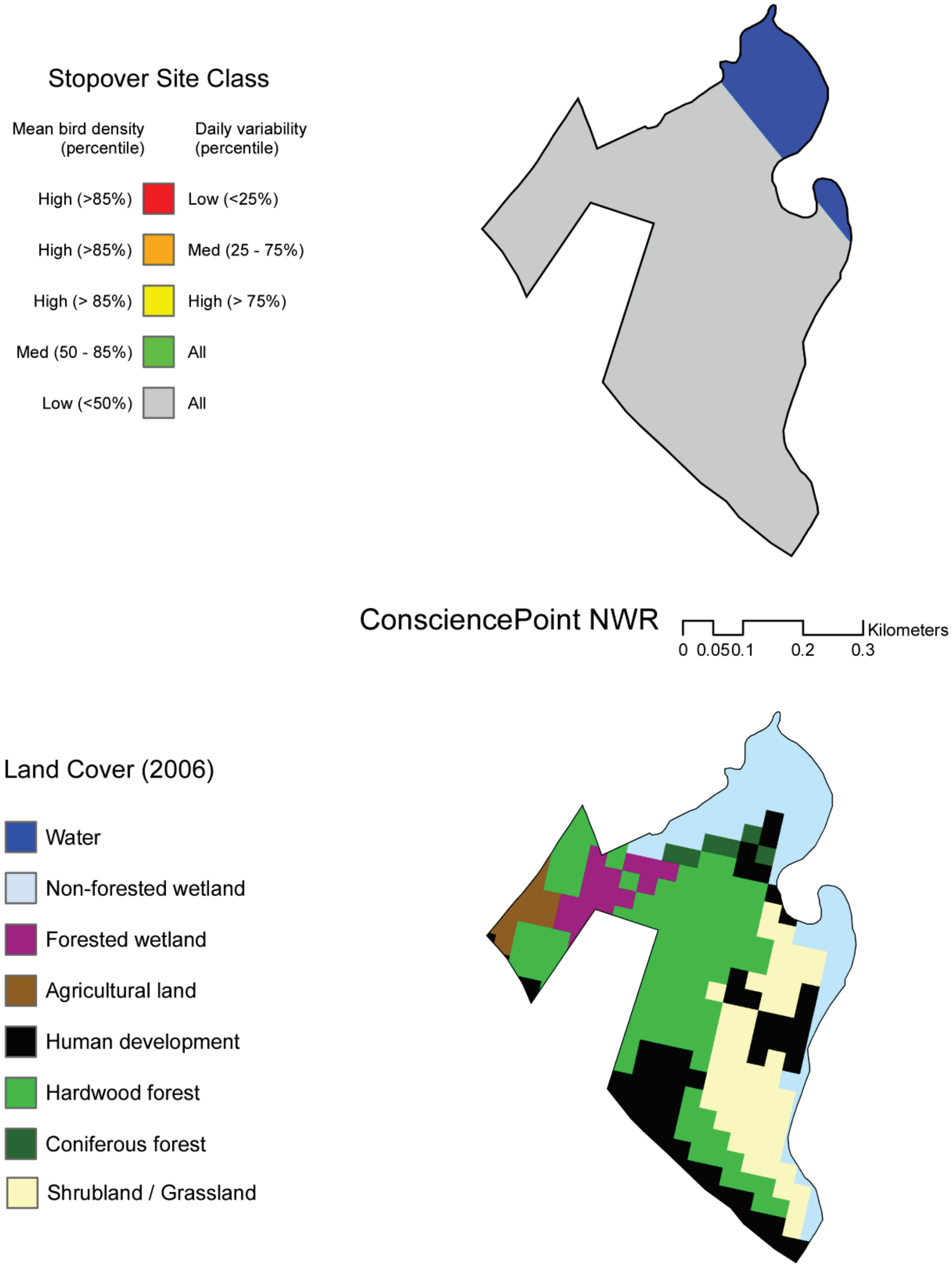
* Stopover site classification for the Bombay Hook NWR in Smyrna, DE is based on 30 sampling days of weather radar data from the KDOX station, Dover, DE.

Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



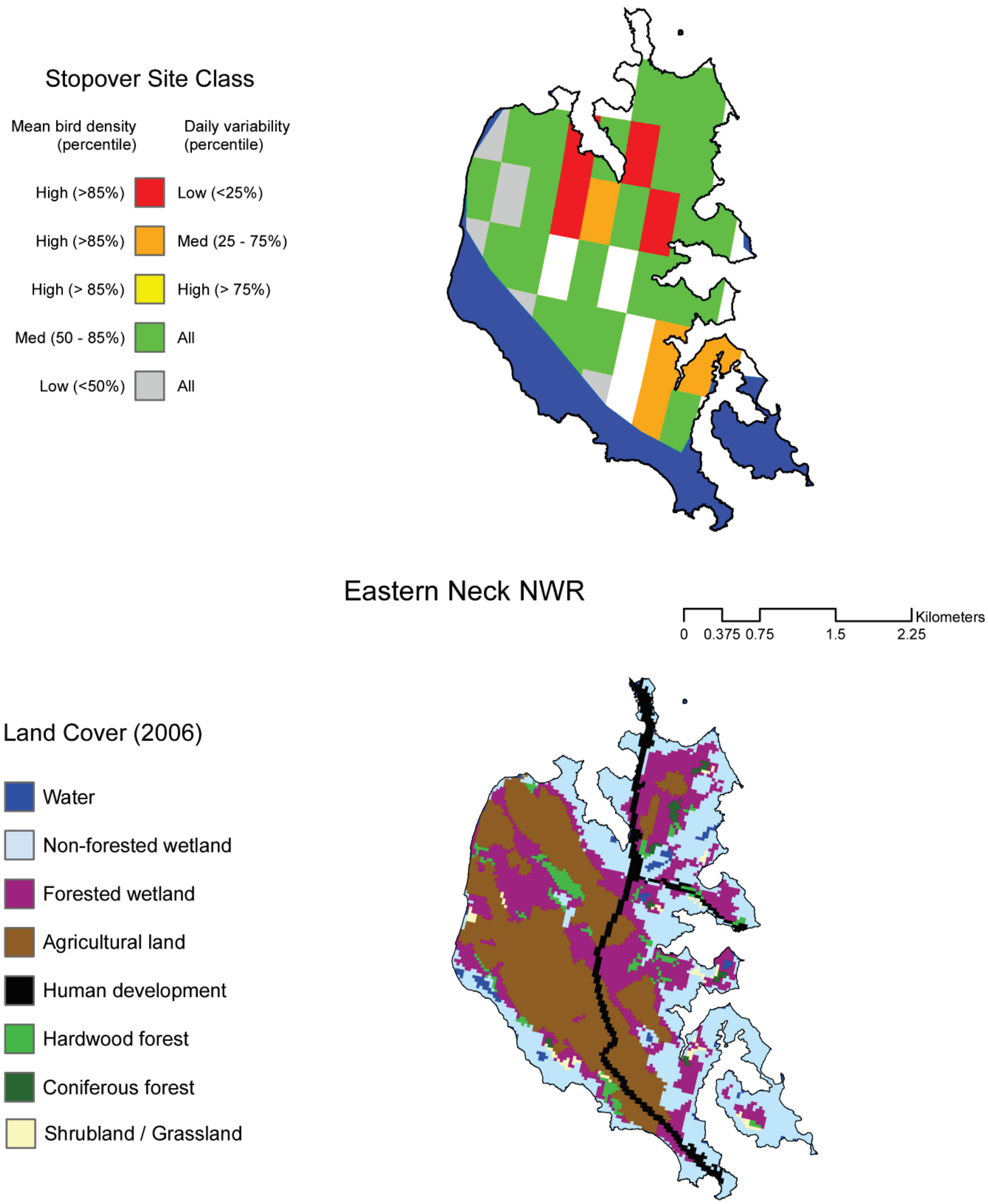
* Stopover site classification for the Cape May NWR in Cape May, NJ is based on 30 sampling days of weather radar data from the KDOX station, Dover, DE.

Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



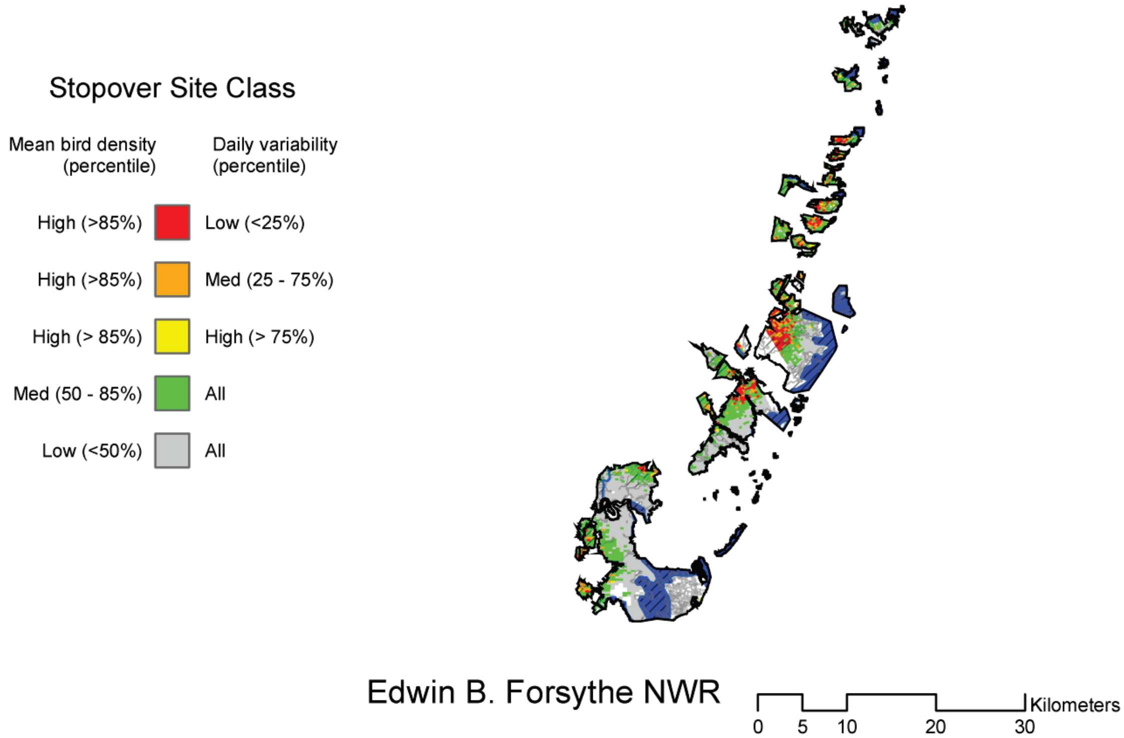
* Stopover site classification for Conscience Point NWR in North Sea, NY is based on 20 sampling days of weather radar data from the KOKX station, New York City, NY.

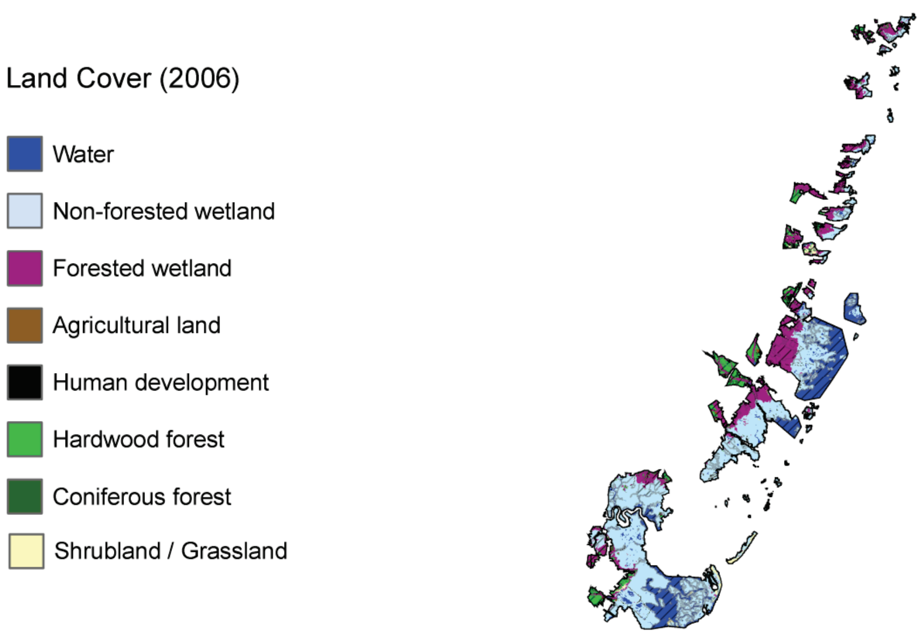
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



* Stopover site classification for Eastern Neck NWR in Rock Hall, MD is based on 8 sampling days of weather radar data from the TBWI station, Baltimore, MD.

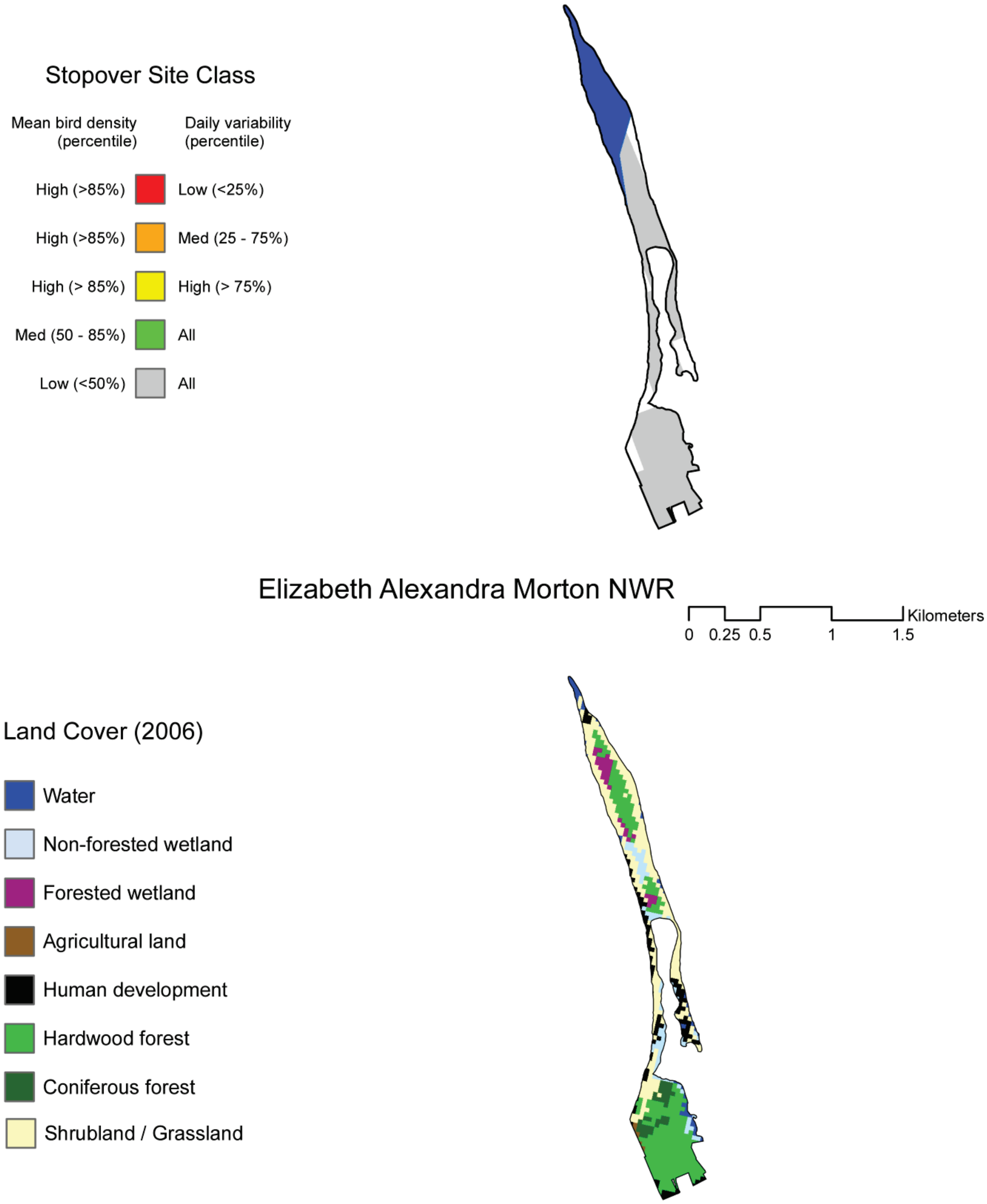
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.





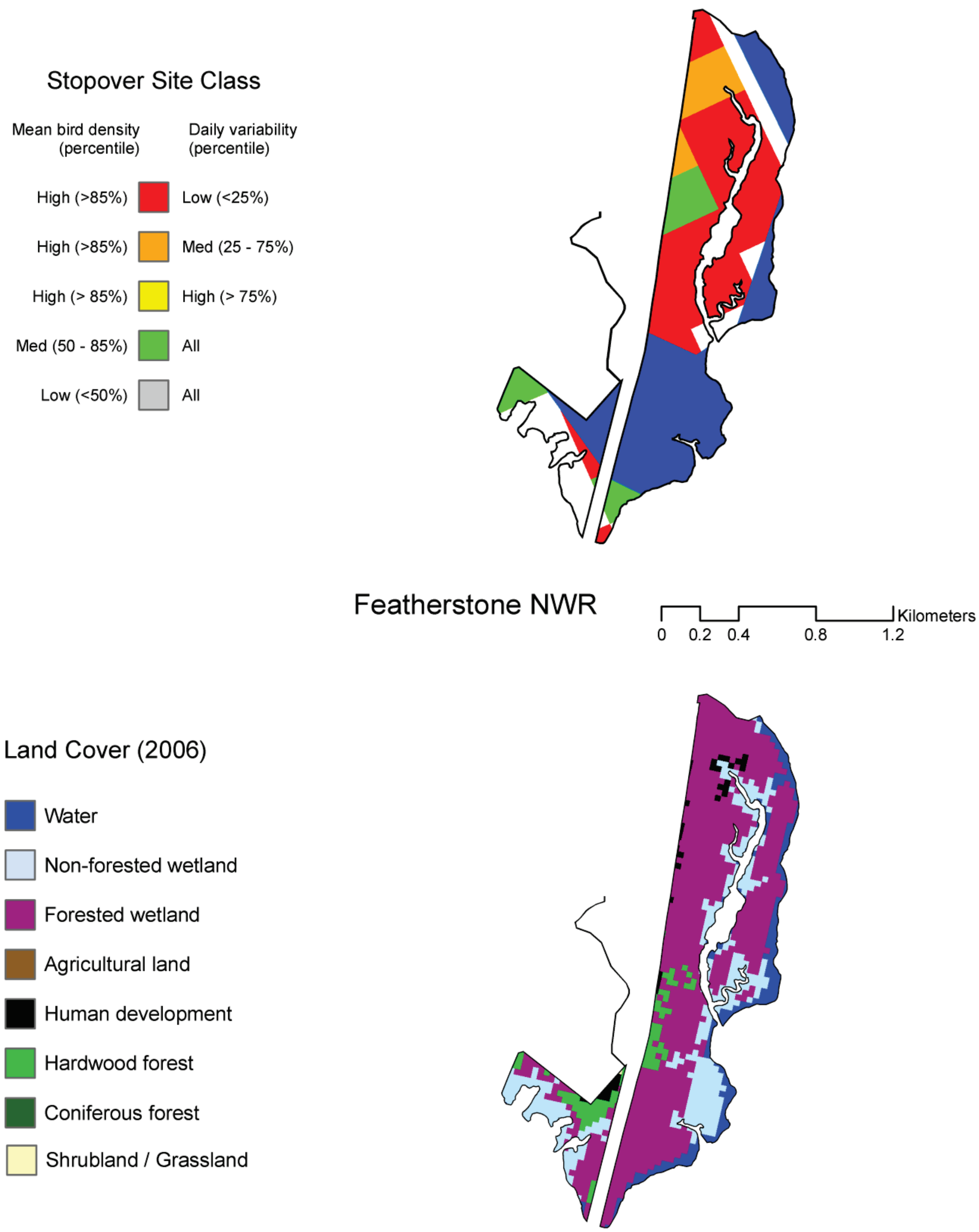
* Stopover site classification for the Edwin B. Forsythe NWR in Oceanville, NJ is based on 19 sampling days of weather radar data from the KDIX station, Mount Holly, NJ.

Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



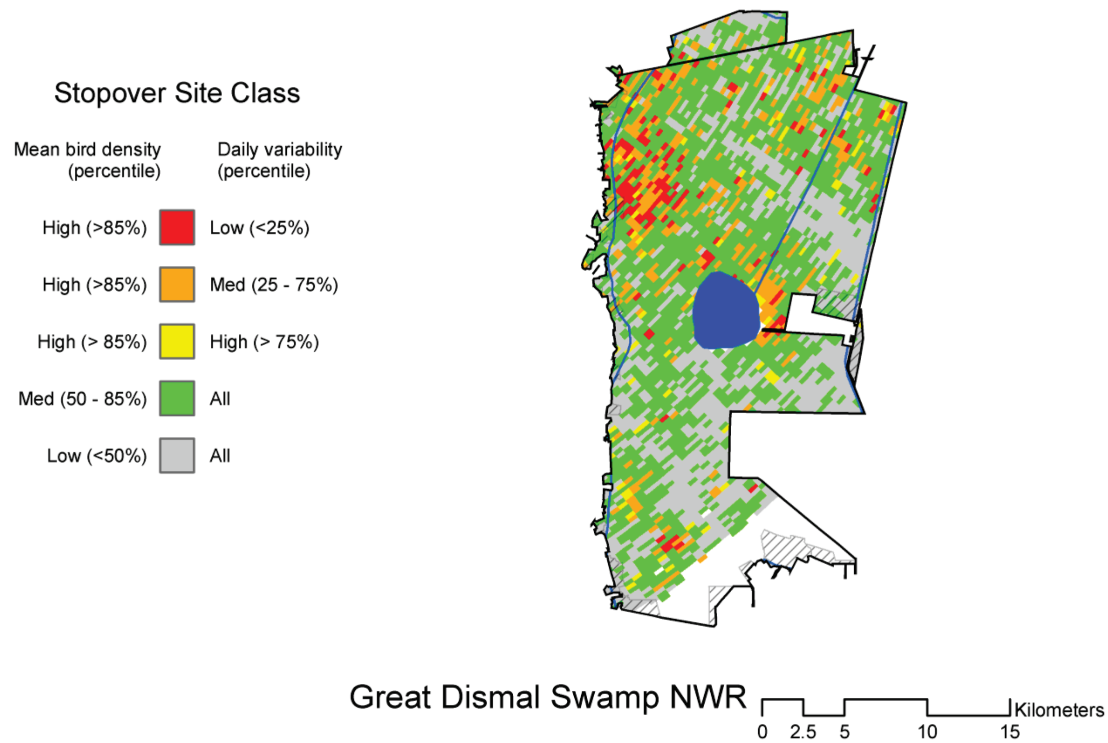
* Stopover site classification for Elizabeth Alexandra Morton NWR in Sag Harbor, NY is based on 20 sampling days of weather radar data from the KOKX station, New York City, NY.

Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



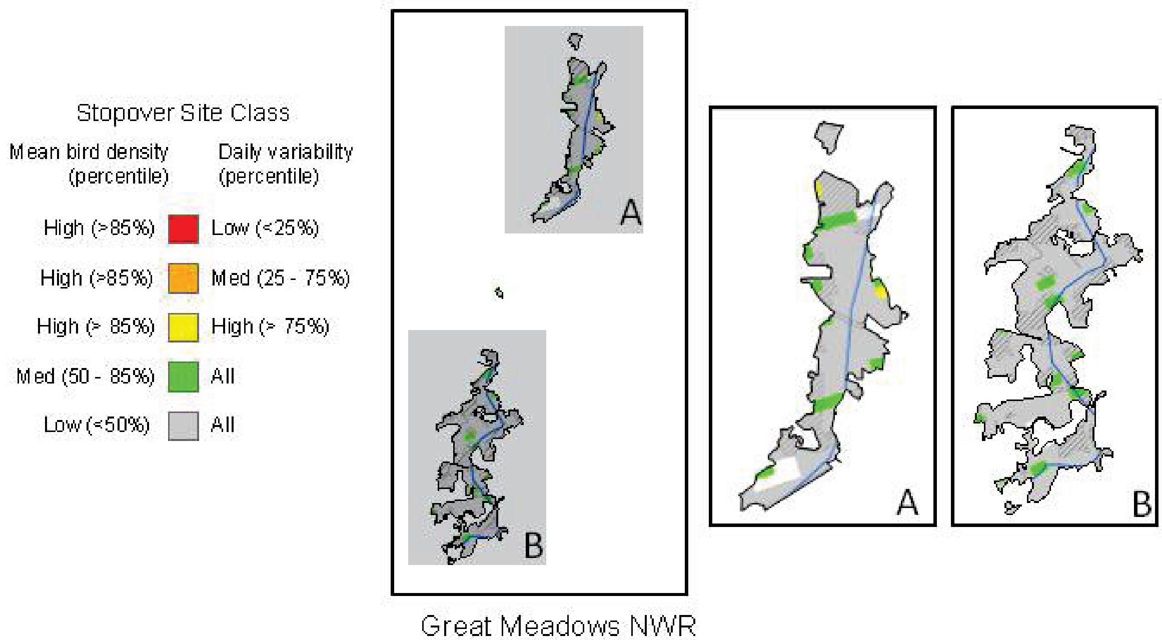
* Stopover site classification for the Featherstone NWR in Woodbridge, VA is based on 19 sampling days of weather radar data from the KLWX station, Washington, DC.

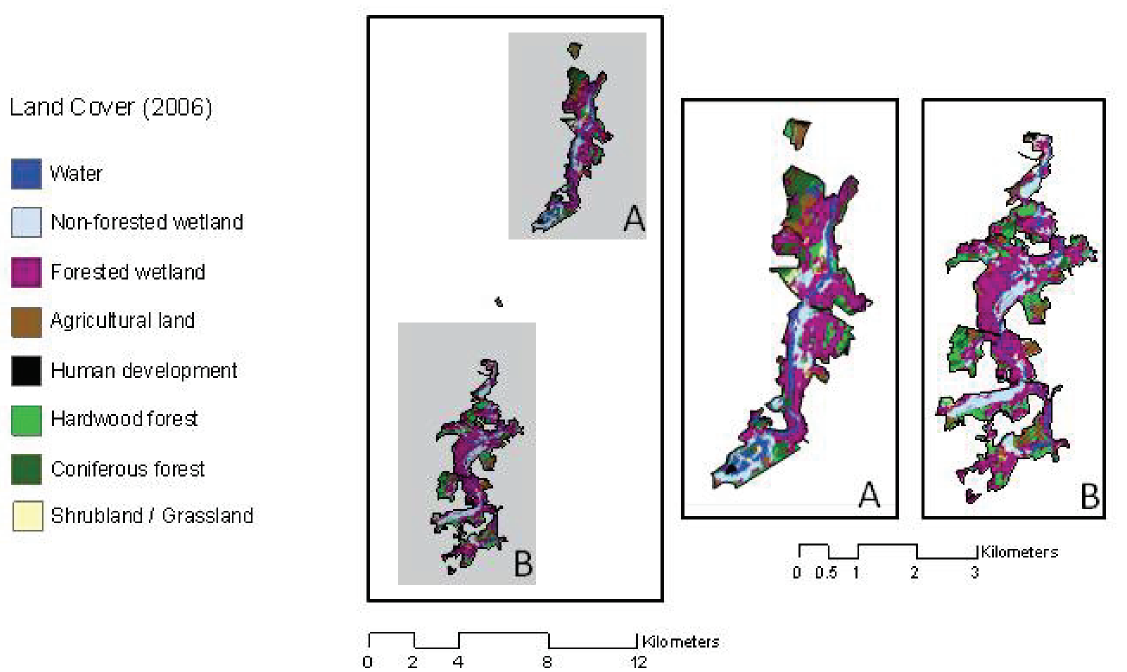
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



* Stopover site classification for the Great Dismal Swamp NWR in Suffolk, VA is based on 25 sampling days of weather radar data from the KAKQ station, Norfolk, VA.

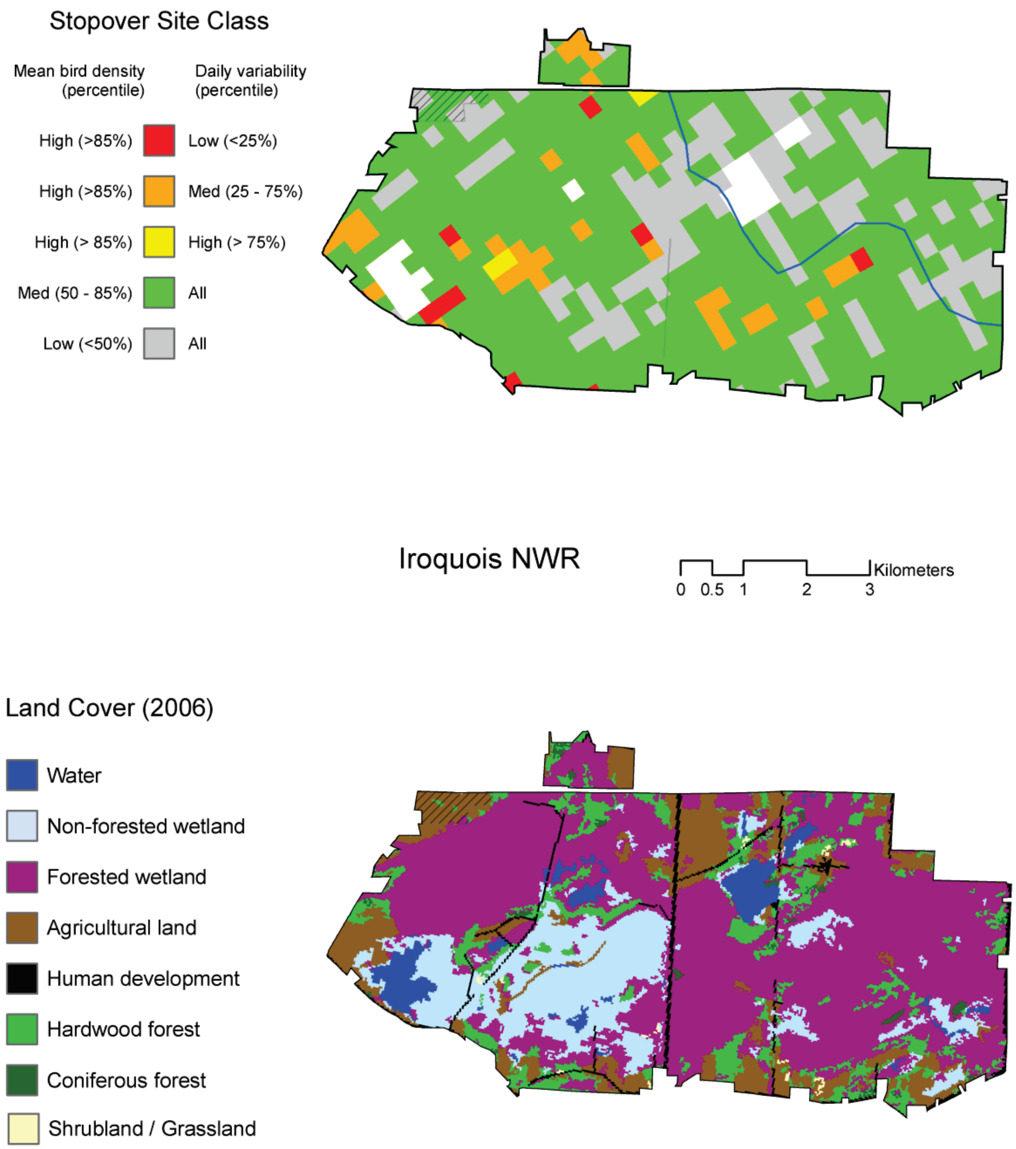
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.





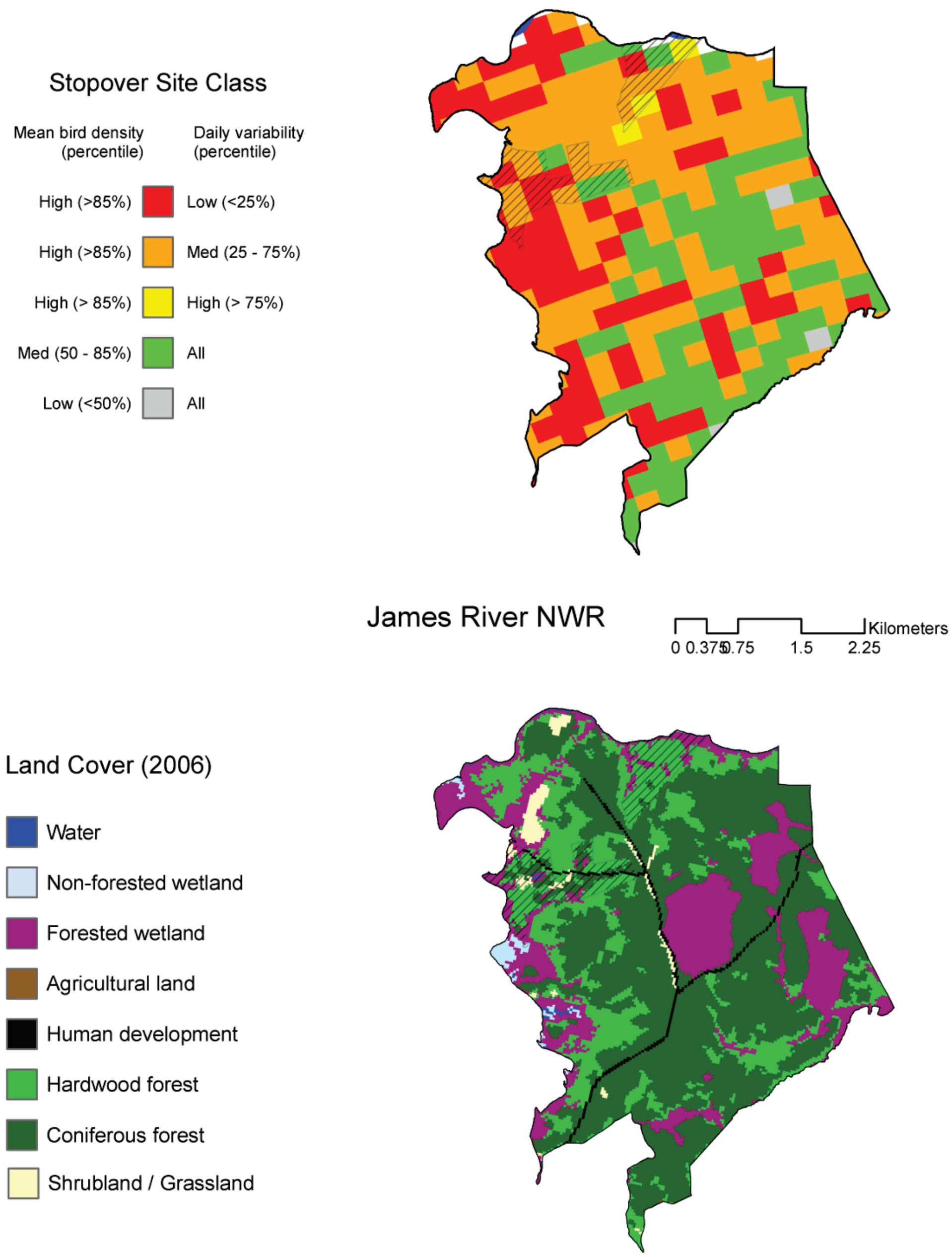
* Stopover site classification for the Great Meadows NWR in Sudbury, MA is based on 28 sampling days of weather radar data from the KBOX station, Boston, MA.

Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



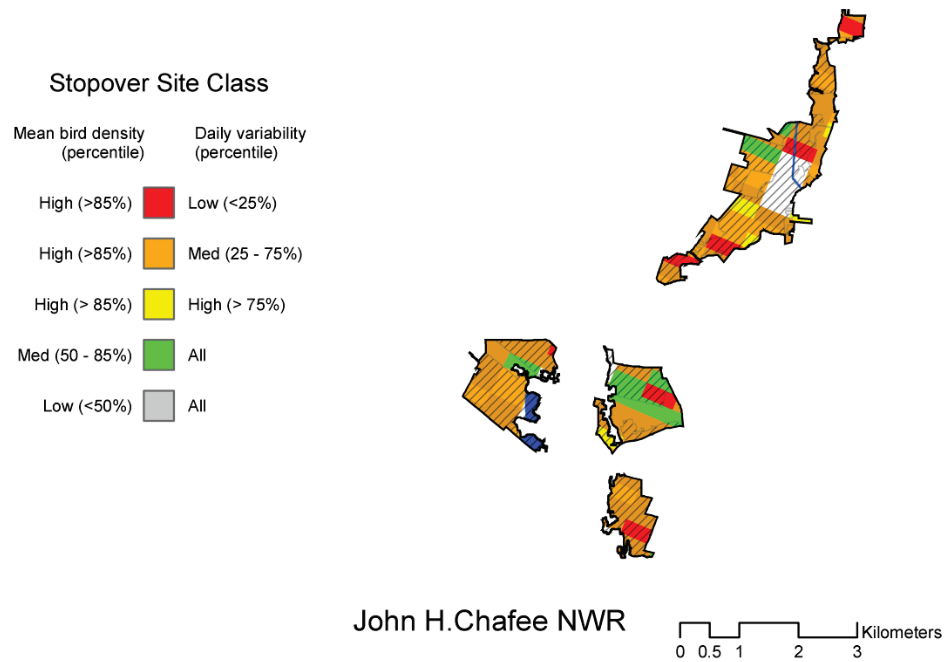
* Stopover site classification for the Iroquois NWR in Basom, NY is based on 19 sampling days of weather radar data from the KBUF station, Buffalo, NY.

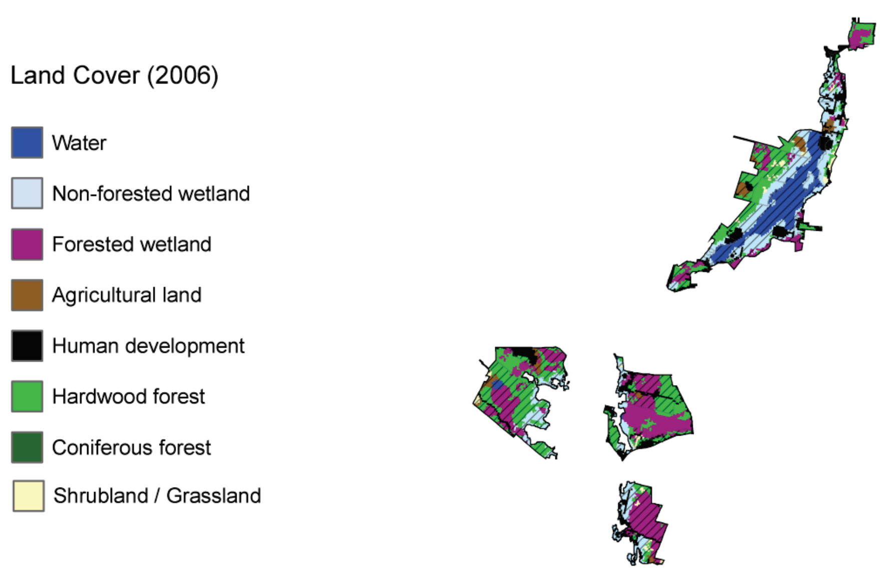
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



* Stopover site classification for the James River NWR in Charles City, VA is based on 25 sampling days of weather radar data from the KAKQ station, Norfolk, VA.

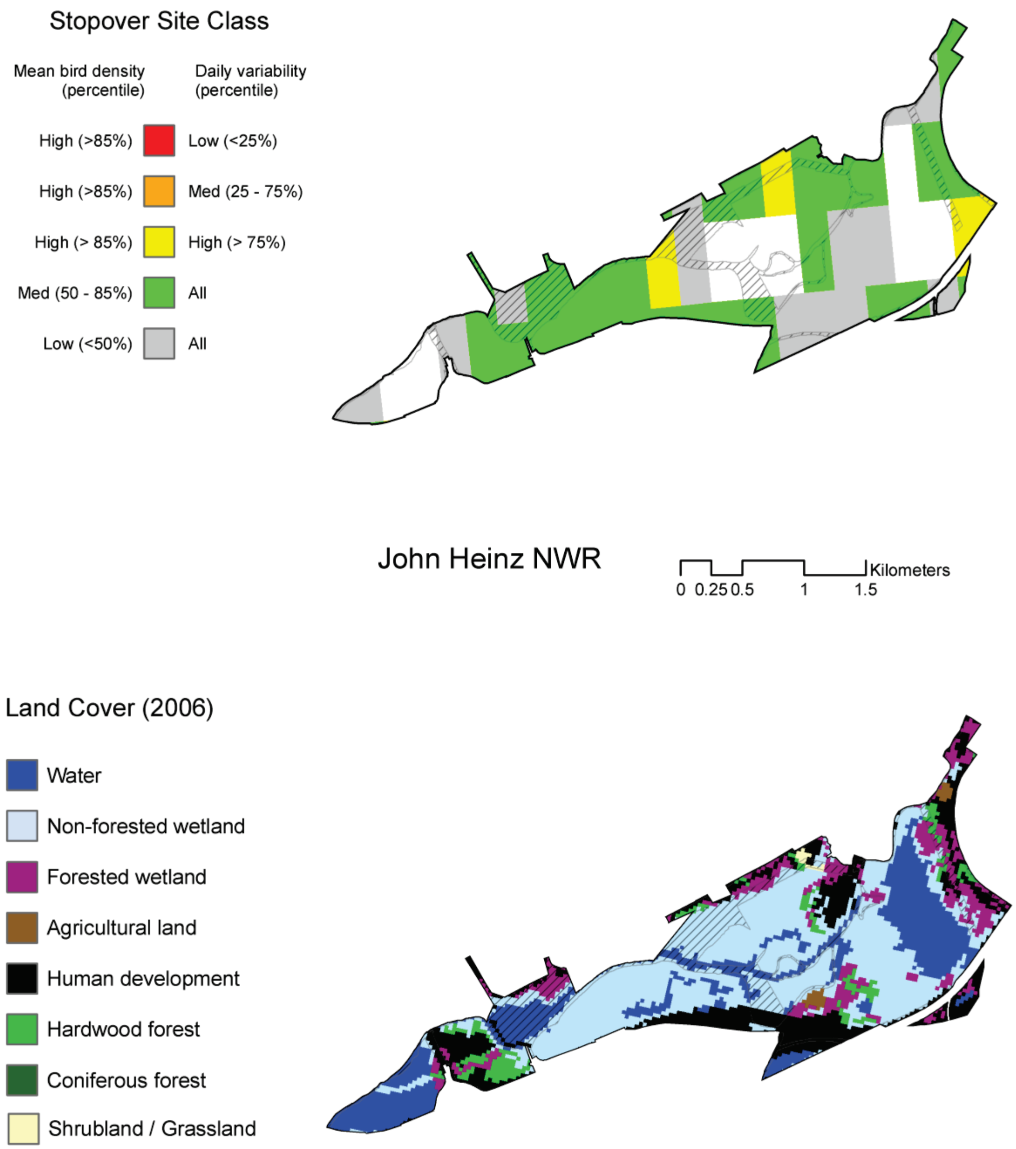
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.





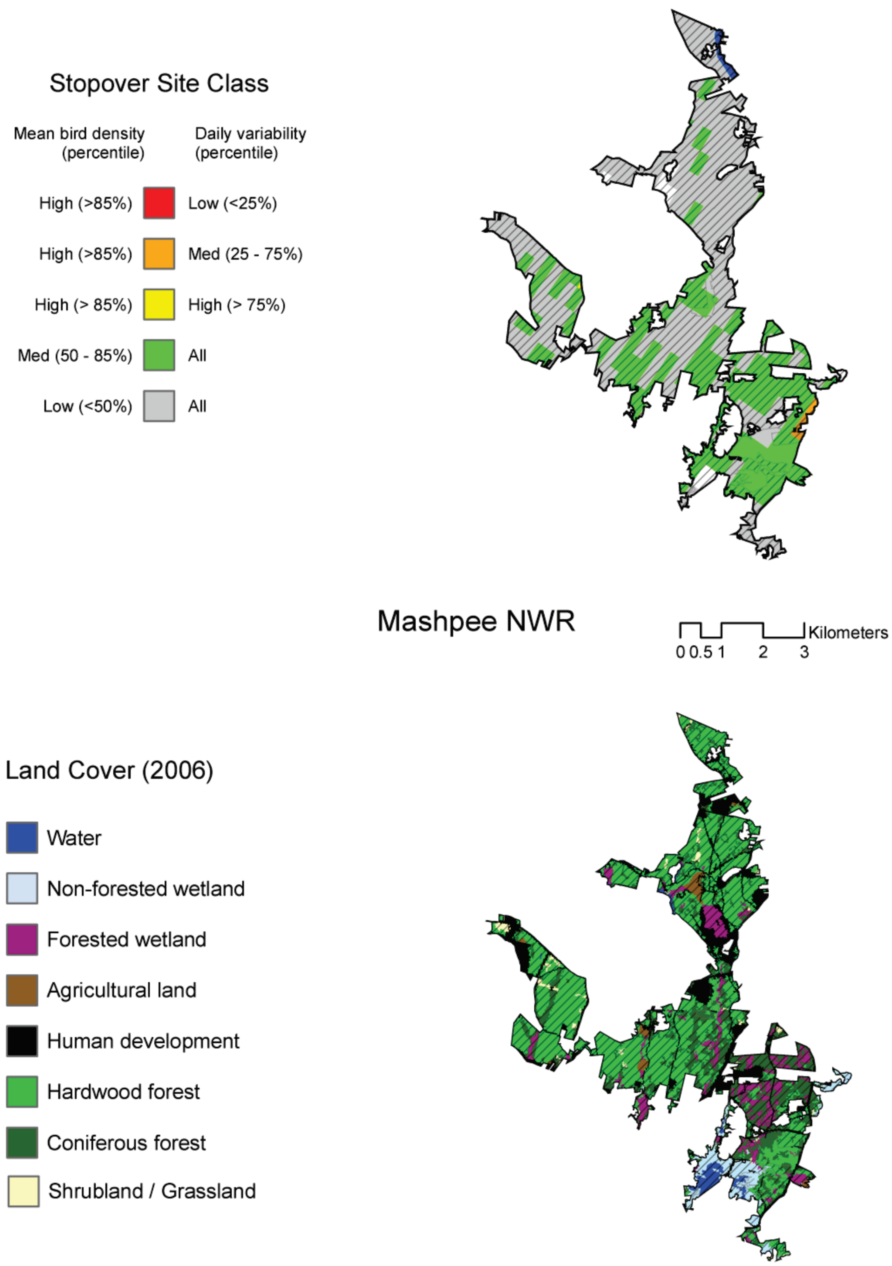
* Stopover site classification for the John H. Chafee NWR in South Kingstown, RI is based on 28 sampling days of weather radar data from the KBOX station, Boston, MA.

Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



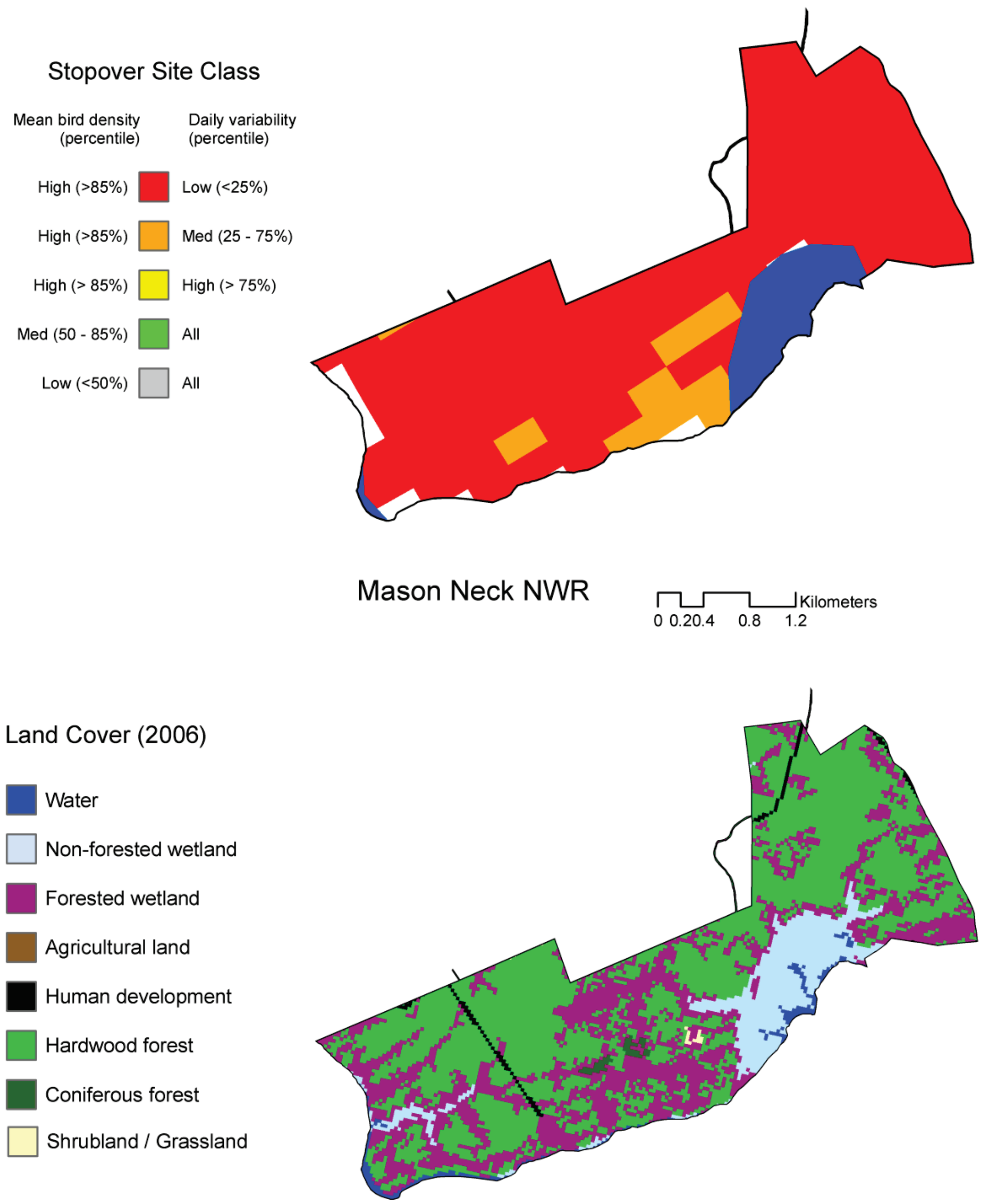
* Stopover site classification for the John Heinz NWR in Philadelphia, PA is based on 19 sampling days of weather radar data from the KDIX station, Mount Holly, NJ.

Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



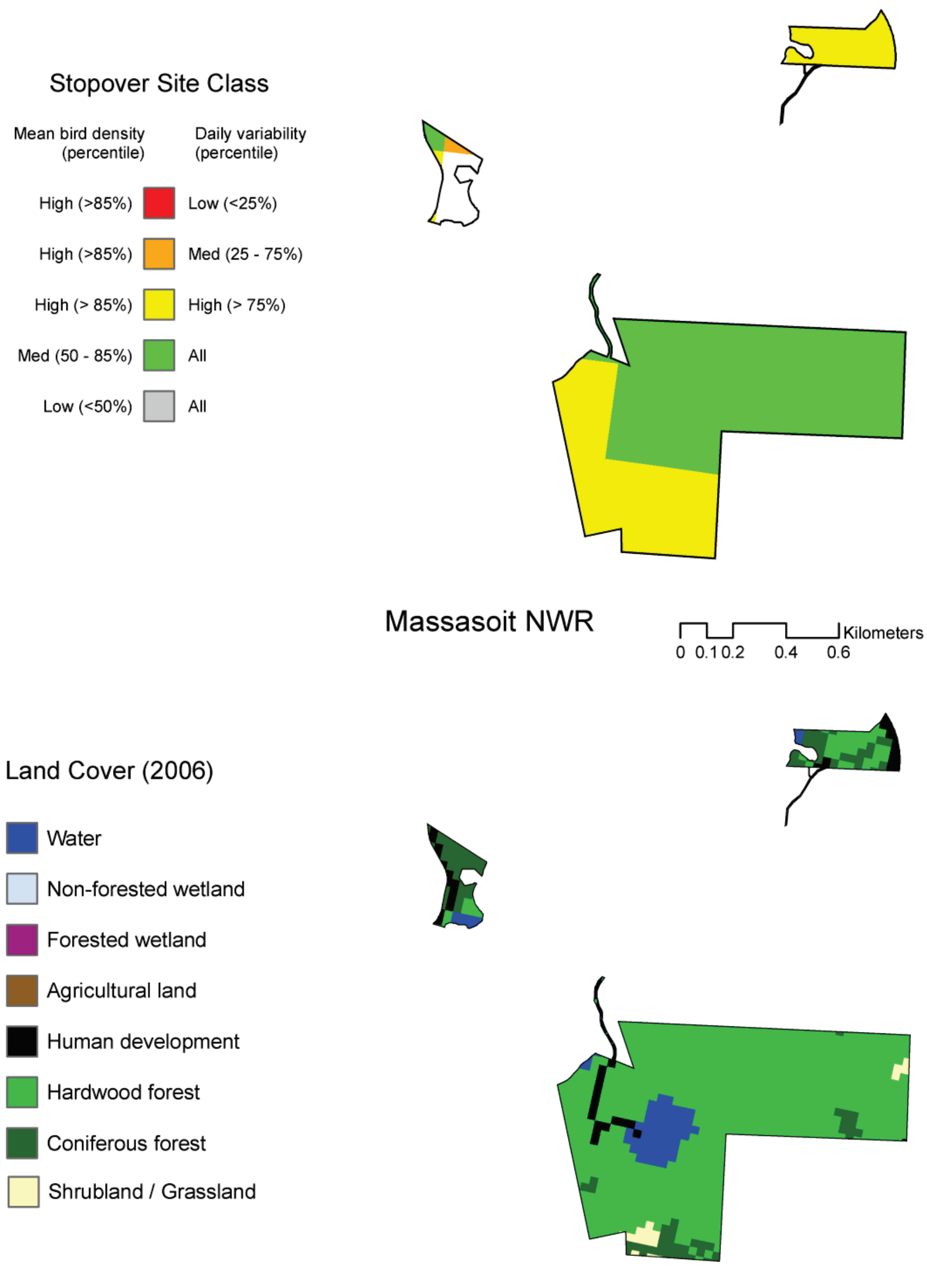
* Stopover site classification for the Mashpee NWR in Sudbury, MA is based on 28 sampling days of weather radar data from the KBOX station, Boston, MA.

Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



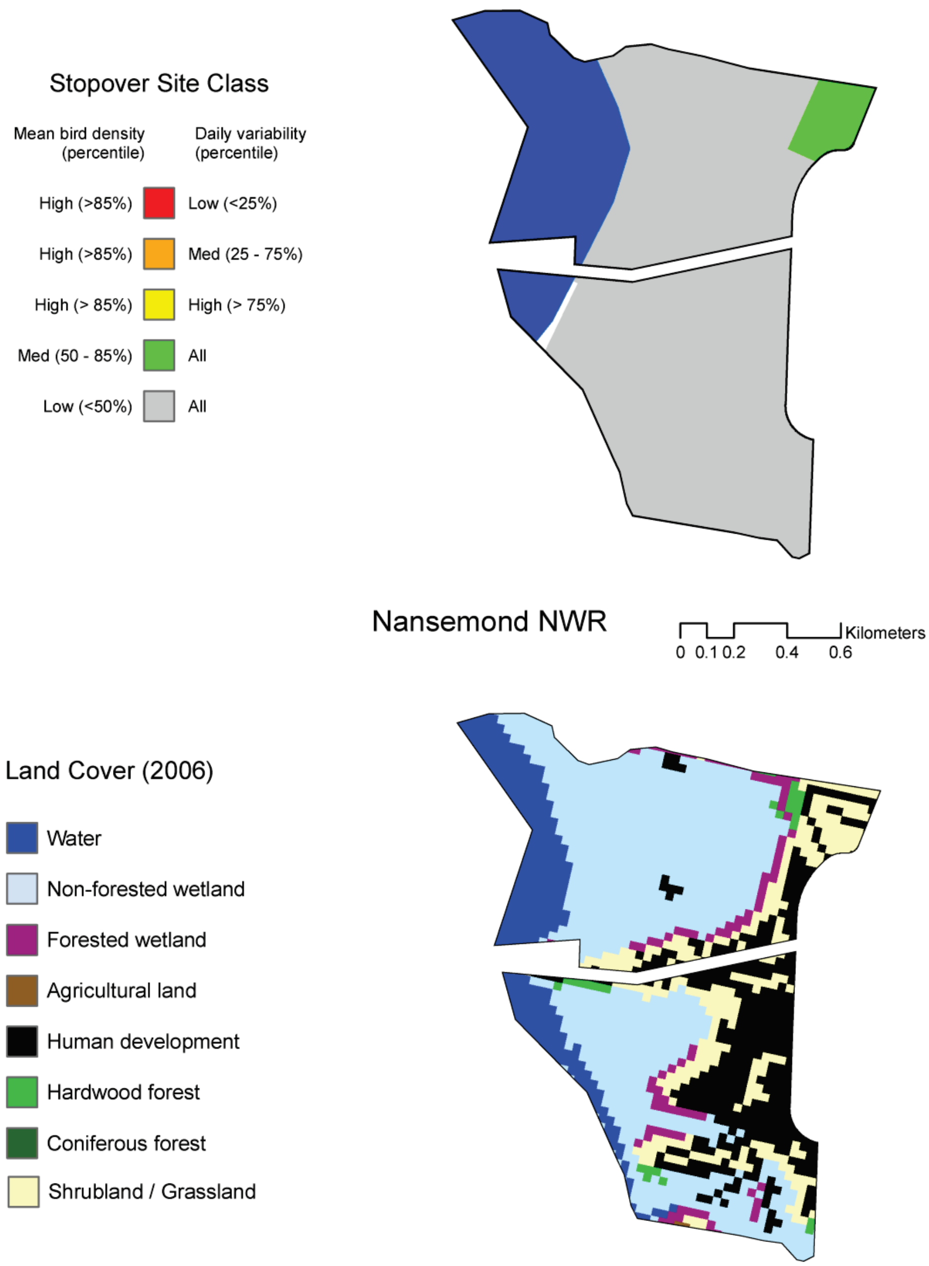
* Stopover site classification for the Mason Neck NWR in Woodbridge, VA is based on 19 sampling days of weather radar data from the KLWX station, Washington, DC.

Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



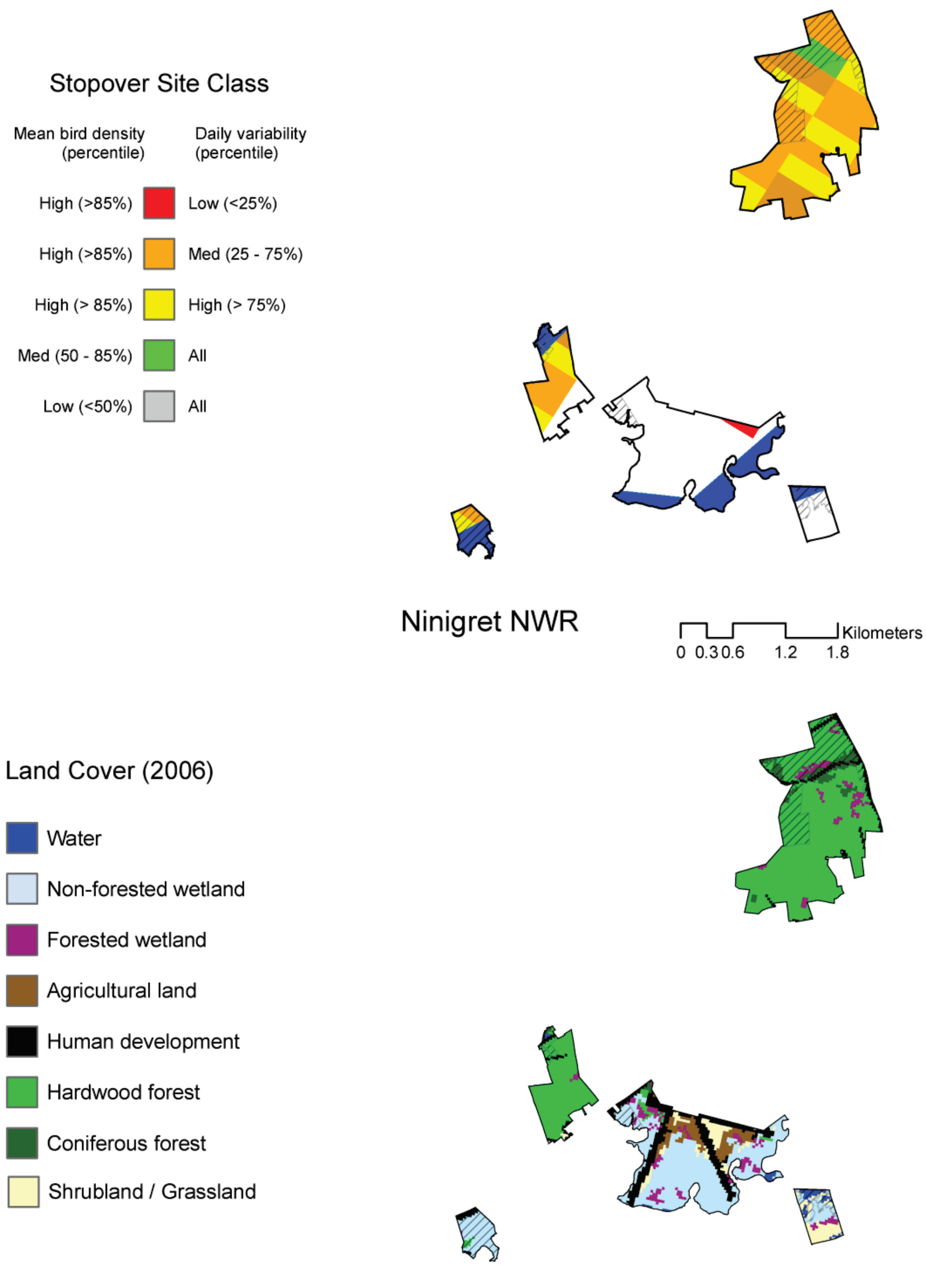
* Stopover site classification for the Massasoit NWR in Plymouth, MA is based on 28 sampling days of weather radar data from the KBOX station, Boston, MA.

Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



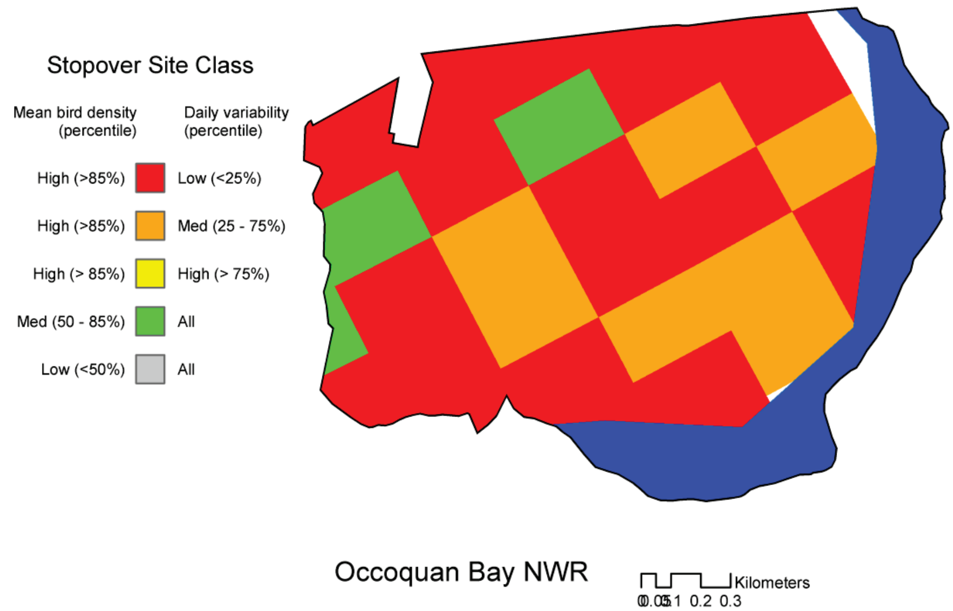
* Stopover site classification for the Nansemond NWR in Suffolk, VA is based on 25 sampling days of weather radar data from the KAKQ station, Norfolk, VA.

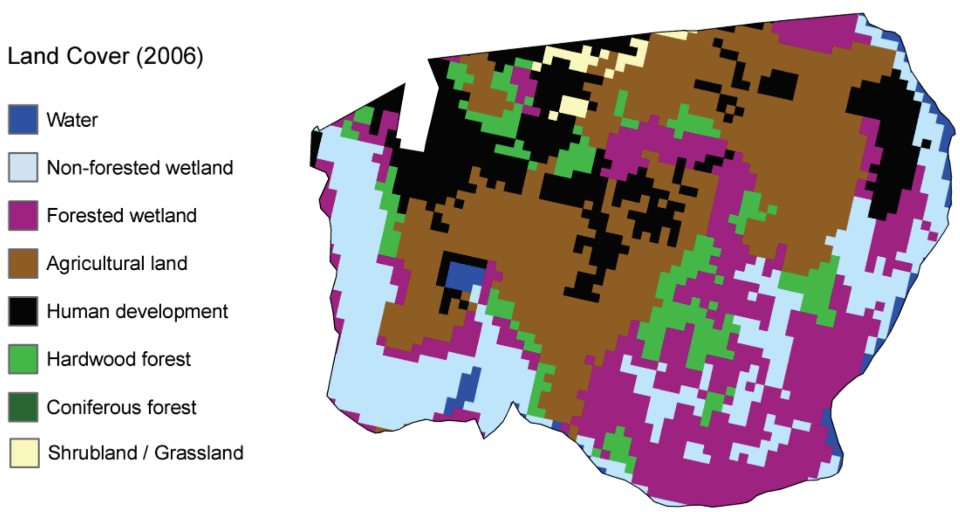
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



* Stopover site classification for the Ninigret NWR in Charleston, RI is based on 28 sampling days of weather radar data from the KBOX station, Boston, MA.

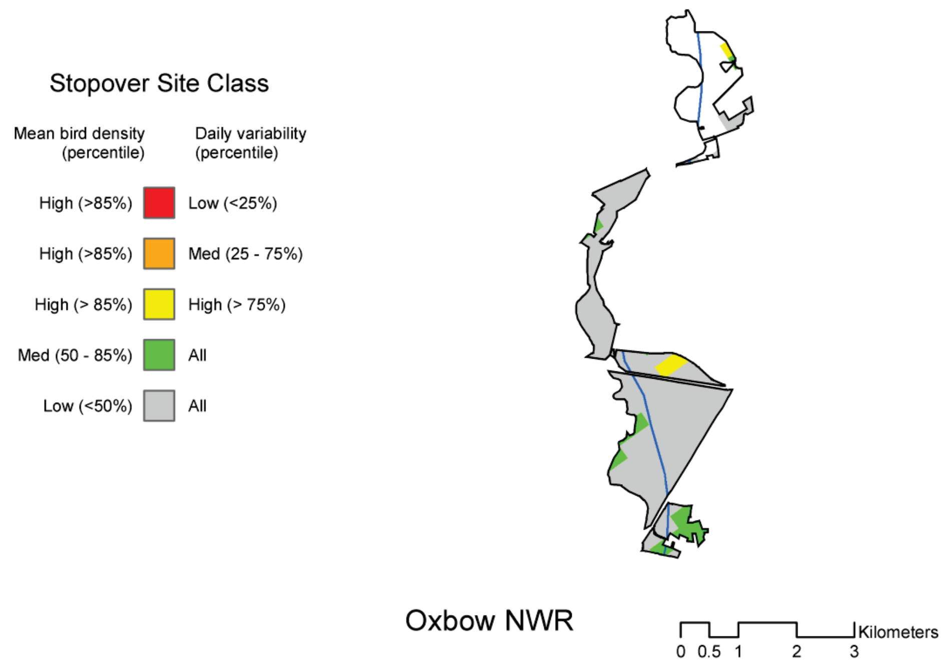
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.

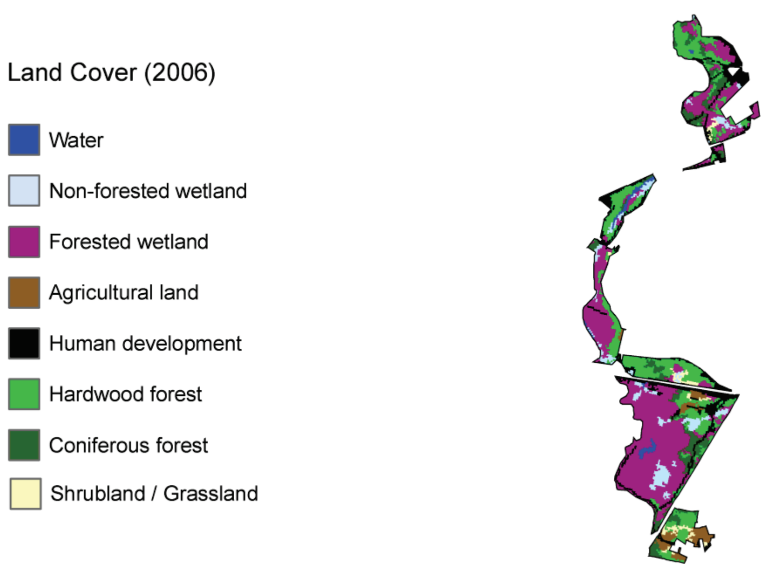




* Stopover site classification for the Occoquan Bay NWR in Woodbridge, VA is based on 19 sampling days of weather radar data from the KLWX station, Washington, DC.

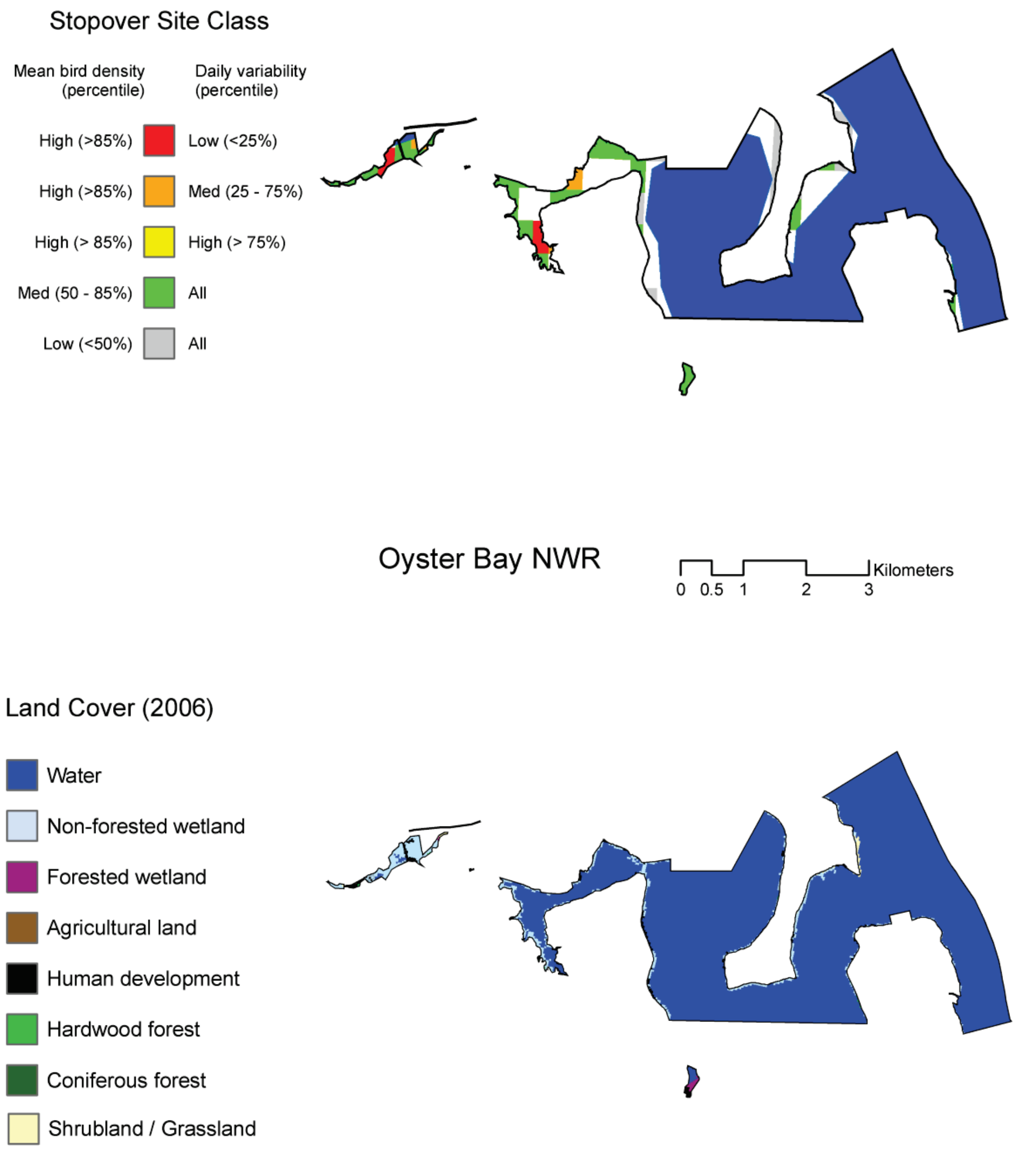
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.





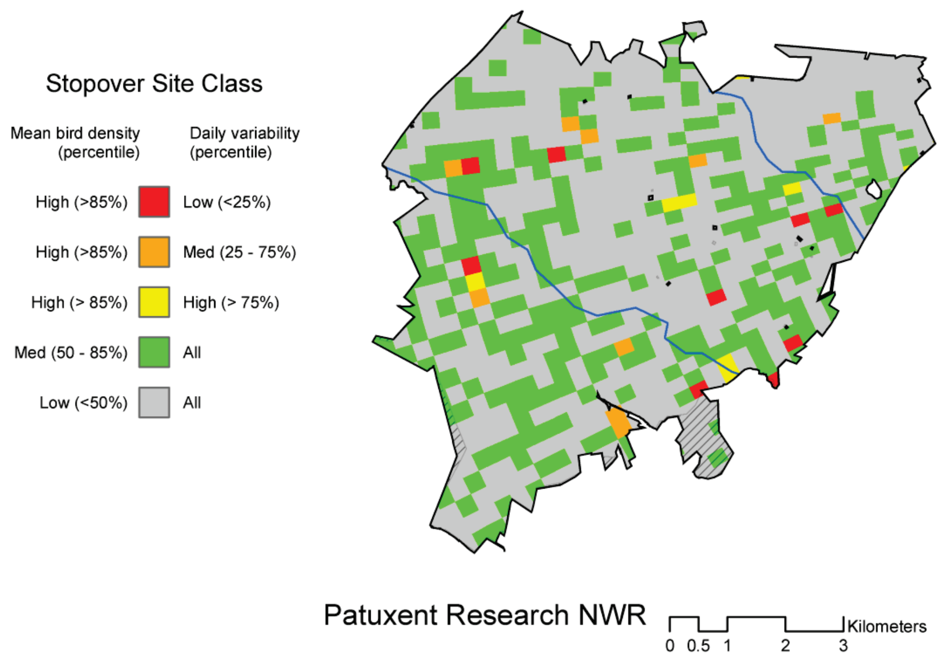
* Stopover site classification for the Oxbow NWR in Harvard, MA is based on 28 sampling days of weather radar data from the KBOX station, Boston, MA.

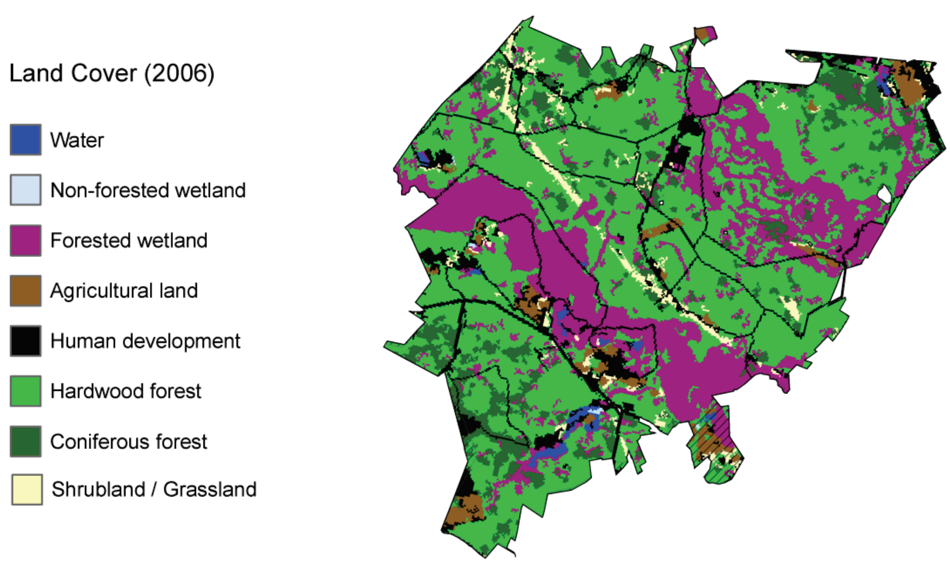
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



* Stopover site classification for the Oyster Bay NWR in Oyster Bay, NY is based on 20 sampling days of weather radar data from the KOKX station, New York City, NY.

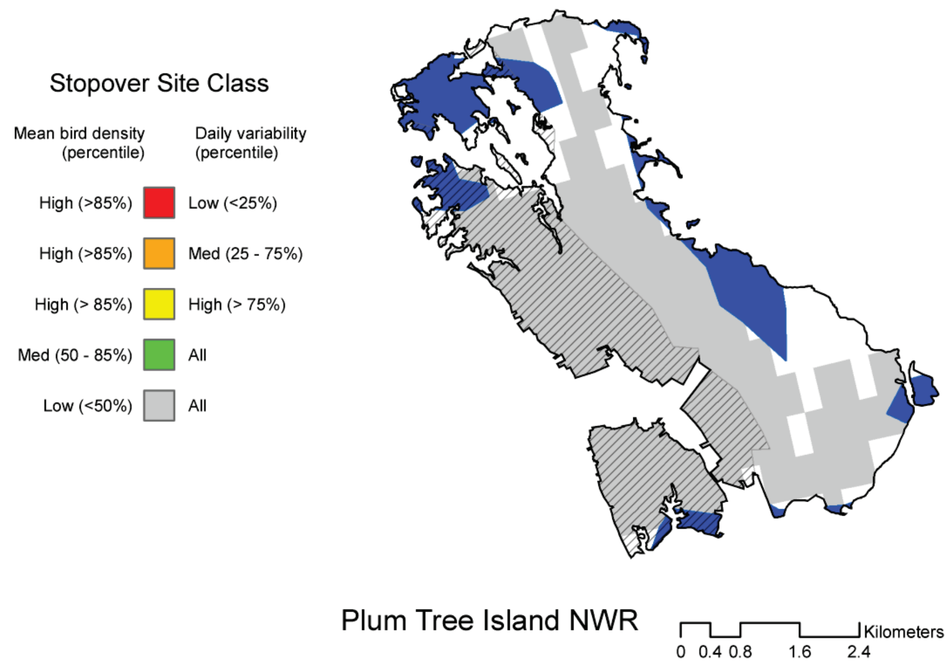
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset (see text for details of classification scheme).

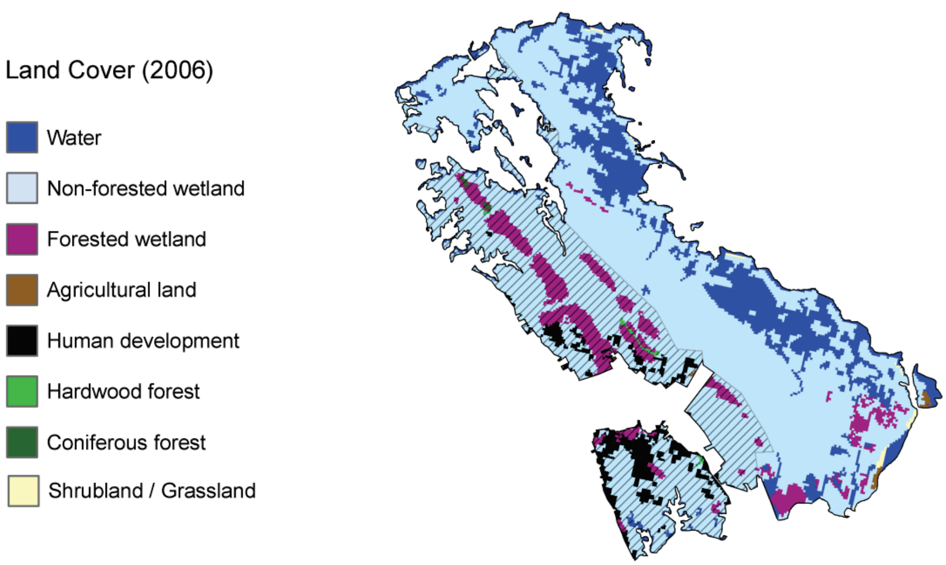




* Stopover site classification for the Patuxent Research NWR in Laurel, MD is based on 8 sampling days of weather radar data from the TBWI station, Benfield, MD.

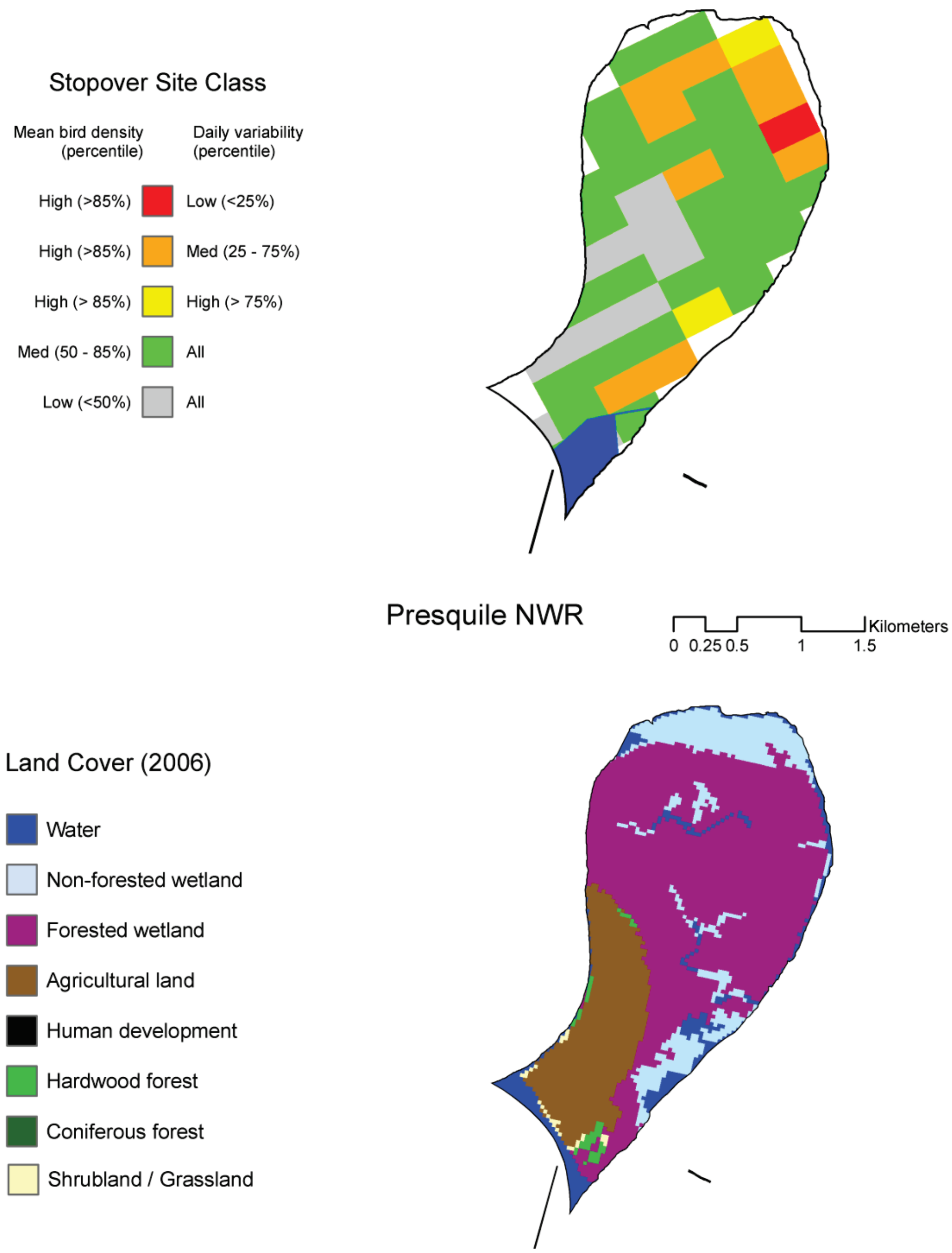
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.





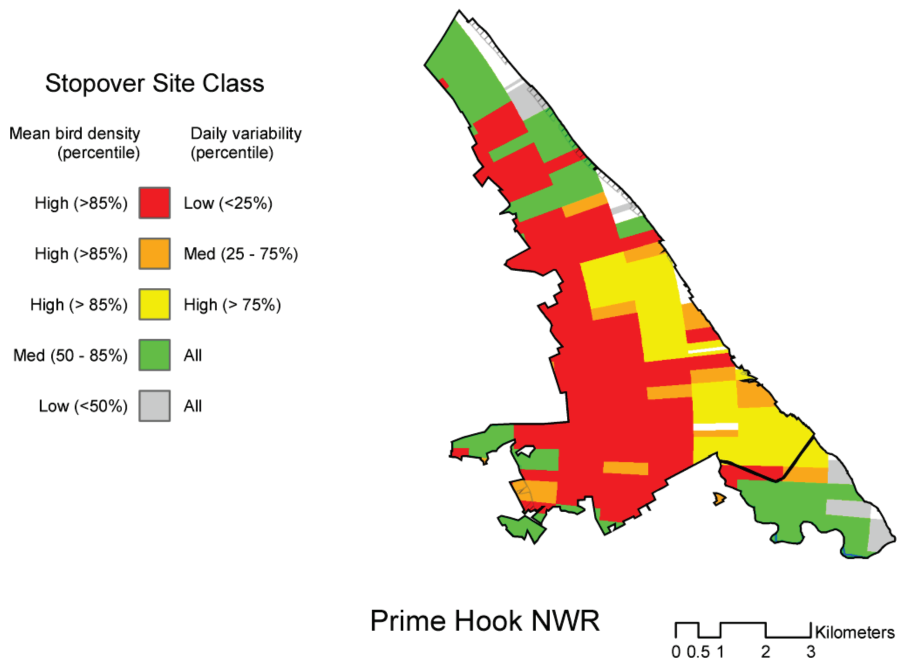
* Stopover site classification for the Plum Tree Island NWR in Poquoson, VA is based on 25 sampling days of weather radar data from the KAKQ station, Norfolk, VA.

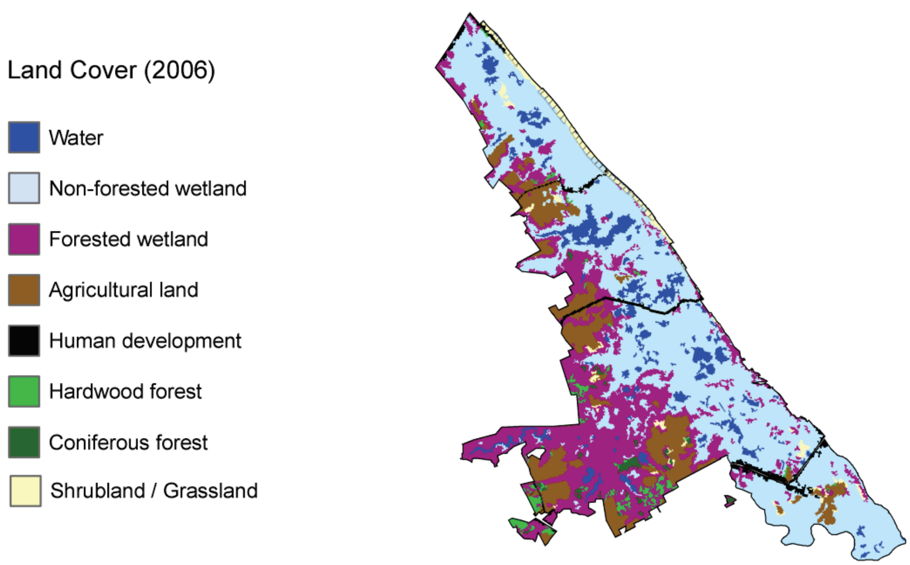
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



* Stopover site classification for the Presquile NWR in Charles City, VA is based on 25 sampling days of weather radar data from the KAKQ station, Norfolk, VA.

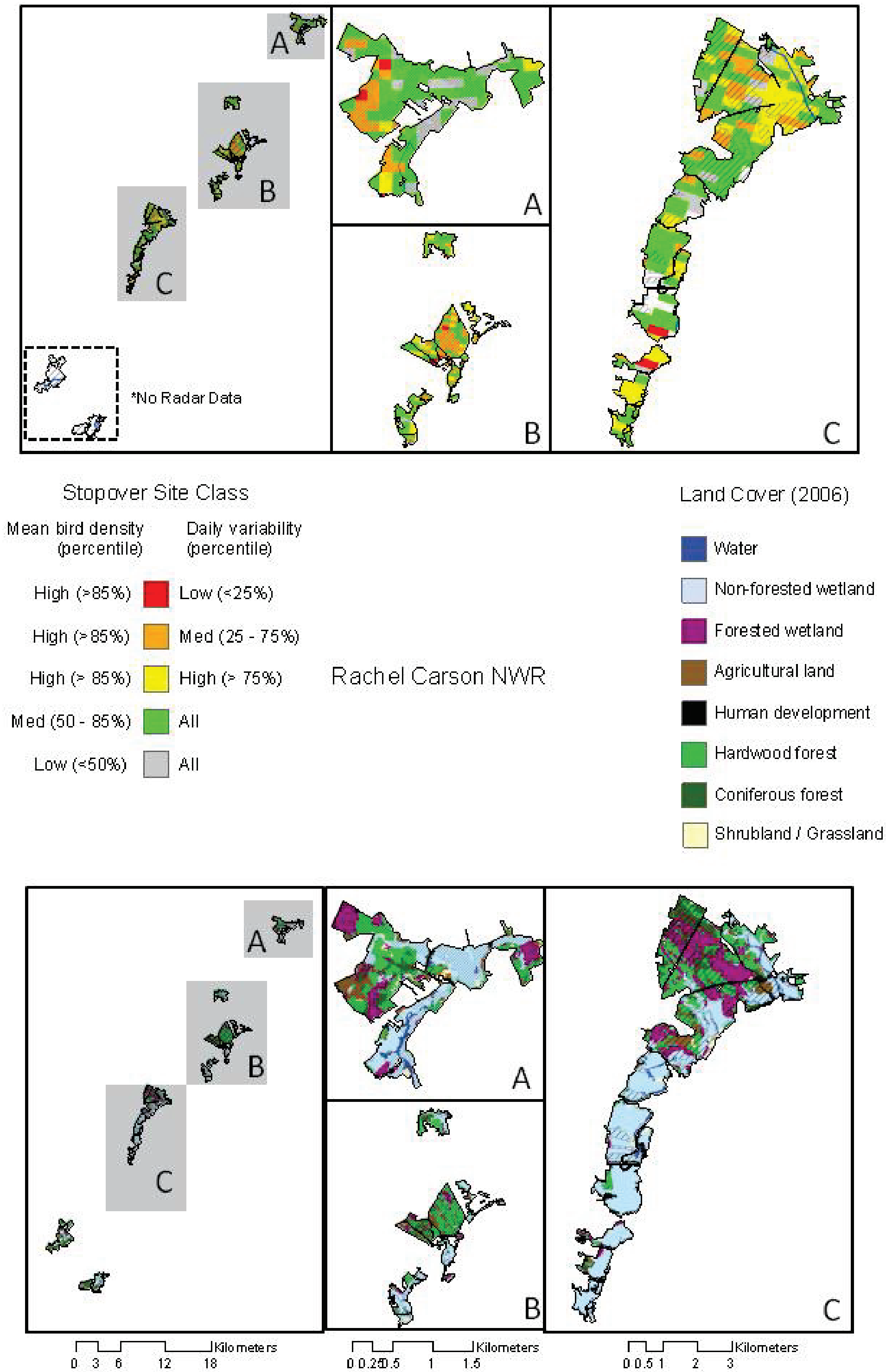
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.





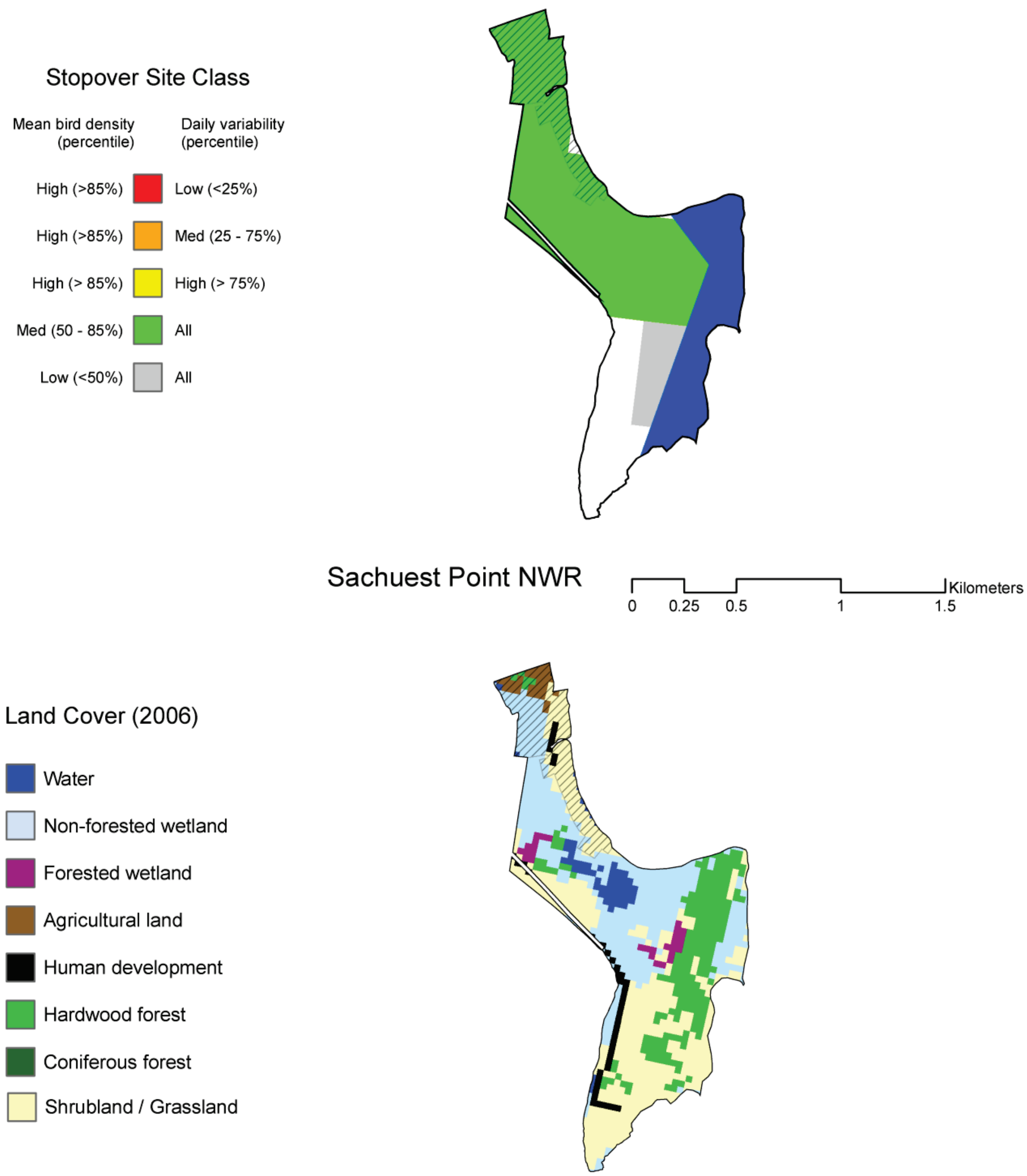
* Stopover site classification for the Prime Hook NWR in Milton, DE is based on 30 sampling days of weather radar data from the KDOX station, Dover, DE.

Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



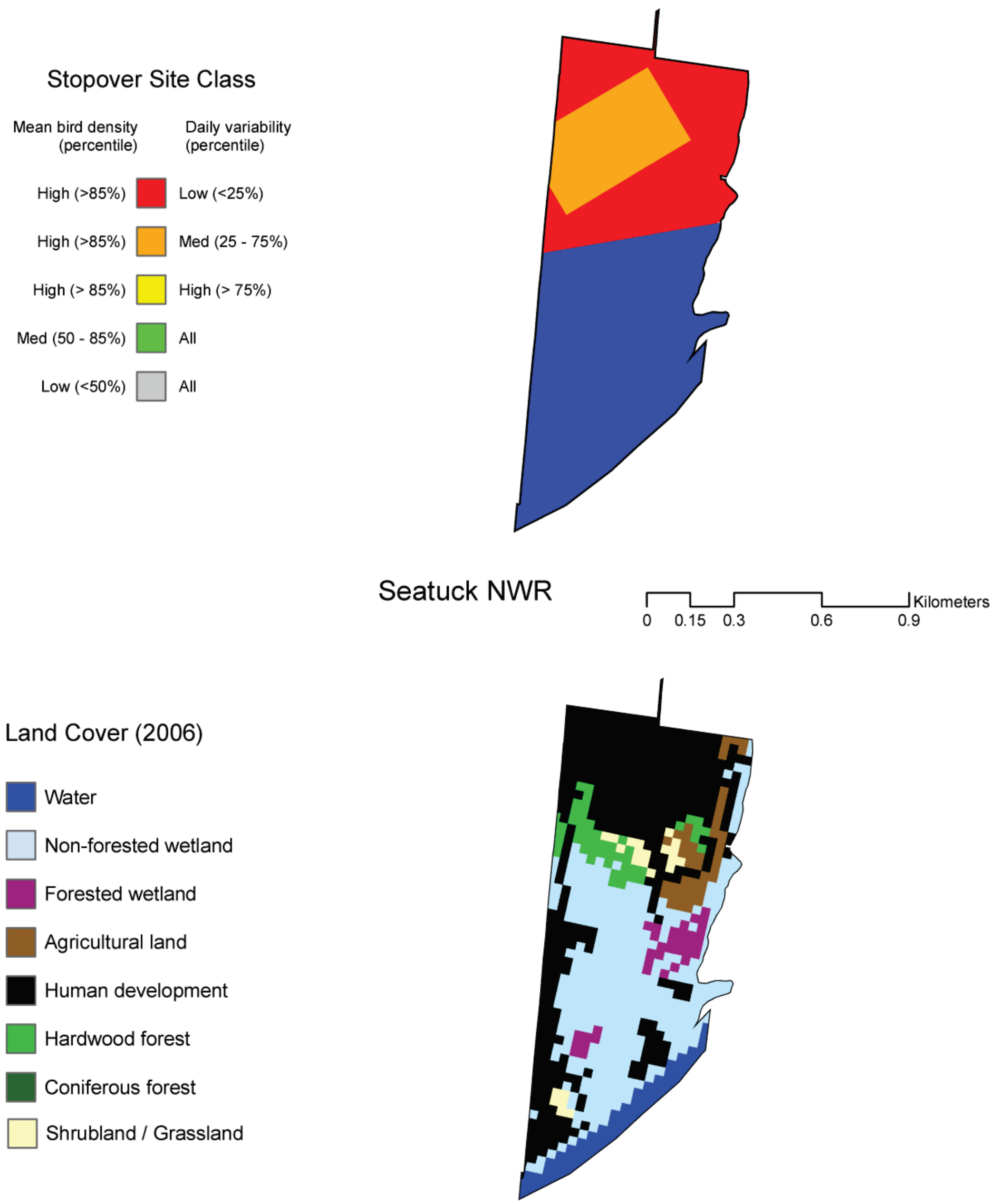
* Stopover site classification for the Rachel Carson NWR in Wells, ME is based on 20 sampling days of weather radar data from the KGYX station, Portland, ME.

Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



* Stopover site classification for the Sachuest Point NWR in Middleton, RI is based on 28 sampling days of weather radar data from the KBOX station, Boston, MA.

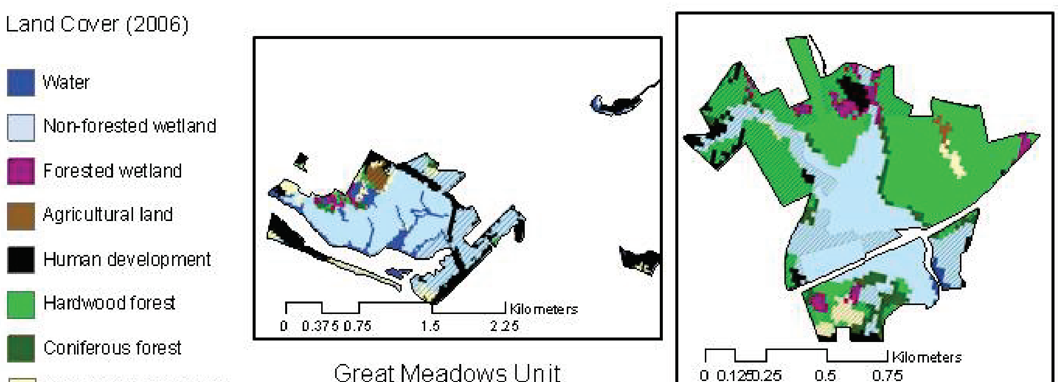
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



* Stopover site classification for the Seatuck NWR in Islip, NY is based on 20 sampling days of weather radar data from the KOKX station, New York City, NY.

Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.

Stewart B. McKinney NWR

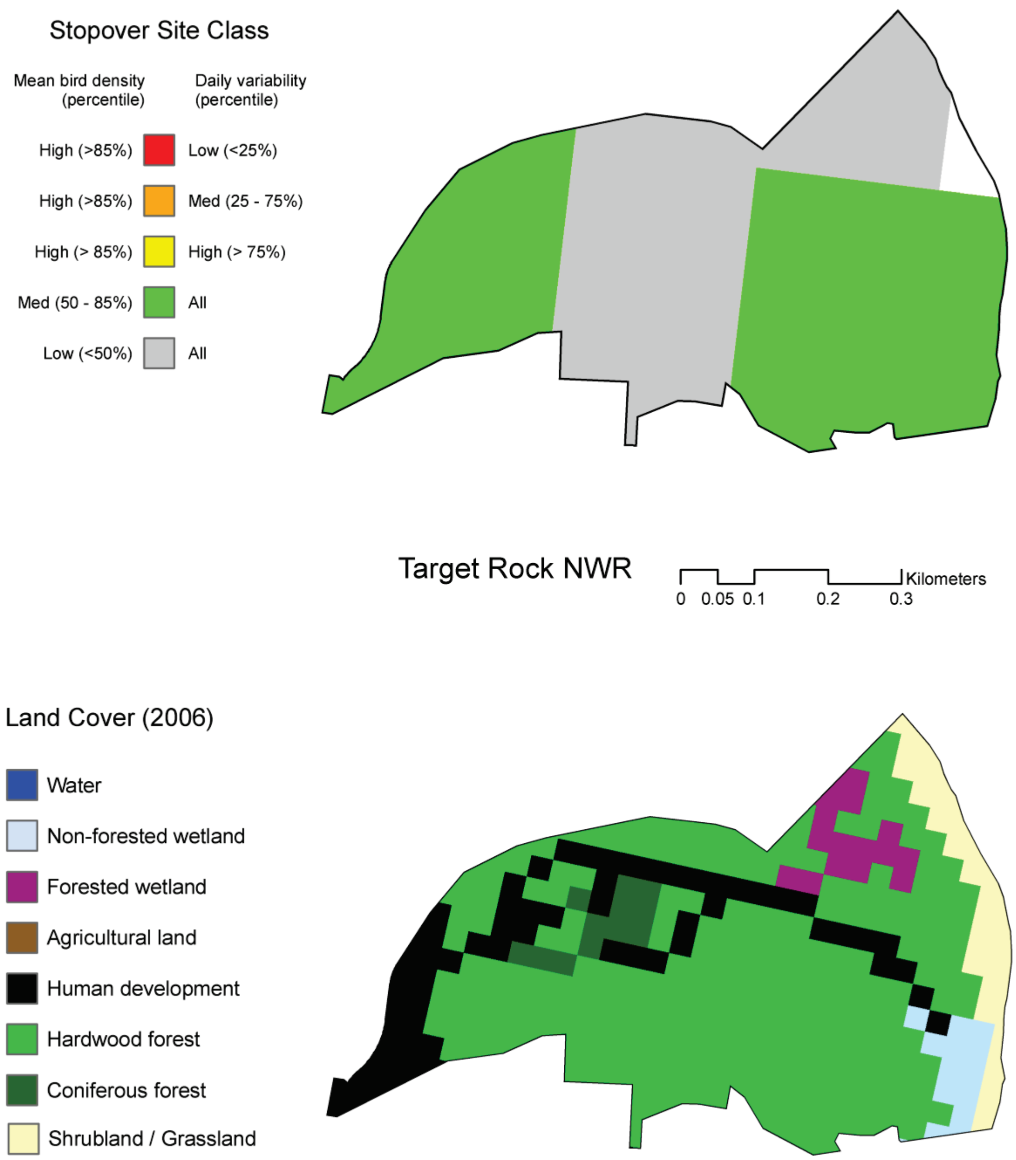


Great Meadows Unit and Milford Point Unit

Salt Meadows Unit

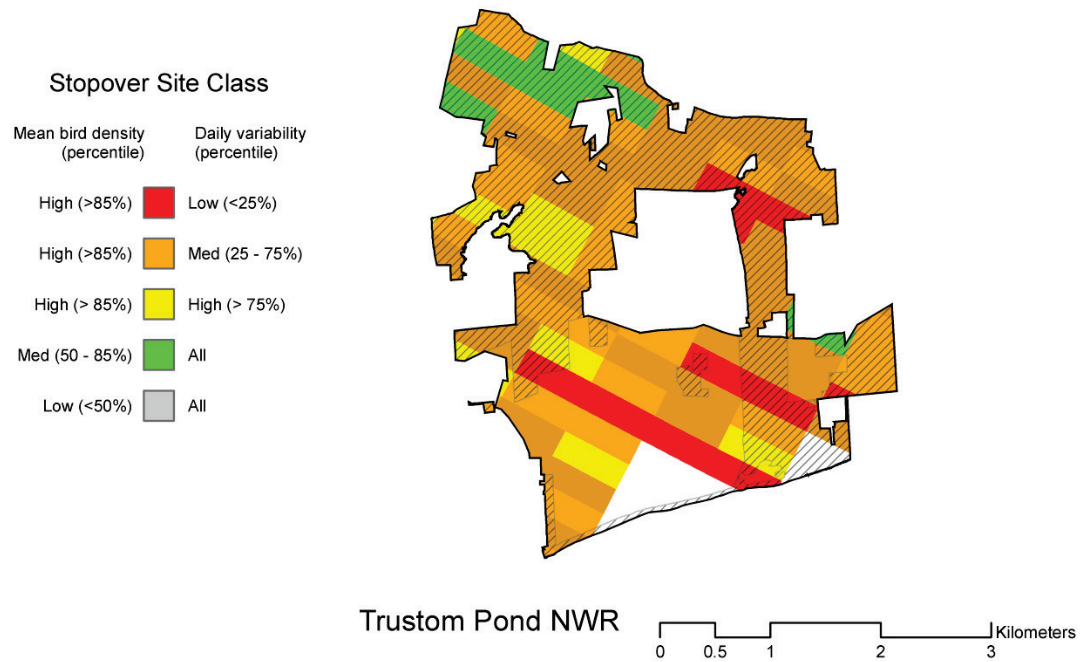
* Stopover site classification for the Stewart B. McKinney NWR in Westbrook, CT is based on 20 sampling days of weather radar data from the KOKX station, New York City, NY.

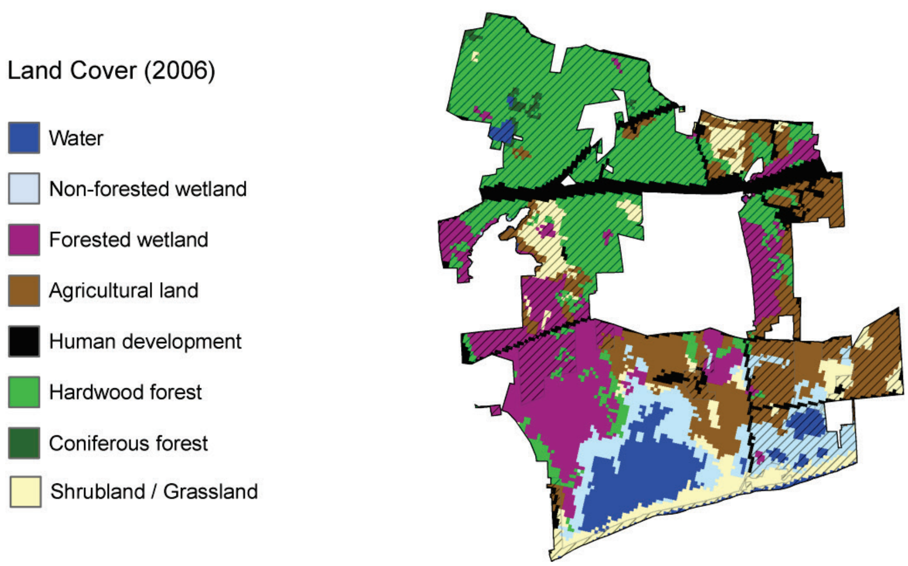
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



* Stopover site classification for the Target Rock NWR in Huntington, NY is based on 20 sampling days of weather radar data from the KOKX station, New York City, NY.

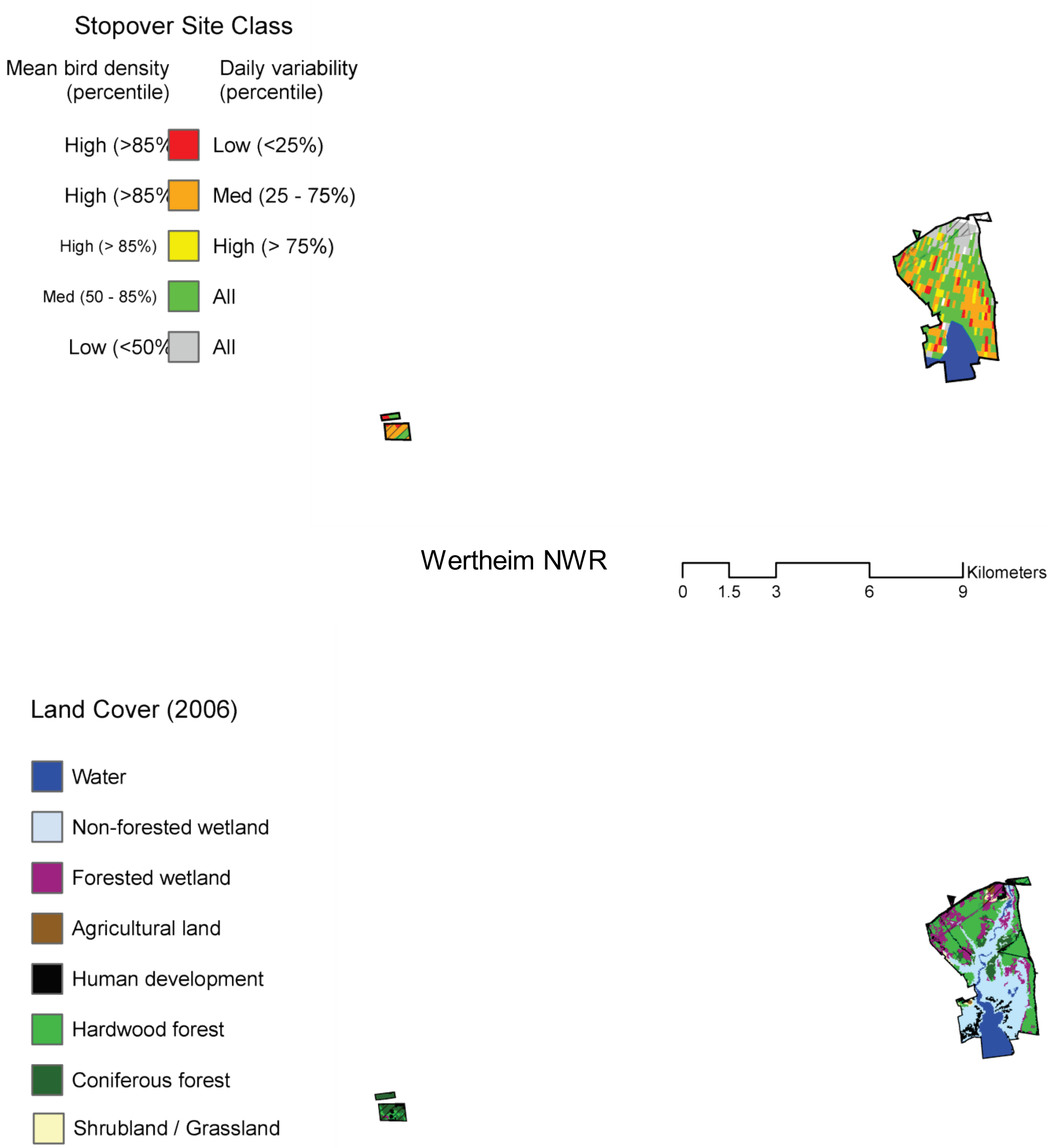
Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.





* Stopover site classification for the Trustom Pond NWR in South Kingstown, RI is based on 28 sampling days of weather radar data from the KBOX station, Boston, MA.

Appendix C (continued). Classified bird stopover density during fall 2008 & 2009* and land cover at radar-observed USFWS Region 5 National Wildlife Refuges. Land cover data are from the 2006 National Land Cover Dataset. Cross-hatching denotes areas approved for future refuge land acquisition.



* Stopover site classification for the Wertheim NWR in Shirley, NY is based on 20 sampling days of weather radar data from the KOKX station, New York City, NY.