Validation of NEXRAD data and models of bird migration stopover sites in the Northeast US

Interim Progress Report

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Total project performance period 1 July 2013 to 31 December 2015.
Progress through 1 December 2014 reported.

Introduction

Identifying important stopover sites is a critical step in development of a comprehensive regional conservation plan for migratory landbirds. All three major bird conservation plans (Brown et al. 2001, Kushlan et al. 2002, Rich et al. 2004) recognize the importance of stopover habitat, and acknowledge that in many cases habitat use during migration is poorly understood. For example, habitat use may be constrained by extrinsic factors (e.g., proximity to the coast) that limit access to habitats with high food availability (Buler and Moore 2011). We recently mapped important migratory landbird stopover areas for the northeastern US (USFWS Region 5) and assessed stopover use at USFWS National Wildlife Refuges using weather surveillance radar (NEXRAD) data (Buler and Dawson 2014). We also developed models to predict stopover site use in portions of the region not sampled by the radars, based on landscape habitat composition, elevation, and geographic location. The maps offer tremendous potential to inform conservation planning. However, calibrating and validating these data and models through ground surveys or supplemental radar observations and further model refinements can improve their accuracy and value for conservation purposes.

All NEXRAD stations are designed to be similarly calibrated so that the measures of the meteorological phenomena they are intended to observe are comparable across radars. Furthermore, the algorithms of Buler and Diehl (2009) and Buler et al. (2012) minimize bias in measures among radars. However, birds are weak reflectors relative to precipitation and radar measures of birds are more sensitive to variability in the precision of the operational calibration among radars. Field data on the density and distribution of birds on the ground can be used to calibrate radar measures to produce absolute estimates of bird density and assess the robustness of comparisons among radars (see Buler and Diehl 2009). Additionally, increasing the sample sizes of nights used to determine bird densities by incorporating more years of data can help reduce sampling bias among radars and improve and strengthen the predictive models.

The Delmarva Peninsula is a particularly important area for migratory birds in North America (Watts and Mabey 1994, Buler and Dawson 2014). The lower Delmarva Peninsula includes 5 of the top 12 designated Important Bird Areas within VA (Weldon 2007). This area is sampled by the NPOL radar operated by NASA through their Wallops Flight Facility with some overlap of the area sampled by the nearby KDOX NEXRAD station (Fig 1). NPOL has finer spatial resolution and greater flexibility in its sampling strategy than NEXRAD radars, providing a more precise and accurate discrimination than was previously possible of the sites and habitats from which migrants emerge. Through an agreement between The Nature Conservancy and NASA, NASA has collected radar data at no cost, providing a unique opportunity to study bird distributions during migration within the Lower Delmarva.

We had a major role in coordinating data collection by the NPOL radar and complemented these data with ground surveys of birds within the NPOL and NEXRAD (KDOX and KAKQ) radar coverage areas in order to compare overlapping observations among different radars and to calibrate radar observations within and among radars. Other funding sponsors for the larger collaborative project to collect ground survey data and analyze NPOL data include Virginia Department of Game and Inland Fisheries, USGS, Maryland Department of Natural Resources, Virginia Coastal Zone Management Program, and the University of Delaware. We will also analyze additional years of data from these and other NEXRAD radars in Region 5 to refine, validate, and improve our region-wide predictive model of autumn migratory landbird "hotspots".

The broad-scale ground survey effort also allows us to compare the influence of factors operating at different spatial scales in explaining habitat use patterns of *en route* landbirds within hardwood forests during autumn migration in the Mid-Atlantic Coastal Plain. We will assess factors at the habitat-patch (e.g., food abundance and habitat composition and structure), landscape (e.g., proportion of forest cover), and regional (e.g., proximity to ecological barrier) scales. This will complement similar efforts to examine multi-scale factors in explaining bird stopover distributions done previously on the Delmarva peninsula (Watts and Mabey 1994) and in other regions: Gulf Coast (Buler et al. 2007), Great Lakes (Johnson 2013, R. Smith, unpubl. data), Maine coast (B. Olsen, unpubl. data).

The project will provide improved landscape-scale data to the Atlantic Coast and Appalachian Joint Ventures and North Atlantic and Appalachian LCCs on the spatial distribution of important stopover sites for southbound migrating birds. Project results and products will allow the USFWS and partners to implement Strategic Habitat Conservation, protecting areas and habitats where they are likely to be most effective, and can contribute directly to the Bird Conservation Region plans of the Atlantic Coast Joint Venture, Comprehensive Conservation Plans for Region 5 refuges, State Wildlife Action Plans, and to broader region-wide planning for migratory bird conservation.

Objectives

1) Calibrate NEXRAD radar data of bird stopover density by collecting ground survey data of bird identities and densities,
2) improve NEXRAD-based models of important stopover sites for USFWS Region 5 by incorporating seven total years of radar data, a more sophisticated modeling method, and better explanatory variables,
3) validate the updated NEXRAD-based predictive statistical models for USFWS Region 5 using ground survey and other radar observations (NPOL and TDWRs),
4) assess habitat use of migrants in relation to food abundance, habitat, and landscape features in the Mid-Atlantic Coastal Plain.

Methods

Weather Radar Data Processing

From the National Climatic Data Center archive, we downloaded Level-II radar data from sixteen WSR-88D radars in the northeastern United States (Fig. 1) for five years (2010-2014) during the fall landbird migration period (15 August-7 November). We also downloaded data from 4 Terminal Doppler Weather Radars (TDWR) collected during autumn 2010 through 2014. Radar data will be processed following Buler and Dawson (2014) using existing software developed by the University of Delaware (UD). Data will be pooled with our previous 2-year (2008 & 2009) dataset, resulting in a final dataset of 7 years for mapping and modeling autumn bird stopover.

WSR-88D radars transmit horizontally polarized electromagnetic radiation at a wavelength of approximately 10 cm (s-band) and a nominal peak power of 750 kW with a half-power beamwidth (3 dB) of 0.95º (Crum and Alberty 1993). We used two data products produced by the radar: radar reflectivity factor, a measure of radar echo strength in units of Z (mm^6 m^{-3}) that is determined by the density and size of the targets in the sampled volume, and mean Doppler radial velocity, a measure of the mean target velocity relative to the radar (knots). Both reflectivity and radial velocity are collected in polar coordinates with a range resolution of 0.25 km. Radar data from the 0.5° elevation angle was screened to identify bird-dominated nights, contaminated nights (e.g., precipitation, sea breeze fronts, and smoke), and anomalous beam propagation (Buler and Diehl 2009).

Biological targets, such as birds and insects, were distinguished by quantifying target airspeeds by vector-subtracting the wind velocity from the target ground velocity. Radar radial velocity data from the 3.5° elevation angle during the peak of nocturnal activity (~ 3 h after sunset) were used to determine target flight directions and airspeeds in conjunction with high-resolution data on winds aloft archived by the North American Regional Reanalysis (NARR) following Farnsworth et al. (2014). These high resolution modeled wind data are available in three-hour composites across the United States at approximately 0.3 degrees (or as fine as 32-km) resolution. We used these data to determine air speeds (u and v wind components) at nine geopotential heights ranging from 650-1000mb within the 100-km range of each radar. Mean air speeds were then computed by weighting speeds by the relative density of biological targets at each height interval based on vertical profiles of reflectivity calculated using methods outlined by Buler and Diehl (2009). Radar scans with mean target air speeds greater than or equal to 5 m per s were considered bird dominated (Larkin 1991, Gauthreaux and Belser 1998). Only bird-dominated nights were used in the analysis.

For each suitable sampling night, an instantaneous sample of radar reflectivity data collected near the time of evening civil twilight (shortly after the onset of nocturnal migration) was used to map the stopover locations of birds. This approach capitalizes on the fact that birds initiate nocturnal migratory flights *en masse* in an abrupt exodus closely synchronized to position of the sun and minimizes the displacement of birds aloft from their ground sources (Buler and Diehl 2009). The nightly density of birds emigrating from stopover locations throughout the migration period will be characterized by the mean radar reflectivity (MN) and the mean coefficient of variation of radar reflectivity (CV) across all nights. "Important" stopover sites will be identified as those areas with above-mean (≥50th percentile) reflectivity, and further categorized as: 1) “consistently high density of emerging migrants” (CV ≤25th percentile and MN ≥85th percentile), 2) “high migrant density with moderate variability” (CV > 25th and < 75th and MN ≥85th percentile), or 3) “high migrant density with high variability” (CV ≥75th and MN ≥85th percentile).

A post-doctoral researcher has been hired to model bird distributions using the combined multi-year radar dataset. Statistical models to predict the median and CV of relative bird density within Region 5 will be developed using model selection/averaging within an information theoretic approach (Burnham and Anderson 2002). Predicted bird stopover use will be classified according to the criteria used for radar-observed data. The relationship of landbirds on migratory stopover with their environment can vary over space (Buler and Moore 2011). Thus, predictive models will be built using a geographically weighted regression (GWR) framework that implements a geographical weighting scheme producing localized regression coefficients for individual locations (Fotheringham et al. 2002). By incorporating spatial variation, GWR can better explain organism-environment relationships than ordinary least-squares regression that applies global regression coefficients (Kupfer and Farris 2007). We will incorporate modeling techniques that allow for nonlinear response functions (e.g., Boosted Regression Trees or Generalized Additive Models) and include more informative model covariates (e.g., NDVI, mean and SD of canopy height) to improve the predictive models similar to our recent NEXRAD analysis for USFWS Region 4 (La Puma and Buler 2013).

Transect Surveys

We established 48 transects (500 m long) in hardwood stands throughout Delaware, Virginia, and Maryland for the multi-partner collaborative project. Surveys at 24 of these sites were directly funded by this project and placed within 80 km of KDOX or KAKQ. All transect locations were chosen based on seasonal mean observed reflectivity (i.e., relative emigrant bird density) during fall 2008 & 2009 as determined by Buler and Dawson (2014). We placed 24 of the sites in areas with high reflectivity and 24 in areas with moderate to low reflectivity. We stratified transects within radar coverage areas into three distance bands based on their proximity to the nearest NEXRAD site (10-20 km, 20-50 km, 50-80 km). This stratification was designed to allow for assessing any residual bias in radar measures after adjusting them for range bias. We used hardwood forest sites because they are the most abundant and consistent natural habitat type in the region and most migrants are forest-dwelling species.

Birds were sampled along the transect during a 30-minute period (a pace of 1 km per hour) from sunrise to four hours post-sunrise. Species, number of individuals, perpendicular distance from transect, distance from observer, and height above ground were recorded for each detection. Height and distances were recorded in distance classes because there is much measurement error in estimating distances (Alldredge et al. 2007): 0-5 m, 5-10 m, 10-15 m, 15-20 m, 20-25 m, 25-50 m, and >50 m within habitat. Flyovers and flythroughs were also recorded.

Food Availability

To assess the amount of food available at each site across the season, we sampled fruit and insect abundance during each site visit. Six 20 m x 20 m plots were placed alongside each transect at every 75 m. Sampling within the plots alternated each visit so that the 75 m, 225 m, and 375 m plots were sampled on one visit and the 150 m, 300 m, and 450 m plots on the following visit.

Fruit sampling consisted of recording all species of plants containing fleshy fruit within the 20 m x 20 m plots, including their abundance, ripeness, and relative height. Number of fruits was binned as follows: 1 (1-10), 2 (11-25), 3 (26-100), 4 (101-250), 5 (251-1000), 6 (1001-3000), and 7 (3001-10000). The ripeness was recorded as the percentage of unripe, ripe, and overripe fruits for each species detected and relative height was recorded as the percentage found in the understory, midstory, and canopy for each species following Smith and McWilliams (2009).

Insect sampling was performed in two ways: 1) visual count of terrestrial arthropods, and 2) enumeration of arthropods from branch clippings. Visual counts were conducted within 0.5 m x 0.5 m ground plots located within the larger 20 m x 20 m plot. Visual surveys were conducted by standing over 0.5 m x 0.5 m plot for 3 minutes and recording the size (mm) and Order of any arthropod species. Bagged branch clippings were collected from within the 20 m x 20 m plot and all arthropods on or in the branch sample were identified to Order and measured (mm). Each branch clipping consisted of approximately 40 leaves from either the dominant site species or one of four common focal species (American Holly [*Ilex opaca*], Red Maple [*Acer rubrum*], Sweetgum [*Liquidambar styraciflua*], Blueberry [*Vaccinium angustifolium*]). Clipped branches were weighed without drying.

Vegetation Sampling

Vegetation was sampled using a modified protocol of James and Shugart (1970) at four 11.3 m radius plot locations along the transect centerline. We measured canopy cover using a densitometer. Ground, shrub, vine (in canopy), and midstory cover estimates were assessed with an ocular tube. Cover estimates were taken at 1, 2, 3, 4, and 5 m locations in each of the four cardinal directions for a total of 20 measurements; presence of vegetation in ocular tube resulted in a plus and a lack of vegetation resulted in a minus. Litter depth was recorded to the nearest millimeter at 4, 8, and 12 m locations in each of the four cardinal directions giving 12 total measurements. Ground cover was measured within 5 m radius of the plot center. Percent cover for forb, fern, moss, *Smilax*, vine, marsh, downed logs, and shrub was also recorded. Shrub density was measured within a 5 m-radius circle. Only stems less than 0.5 m in height and less than 3 cm diameter were counted for shrub density. Tree density was measured within the 11.3 m-radius plot circle. Tree stems with a diameter at breast height (dbh) less than 2.5 cm and with a dbh between 2.5 cm and 8 cm were counted and binned according to their respective dbh classes. Tree species and exact dbh was recorded for all trees with a dbh greater than 8 cm. Canopy height was measured using a clinometer. Distance to the four tallest trees within the vegetation sampling plot and the percent slope read from the clinometer for the top and bottom for each tree was recorded to calculate average canopy height. Crown density was measured using the same methods used measuring canopy height with the addition of a clinometer reading at the base of the crown for each of the four tallest trees.

Data Analysis

Detection probabilities and bird density estimates:

We estimated detection probabilities and migrant densities within R (R Development Core Team 2008) and the extension package unmarked (Fiske and Chandler 2011). Temperature, wind and sky measurements, and observer were incorporated as covariates. Neotropical migrant, temperate migrant, and non-resident birds were lumped to ensure adequate sample size. We used detections from all distances within the habitat to fit a detection function. We then tested models using no, single, and multiple covariates among half-normal and hazard rate detection functions. We used Akaike's Information Criterion adjusted for small sample sizes (Hurvich and Tsai 1989) to rank models based on their ability to explain the data (Akaike 1973). Using the top-ranked detection function model, we computed a mean visit density (birds per hectare per visit) for each transect.

Optimal sampling time of radar data:

We compared bias-adjusted radar reflectivity measures, interpolated to a series of time points at different sun elevation angles, to the observed bird density on the ground using a series of Pearson correlation tests to determine the optimal sampling time of migrant land birds emerging from stopover sites during the onset of migration, or exodus. The interpolated sun angle time points range from 0° to 10° below the horizon at 0.5° intervals. Thus far, we have conducted this analysis using 2013 data only. We georeferenced center transect lines within a geographic information system (GIS) and built 50-m wide buffers around transects to represent the area where we effectively sampled birds with ground surveys. We intersected the two-dimensional boundaries of georeferenced radar sampling volumes from around the KDOX and KAKQ radars with the buffered transects to identify the portions of radar sampling volumes that coincided with transects. The bias-adjusted reflectivity measures from these sampling volumes were used to determine an area-weighted mean reflectivity over each transect for comparison to ground bird counts.

Preliminary Results and Progress to Date

Objective 1:

- **Field data collection 100% complete** - We completed the second and final season of transect bird surveys in November 2014. For each sampling season, we had 8 full-time surveyors (2 of which were graduate students coordinating data collection) that completed 1,593 (836 in 2013 and 757 in 2014) total surveys among the 48 transects. Individual transects were visited 17 times on average in 2013 and 15 times in 2014.
- A total of 139 identified bird species were detected during the study, with 72 species of nocturnally-migrating birds (Appendix A). In general, raw numbers of long-distance

Neotropical migrants (breeding and transient residents) showed a steady decline throughout the fall from their peak during August (Fig 3). Numbers of short-distance Temperate migrants (transient and winter residents) began to arrive to the region in early October and reached their peak during late October.

- **Bird density calculations 50% complete** - We have calculated detection probabilities at each transect to produce bird density estimates for all transects during 2013 for migrating birds (Table 1). Nocturnal migrants comprised 74.92% of all migrant birds detected in 2013 and 75.46% in 2014. Seasonal mean migrant densities for transects ranged from 1.23 to 4.83 with an overall mean of 2.61 birds per hectare per visit in 2013. We are still calculating densities for 2014 data.
- We tested correlations between preliminary seasonal mean migrant densities at 17 transects during 2013 that were within the KDOX radar range and seasonal mean radar reflectivity at different sun elevation angles (Fig 4). The peak correlation (r = 0.69) occurred at a sun angle of 6° below the horizon (i.e., the end of evening civil twilight) (Fig 5). However, we found the correlation between reflectivity at civil twilight and bird density at the 12 KAKQ transects was not significant (r = -0.365, P = 0.24).
- The lack of correlation at KAKQ sites and the moderate correlation at KDOX sites highlight the fact that emigrant density from radar and daily bird density at the ground measure different things. Ground counts are essentially a measure of bird use days or rate of habitat use (i.e., birds using the transect on a given day). Radars measure the number of emigrants leaving the site over the course of a migration season. The product of these two measures can actually be used to produce an estimate of stopover length (e.g., O'Neal et al. 2012). Thus, variability in stopover length among sites will confound the relationship between radar and ground counts. Because of this, we can model the relationship between daily bird use and emigrant density by controlling for confounding factors that would influence quality of stopover habitat and stopover length such as proximity to the coastline and the amount of hardwood forest in the surrounding landscape (Buler et al. 2007). In fact, we found a moderate partial correlation between emigrant density and daily bird use after we controlled for these two factors using a GAM approach (Fig 6).

Objective 2:

- **Processing of NEXRAD data 85% complete** - Along with a team of four volunteer and paid undergraduate student researchers, we screened five additional years (2010-2014) of data from 16 radar stations to incorporate into models. On average, 18% of all nights were suitable for sampling migrants at exodus for mapping stopover distributions across years and radars (Table 2). However, there was an order of magnitude of variability in the number of sampling nights among radar and years. The number of suitable sampling nights for a given radar season ranged from 3 to 38. The most common sources of contamination of radar data included precipitation (48% of all screened nights), insect-dominated bioscatter (14%), and anomalous radar beam propagation (14%).

- Improvements to target identification algorithms - While not explicitly mentioned as a project task, we spent time during three months to improve methods to discriminate birds from insects by replacing radiosonde weather data with North American Regional Reanalysis (NARR) data. This is an important advancement to our data processing because it allows us to objectively determine the flight speed and direction of biological targets at all radars (i.e., not just radars with affiliated radiosonde balloons). Although less resolute in height than radiosonde, NARR provides a better temporal match because we get modeled weather data every three hours instead of every twelve hours as the radiosonde provides. NARR covers the entire United States thus allowing us to incorporate wind data at radars that have no radiosonde launch. Additionally, because NARR is modeled at a finer spatial scale (approximately every 30 km), we can obtain average wind measures across the entire radar domain, as opposed to just where the radiosonde is launched. To incorporate NARR, we first developed R code to download data for each night of interest. We filtered NARR data points to those within a 100-km radius from the radar center and at 650-1000mb. These data were then incorporated into our calculations for mean target speed and direction.
- A new possible source of sampling bias identified - Buler and Dawson (2014) found a spatial trend of increasing emigrant density to the south and west that could be due to temporal sampling bias given variability in the timing of the onset of migration across the region. Currently our protocol is to interpolate exodus to the same sun angle among all radars (6 degrees below horizon). However, we are currently testing the assumption that the timing of migratory flight is the same across the study region. Preliminary analysis appears to indicate that the onset of migration varies among radars and that the timing of flight is slightly later for more northerly radars. If further investigation confirms this variability in timing of exodus among radars, we may change our protocol to use a radar-specific sun angle for sampling exodus. This is another new improvement to radar processing methods not explicitly mentioned as a project task but that has emerged as an important source of bias that needs to be addressed.
- We will produce maps of emigrant stopover densities at radars across all study years once the 2014 season has been processed and the best approach for reducing temporal sampling bias has been decided.
- **Assembling covariate data for predictive models 85% complete -** For the entire Northeastern region, we downloaded the Normalized Difference Vegetation Index (NDVI) data product from the Global Moderate-resolution Imaging Spectroradiometer (MODIS) operating aboard NASA’s Terra satellite. A composite NDVI image is produced every 16 days at 250-meter spatial resolution, providing consistent data to compare vegetation greenness/leaf-out across the season and region.

- **Building predictive models of migrant distributions 0% complete** - A post-doctoral researcher, Jamie McLaren from the University of Amsterdam, was hired and will begin work in January 2015 to model bird distributions using the combined multi-year radar dataset.
- We have been exploring the use of GWR4, a software package that fits mixed geographically-weighted regression models having global and local parameters. We have also acquired R code for conducting STEM (SpatioTemporal Exploratory Model) analysis developed by Fink et al. (2010) as an alternative approach to using GWR. STEM allows for compiling output from an ensemble of models fit at multiple spatial and/or temporal scales on an underlying modeling framework (e.g., Regression-tree, GAM, GLM). STEMs are well suited for exploring distributional dynamics arising from a variety of processes.

Objective 3:

- **Processing of non-NEXRAD radar data as independent dataset for validating predictive models 20% complete** - We obtained a second year of observations from NASA's NPOL radar. After meeting with NASA engineers, we designed data collection around minimizing ground clutter and blockage and re-defining the sampling protocol to include more data around sunset. Additionally, there were fewer interruptions this year than last and we thus obtained observations for more dates in Fall 2014. Due to blockage northeast of the radar, we chose to limit the scans from the 130° through the 335° azimuth. NASA engineers also collected, at two azimuths (223° and 297°), Range Height Indicator (RHI) scans where the radar varies its elevation angle providing vertical observations of targets. Due to its different data structure, we had to determine new methods for processing NPOL data. We were successful in compiling a summary for 2013 data, although all nights available were identified as insect-dominated. Processing is ongoing for the 2014 dataset but we have run some preliminary target identification and determined that some nights in 2014 are dominated by bird targets.
- We have made no progress yet with the Terminal Doppler Weather Radar (TDWR) analysis. Basegrids already exist for 3 TDWRS; we will need to create one for the JFK, NY radar. We expect to begin screening TDWR data in February 2015.

Objective 4:

- **Data entry and proofing 50% complete:** We have quality controlled and analyzed food availability data from the 2013 field season. We present the results for sampling from the 24 survey sites sponsored by USFWS. Proofing and analyzing food availability data from the 2014 field season is ongoing.

- Vegetation sampling was conducted at 48 survey sites in 2013. We sampled an additional site in 2014 due to site relocation. Data is completely entered and proofed for sites within the KDOX radar range, but data entry and proofing is ongoing for sites within the KAKQ radar range.
- Preliminary results of food availability: General trends in 2013 among 24 survey sites within the KAKQ and KDOX radars indicate that invertebrate availability declined as the season progressed (Fig 7). Arachnids were the most abundant invertebrate, comprising nearly half of all inverts detected through visual counts and branch clipping. Other abundant invertebrates included Dipterans, Formicids, Hemipterans, and Lepidoptera larvae. Availability of fruiting species varied among transects (Fig 8). American holly was the most prevalent (19 of 24 sites) and abundant fruit across all transects. The abundance and diversity of fruit was greater for the more southern KAKQ sites compared to the northern KDOX sites. The availability of ripe fruit increased as the season progressed (Fig 9). The phenology of ripening of fruits varied among species and regions (Fig 10). For example, American holly ripened earlier at more southern sites.
- **Analysis integrating radar and ground data to assess relative stopover length 33% complete:** We have preliminarily found that relative stopover length (mean daily migrant ground density/mean emigrant density) was positively related to ripe fruit availability and negatively related to insect availability and proportion of hardwood forest in the surrounding landscape (Fig 11). Relative stopover length was also relatively lower at the immediate coastline and at sites farthest from the coastline.
- Based on the GAM model explaining relative stopover length, we have derived a preliminary classification scheme of the functional use of stopover habitats based on the spectrum of "fire escapes" to "convenience stores" to "full-service hotels" based on Mehlman et al. (2005) (Fig 12). We plan on further refining this classification scheme to be able to group transect sites into functional use types.

Products to date

Here is a list of 6 oral scientific presentations and one poster that have been made about the USFWS-funded project. The presenter/s is underlined. Note that Andrew Arnold is the Master's student at Old Dominion University that is working on the project through support from Maryland DNR.

2013. <u>Buler, J. J.</u> Recent applications of weather radar for understanding the stopover ecology of migrating birds, Old Dominion University, Department of Biological Sciences, Norfolk, VA

2013. <u>Arnold, A.</u>, J. J. Buler, T. Schreckengost, and E. L. Walters. Using radar-based data to predict forested hardwood habitat use by migrants along the Eastern Shore of Virginia and Maryland: A preliminary report, Coastal Upland Management Meeting, Eastern Shore of Virginia National Wildlife Refuge, Cape Charles, VA

2014. Arnold, J.A., E. L. Walters, T. Schreckengost, and J. J. Buler. 2014. Migratory bird use of forested stopover sites on the lower Delmarva Peninsula and a comparison with radar-based predictive models. Virginia Coastal Avian Partnership Meeting, Eastern Shore Community College, Melfa, VA

2014. Buler, J. J. Some revelations of bird migration and stopover ecology from weather surveillance radar observations, Villanova University, Department of Biology, Philadelphia, PA

2014. Arnold, J. A., T. Schreckengost, J. J. Buler, and E. L. Walters. Assessing habitat use and quality of stopover sites during fall migration, North American Congress for Conservation Biology, University of Montana, Missoula, MT

2014. Buler, J. J., D. Dawson, D. La Puma, J. Smolinksy, T. Schreckengost, A. Arnold, E. Walters. Broad-scale mapping and monitoring of migratory landbird stopover sites using the national network of weather radars, Joint Meeting of the Northeast and Southeast Partners in Flight, Virginia Beach, VA

2014. Arnold, J. A., T. Schreckengost, J. J. Buler, and E. L. Walters. Assessing avian use of forested stopover habitat during fall migration along Virginia's Eastern Shore. Tidewater Student Research Poster Session, Christopher Newport University, Newport News, VA

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Table 1. Detection probabilities and detection-corrected migrant bird densities within 50 m of the transect centerline during fall 2013. Number of visits to each transect and the radar, if any, the transect falls within range of.

Transect	Radar	Number of Visits	% detected within 50 m	Density (birds/ha/visit)
GDSW	AKQ	13	0.51	1.35
CBSN	AKQ	19	0.48	1.72
GDSE	AKQ	19	0.48	2.21
HCWP	AKQ	19	0.52	2.22
CPSP	AKQ	20	0.54	2.46
GDNW	AKQ	14	0.40	2.61
MSBT	AKQ	20	0.58	2.73
SOQU	AKQ	15	0.48	2.78
CSNA	AKQ	19	0.57	2.87
RACP	AKQ	19	0.44	3.22
PACP	AKQ	19	0.28	3.40
ZUNI	AKQ	16	0.47	4.18
MCWS	DOX	16	0.69	1.23
MAHO	DOX	18	0.41	1.80
WICO	DOX	19	0.55	1.82
NASS	DOX	18	0.60	1.83
BFLP	DOX	17	0.54	1.89
PHWA	DOX	17	0.79	2.24
IDYL	DOX	18	0.63	2.49
CHSP	DOX	18	0.67	2.58
NWWA	DOX	17	0.72	2.76
FBNP	DOX	17	0.74	2.80
KPSP	DOX	17	0.70	2.80
THWO	DOX	16	0.65	2.83
BLWA	DOX	17	0.67	2.90
MASP	DOX	18	0.42	3.21
TUSP	DOX	17	0.78	3.26
BHNW	DOX	14	0.70	3.99
MNWA	DOX	16	0.63	4.83
QUIN	Outside	16	0.60	1.27
NAMI	Outside	19	0.58	1.69
BROW	Outside	17	0.54	1.73
MARU	Outside	17	0.63	1.93
MILA	Outside	17	0.70	1.95
EAVA	Outside	17	0.61	2.09
FOES	Outside	17	0.56	2.26
CACH	Outside	18	0.44	2.51
KIPT	Outside	16	0.54	2.58
PUDD	Outside	18	0.53	2.64
MAFA	Outside	15	0.37	2.84
MUHU	Outside	18	0.42	3.12
WAIS	Outside	14	0.54	3.16
OAGR	Outside	18	0.42	3.40
PIHA	Outside	18	0.45	3.45
POSF	Outside	18	0.53	3.46
PHFA	Outside	17	0.28	3.53
PRAN	Outside	17	0.40	3.88
SANE	Outside	18	0.52	3.93

Table 2. Number of suitable sampling nights for each radar and year for the autumn migration season. The percent of suitable nights out of all screened nights by radar across years is also presented.

	Radar	Year							Total	%
		2008	2009	2010	2011	2012	2013	2014		
NEXRAD	AKQ	10	9	9	6	5	16	n/a	55	11
	BGM	18	12	20	4	5	8	n/a	67	13
	BOX	14	8	12	10	20	26	n/a	90	18
	BUF	11	8	4	3	5	9	n/a	40	8
	CBW	8	5	17	16	25	17	n/a	88	17
	CCX	9	15	29	17	26	27	n/a	123	24
	DIX	12	6	16	16	12	30	n/a	92	18
	DOX	13	19	23	8	12	13	n/a	88	17
	ENX	24	17	16	12	9	20	n/a	98	19
	FCX	17	10	30	13	20	16	n/a	106	21
	GYX	21	17	23	24	38	36	n/a	159	31
	LWX	11	26	23	19	28	28	n/a	135	26
	OKX	19	8	20	13	8	27	n/a	95	19
	PBZ	16	24	19	20	16	28	n/a	123	24
	RLX	19	15	5	8	8	10	n/a	65	13
	TYX	7	9	21	16	13	13	n/a	79	15
TDWR	TJFK	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	TPHL	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	TBWI	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	TDCA	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Total		229	208	287	205	250	324	n/a	1503	18

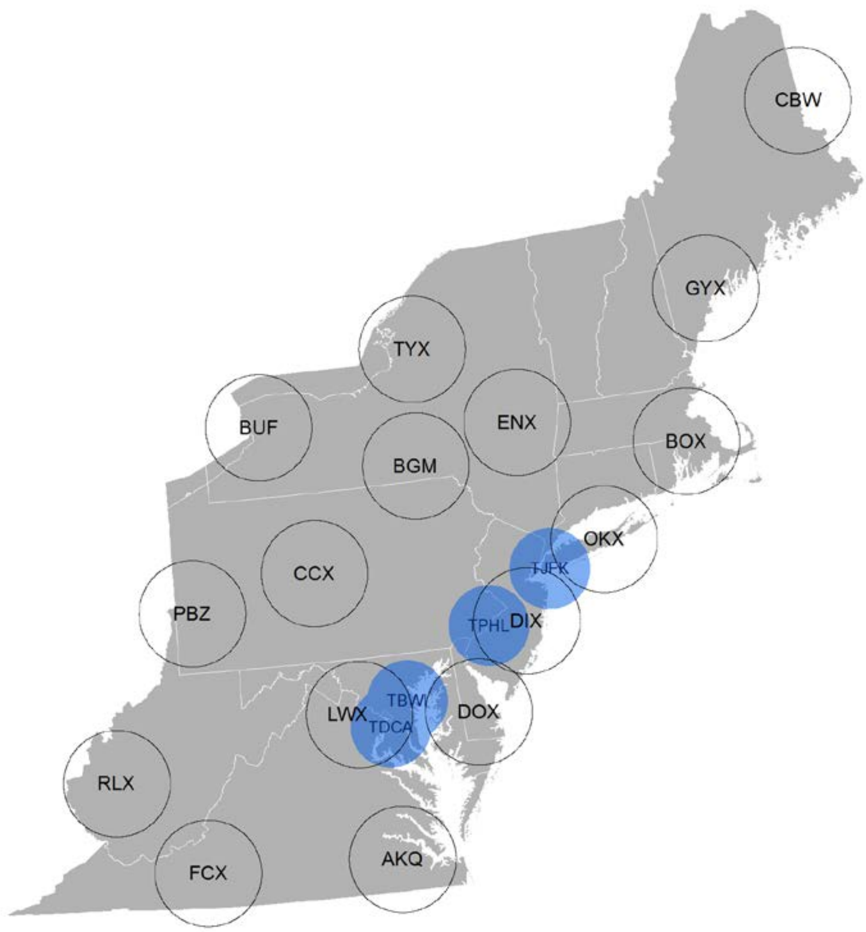


Figure 1. Location, short name, and radar coverage area (80 km radius) of 16 NEXRAD sites used in the study within USFWS Region 5. Blue areas denote the coverage area (60 km radius) of TDWR sites used in the study.

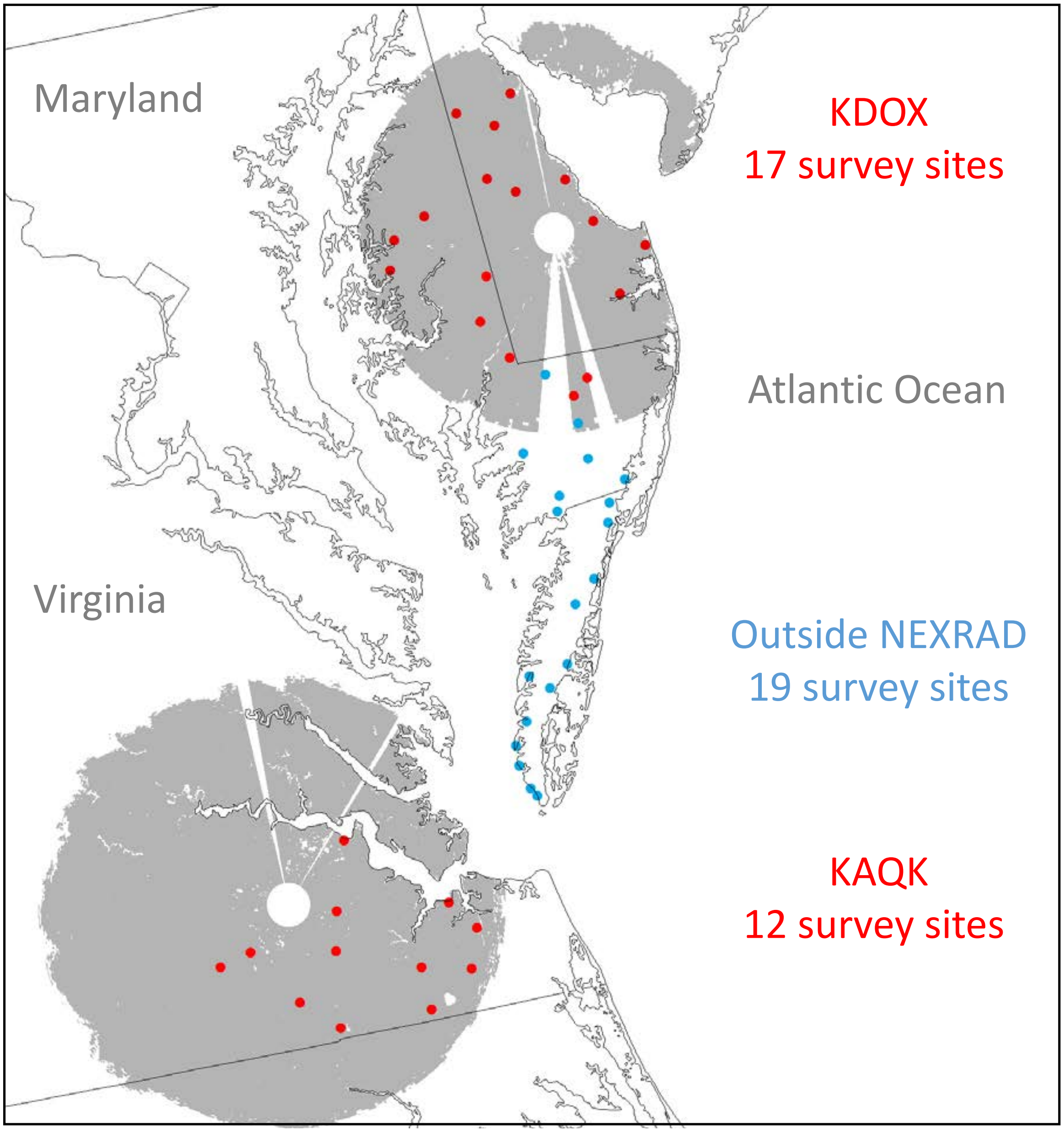


Figure 2. Locations of 48 hardwood forest transect survey sites within (red) and outside (blue) of NEXRAD coverage areas (grey shaded areas) where bird surveys were conducted.

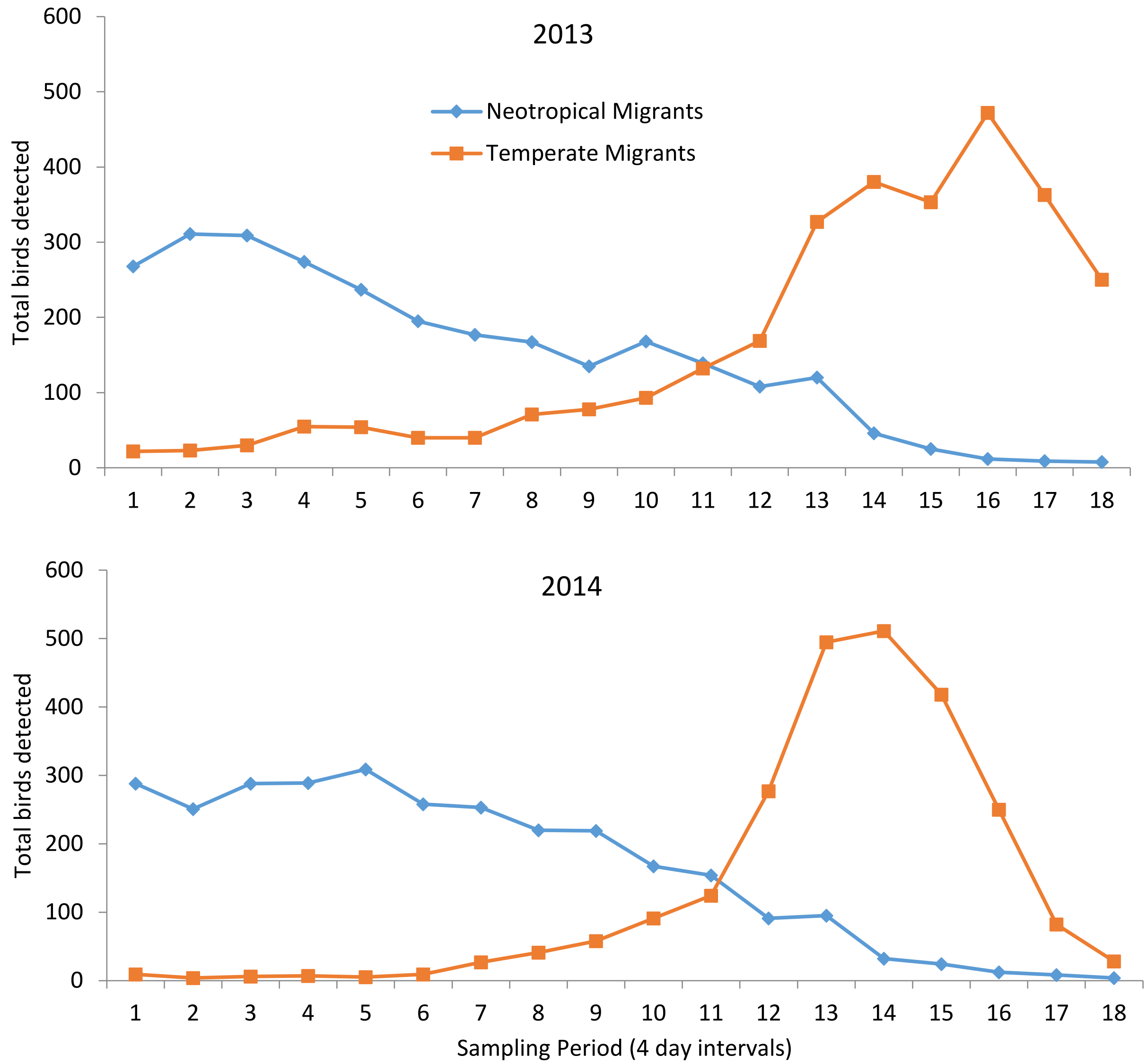


Figure 3. Total number of migrants (Neotropical versus temperate) detected throughout the fall field season for all 48 transects by year.

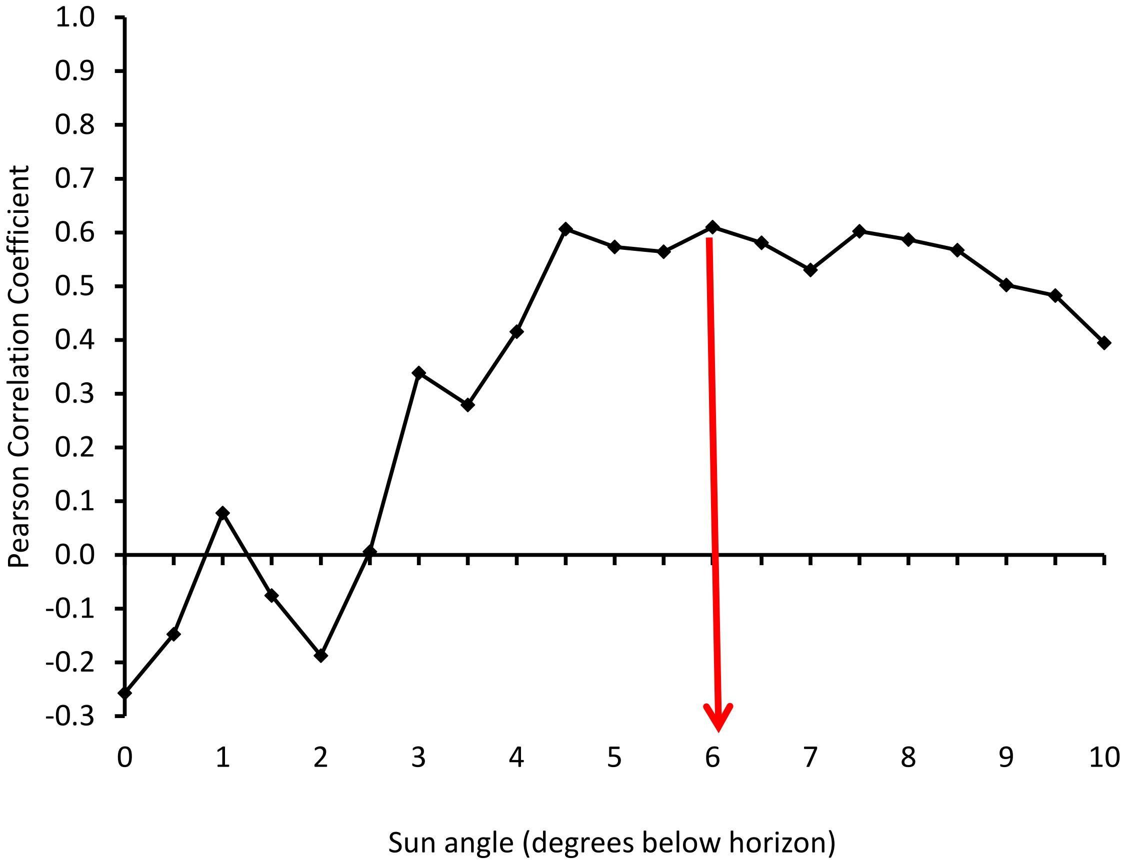


Figure 4. Scatterplot of correlation coefficients between seasonal mean reflectivity of emigrating birds sampled at a series of sun angles and the seasonal mean migrant bird density on the ground among 17 transect sites within the DOX radar range during 2013. The red arrow denotes the sun angle of the strongest correlation.

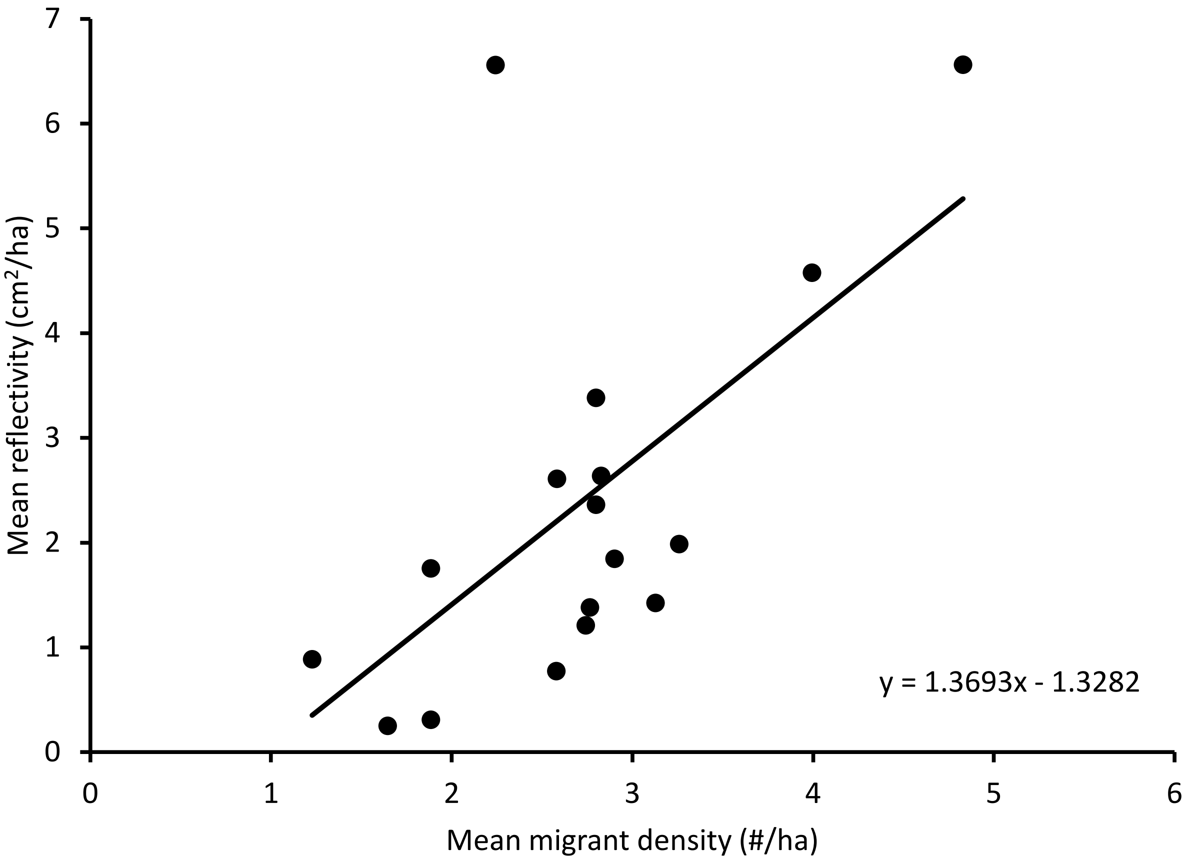


Figure 5. Scatterplot of seasonal mean reflectivity of emigrating birds at the end of civil twilight (i.e., sun angel 6 degrees below horizon) and the seasonal mean migrant bird density on the ground among 17 transect sites within the DOX radar range during 2013. The equation of the line of best fit is presented.

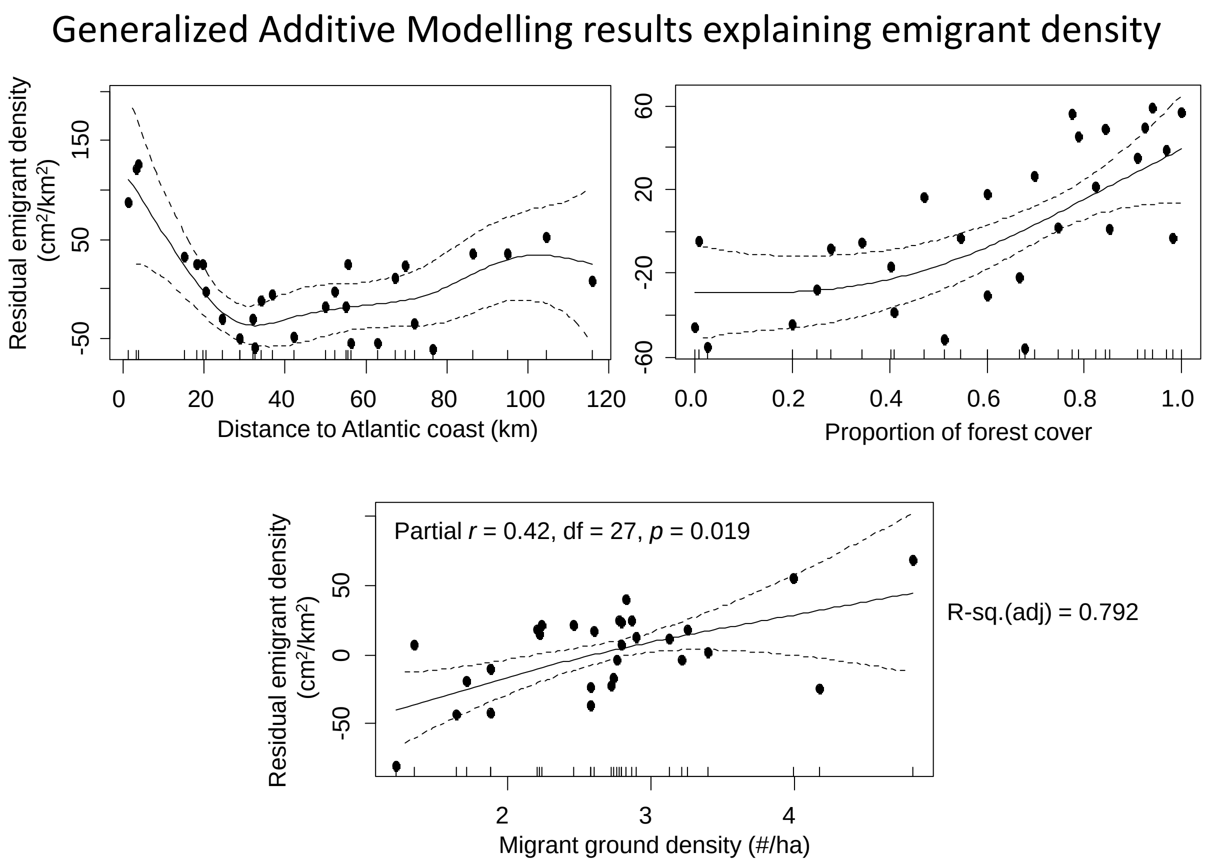


Figure 6. Partial regression scatter plots of individual covariates of GAM model explaining radar-observed emigrant density among 29 transects sites within radar coverage at AKQ and DOX during fall 2013. Overall model adjusted R^2 value was 0.792. Partial correlation of migrant ground density and emigrant density after controlling for distance of transect from the Atlantic coast and the proportion of forest cover within the radar sample volume encompassing the transect was 0.42.

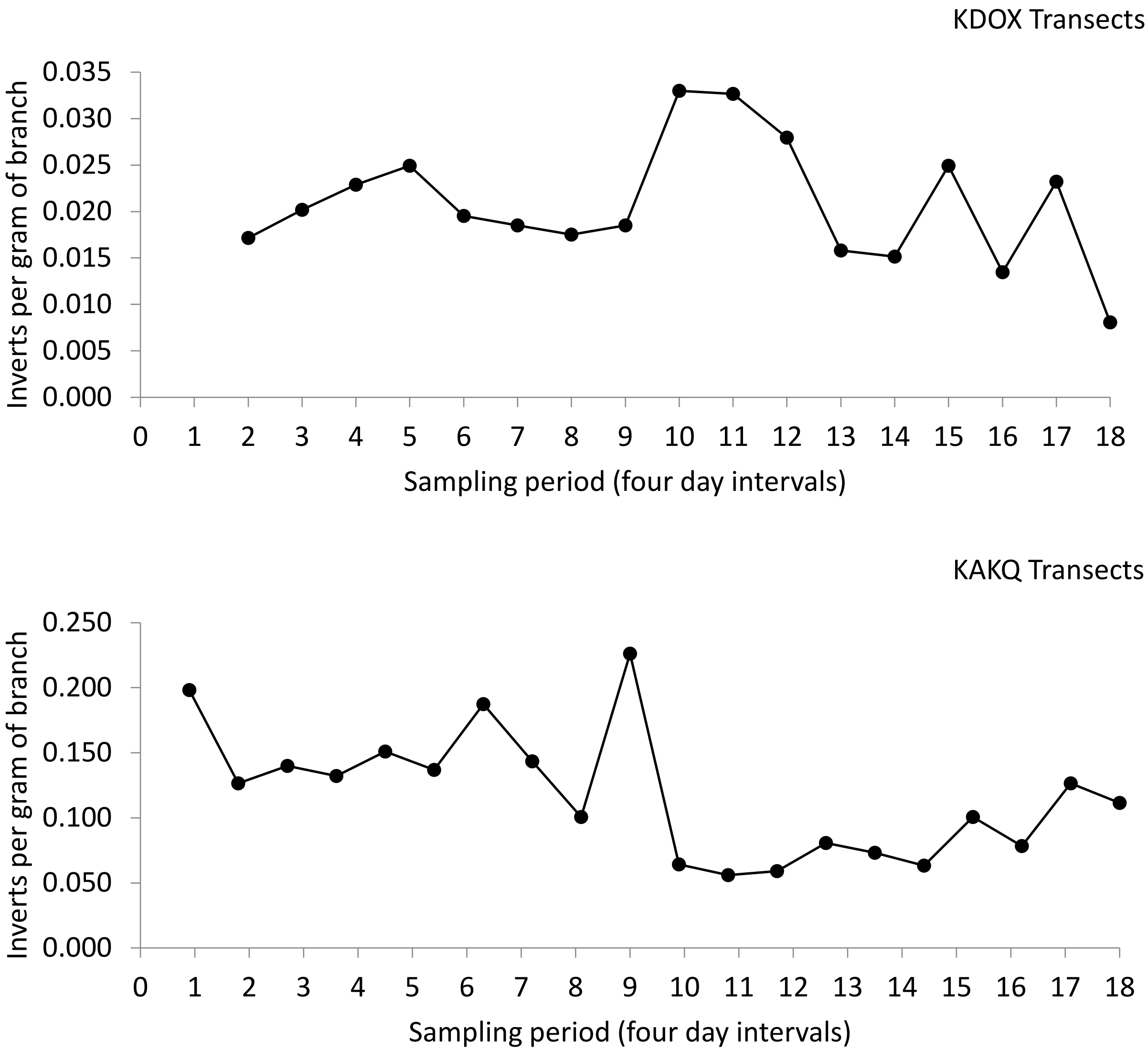
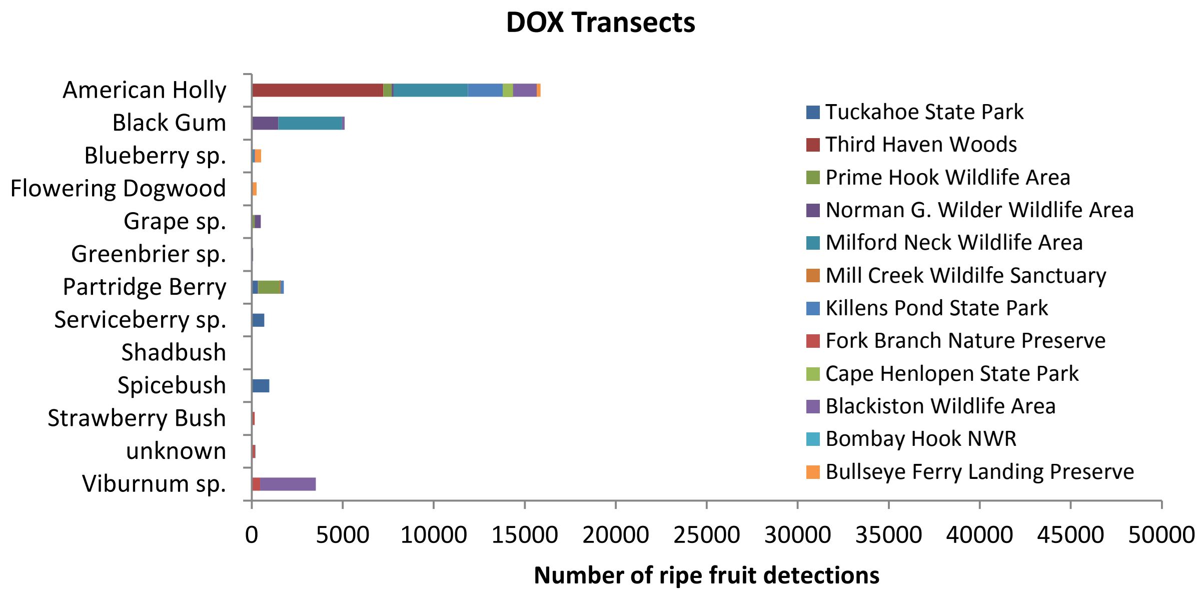


Figure 7. Scatterplot of mean invertebrate density from branch clipping across transects from KDOX and KAKQ during each sampling period of 2013.



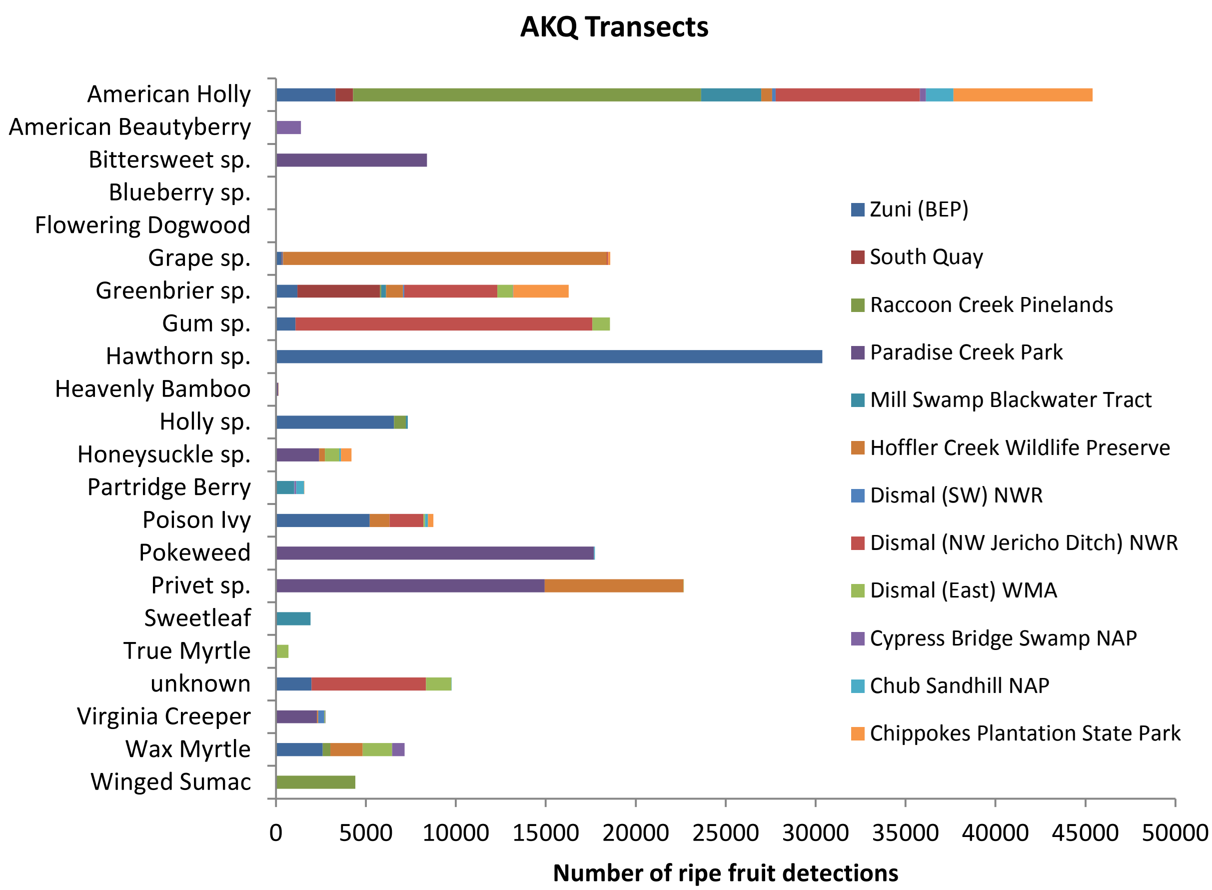


Figure 8. Histograms of total numbers of ripe fruit detected during the 2013 season by plant species among transect sites.

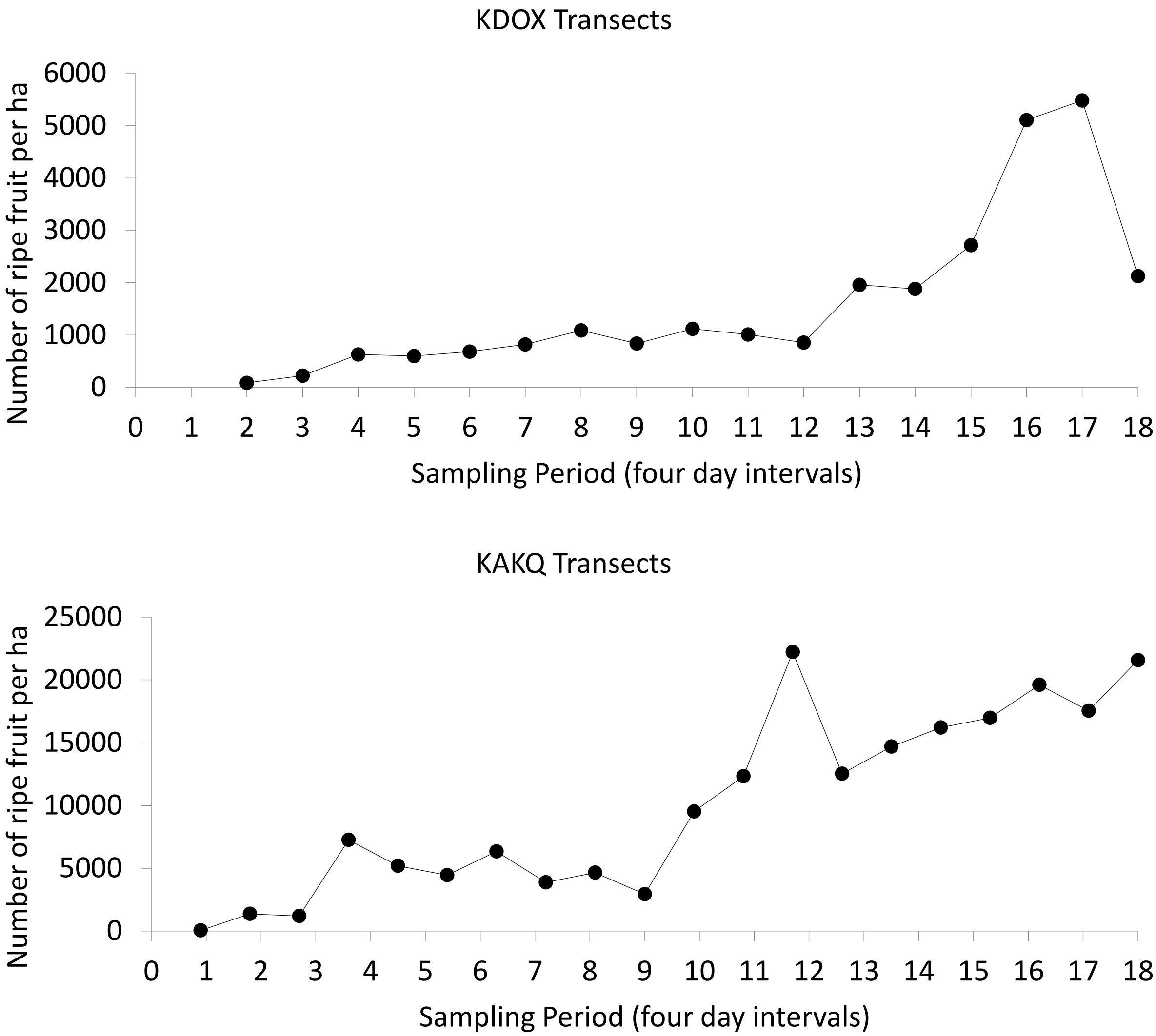


Figure 9. Scatterplot of mean ripe fruit density across transects from KDOX and KAKQ during each sampling period of 2013.

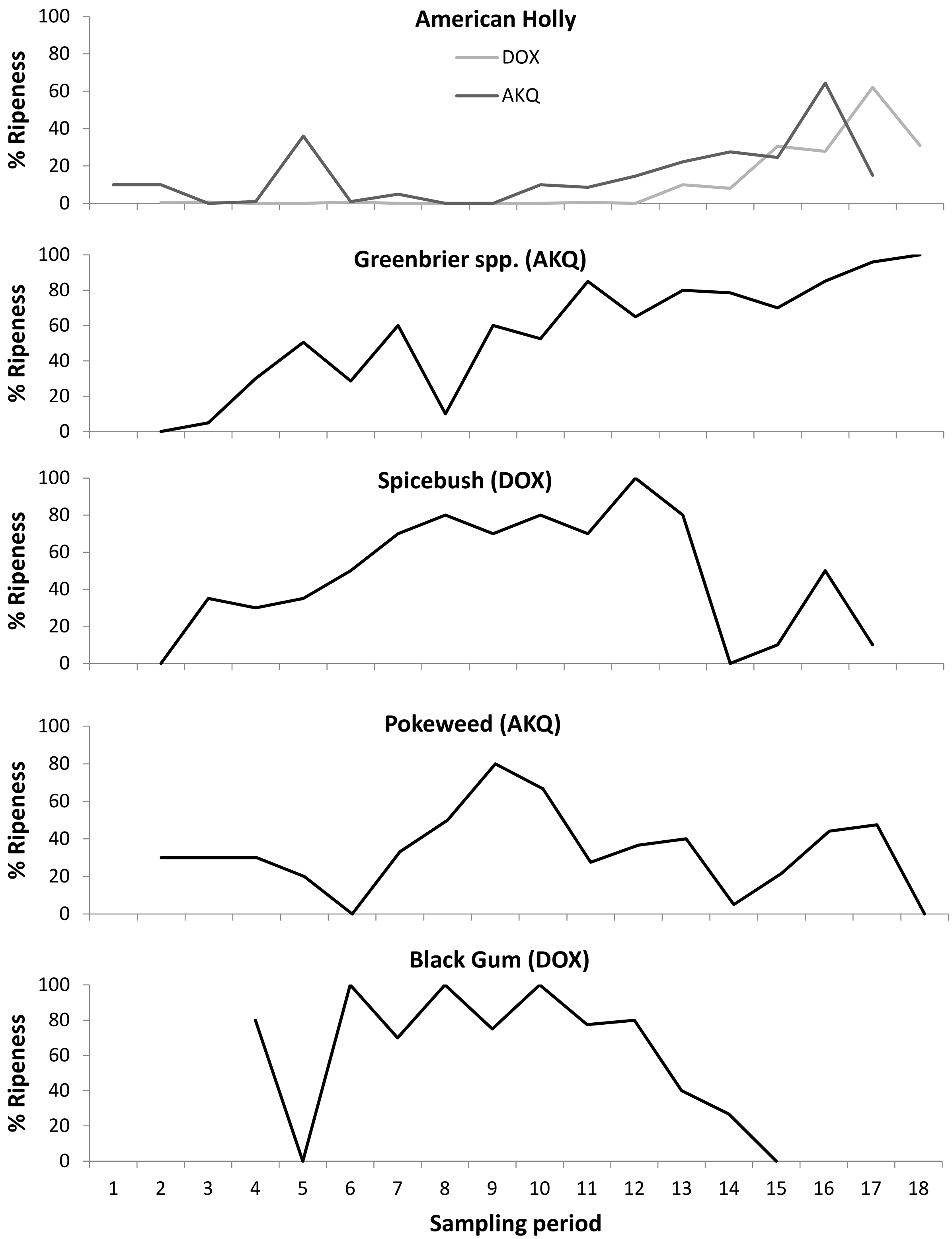


Figure 10. Phenology of fruit ripeness for species among different regions (denoted in parentheses) during 2013.

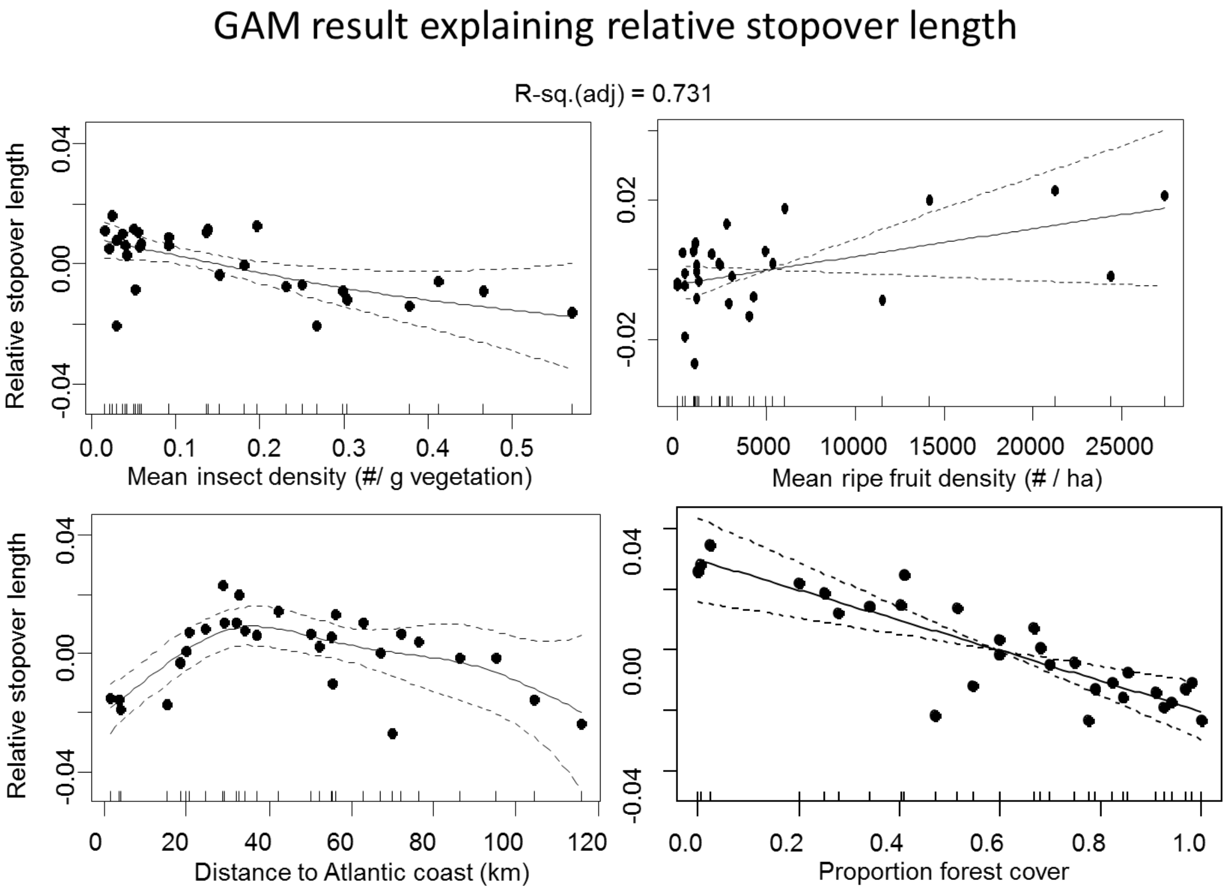


Figure 11. Partial regression scatter plots of individual covariates of GAM model explaining relative bird stopover length among 29 transects sites within radar coverage at AKQ and DOX during fall 2013. Overall model adjusted R^2 value was 0.731.

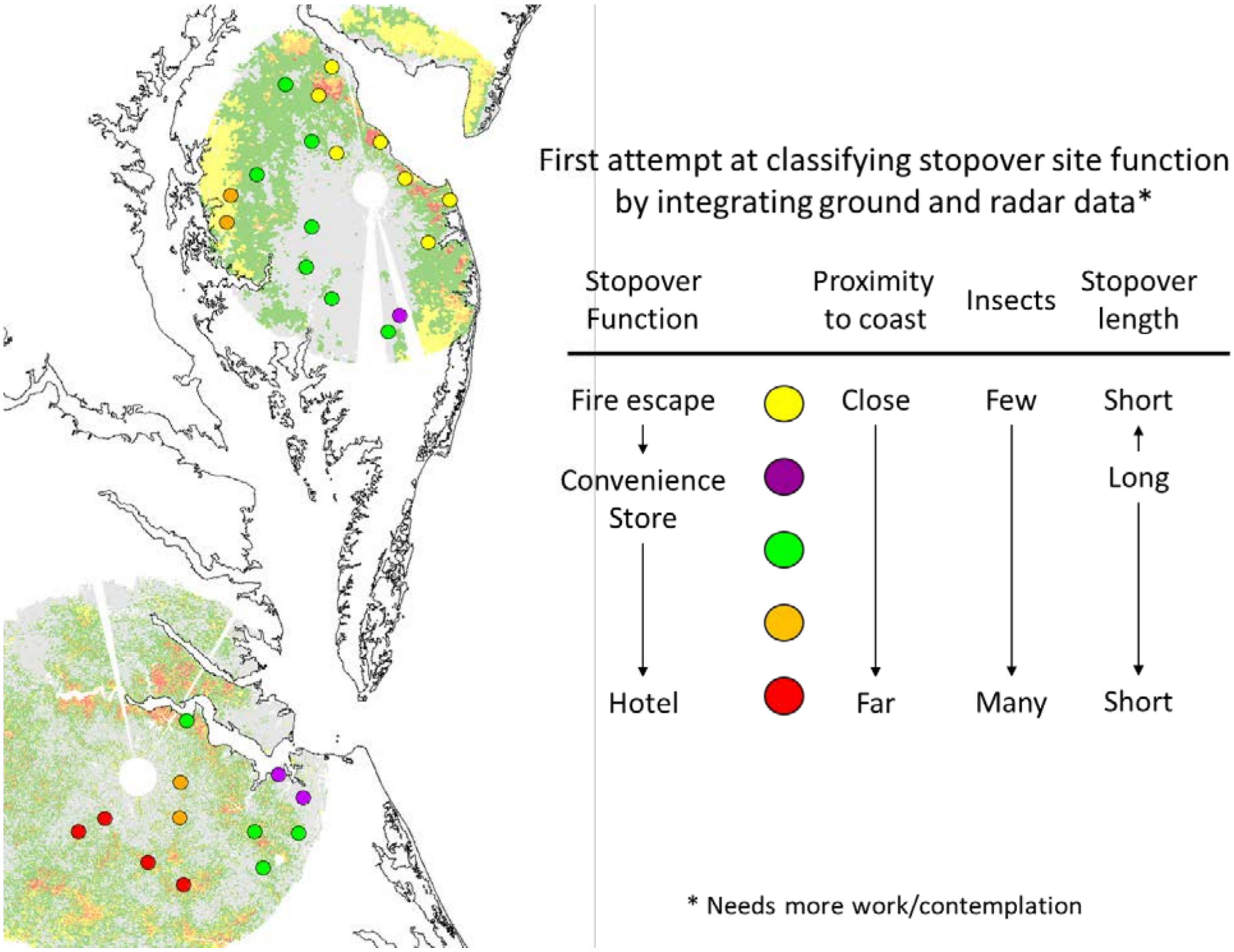


Figure 12. Map depicting the 5 stopover function types of 29 transect sites during fall 2103 along the spectrum of fire escapes to hotels. Clustering based on proximity to coast, insect availability, and relative stopover length as proof of concept. We are still developing a rigorous approach for using relative stopover length to aid in identifying functional use of sites. Classified radar imagery of stopover use during 2008-2009 from AKQ and DOX are shown for reference.

Appendix A. Complete list of bird species and species groups detected during fall 2013 among 48 transect locations. Migration status classifications (mi – transient, su – summer breeder, wi – winter resident, yr – year-round) and total detections are also presented.

Common Name	Scientific Name	Migration Status	Total Detections
(Eastern) Tufted Titmouse	Baeolophus bicolor	yr	1208
Acadian Flycatcher	Empidonax virescens	su	235
American Crow	Corvus brachyrhynchos	yr	545
American Goldfinch	Spinus tristis	yr	244
American Kestrel	Falco sparverius	yr	1
American Pipit	Anthus rubescens	wi	2
American Redstart	Setophaga ruticilla	mi	159
American Robin	Turdus migratorius	yr	590
American Woodcock	Scolopax minor	yr	4
Bald Eagle	Haliaeetus leucocephalus	yr	12
Barn Owl	Tyto alba	yr	1
Barn Swallow	Hirundo rustica	su	3
Barred Owl	Strix varia	yr	14
Bay-breasted Warbler	Setophaga castanea	mi	1
Belted Kingfisher	Megaceryle alcyon	yr	9
Black Vulture	Coragyps atratus	yr	4
Black-and-white Warbler	Mniotilta varia	mi	102
Blackburnian Warbler	Setophaga fusca	mi	2
Blackpoll Warbler	Setophaga striata	mi	25
Black-throated Blue Warbler	Setophaga caerulescens	mi	118
Black-throated Green Warbler	Setophaga nigrescens	mi	5
Blue Grosbeak	Passerina caerulea	su	18
Blue Jay	Cyanocitta cristata	yr	607
Blue-gray Gnatcatcher	Polioptila caerula	su	16
Blue-headed Vireo	Vireo solitarius	mi	9
Blue-winged Warbler	Vermivora cyanoptera	su	1
Bobolink	Dolichonyx oryzivorus	mi	6
Brown Creeper	Certhia americana	wi	77
Brown Thrasher	Toxostoma rufum	yr	27
Brown-headed Cowbird	Molothrus ater	yr	24
Brown-headed Nuthatch	Sitta pusilla	yr	16
Canada Goose	Branta canadensis	yr	44
Canada Warbler	Cardellina canadensis	mi	4
Carolina Chickadee	Poecile carolinensis	yr	926
Carolina Wren	Thryothorus ludovicianus	yr	1654
Caspian Tern	Hydroprogne caspia	su	2
Cedar Waxwing	Bombycilla cedrorum	yr	55
Chestnut-sided Warbler	Setophaga pensylvanica	mi	7
Chimney Swift	Chaetura pelagica	su	23
Chipping Sparrow	Spizella passerina	su	4
Common Grackle	Quiscalus quiscula	yr	112
Common Yellowthroat	Geothlypis trichas	su	8
Cooper's Hawk	Accipiter cooperii	yr	5
Dark-eyed (Slate-colored) Junco	Junco hyemalis	wi	5
Double-crested Cormorant	Phalacrocorax auritus	yr	1
Downy Woodpecker	Picoides pubescens	yr	552

Eastern Bluebird	Sialia sialis	yr	53
Eastern Phoebe	Sayornis phoebe	su	13
Eastern Screech-Owl	Megascops asio	yr	14
Eastern Towhee	Pipilo erythrophthalmus	yr	55
Eastern Whip-poor-will	Antrostomus vociferus	su	1
Eastern Wood-Pewee	Contopus virens	su	260
European Starling	Sturnus vulgaris	yr	2
Field Sparrow	Spizella pusilla	su	8
Fish Crow	Corvus ossifragus	yr	19
Fox Sparrow	Passerella iliaca	wi	4
Golden-crowned Kinglet	Regulus satrapa	wi	462
Golden-winged Warbler	Vermivora chrysoptera	mi	1
Gray Catbird	Dumetella carolinensis	su	66
Gray-cheeked Thrush	Catharus minimus	mi	6
Great Blue Heron	Ardea herodias	yr	22
Great Crested Flycatcher	Myiarchus crinitus	su	89
Great Egret	Ardea alba	yr	2
Great Horned Owl	Bubo virginianus	yr	8
Greater Yellowlegs	Tringa melanoleuca	mi	1
Hairy Woodpecker	Picoides villosus	yr	191
Hermit Thrush	Catharus guttatus	wi	153
Herring Gull	Larus argentatus	yr	1
Hooded Warbler	Setophaga citrina	su	24
House Finch	Carpodacus mexicanus	yr	5
House Wren	Troglodytes aedon	su	5
Indigo Bunting	Passerina cyanea	su	15
Kentucky Warbler	Geothlypis formosa	su	1
Killdeer	Charadrius vociferus	yr	9
Laughing Gull	Leucophaeus atricilla	su	9
Least Flycatcher	Empidonax minimus	mi	5
Magnolia Warbler	Setophaga magnolia	mi	15
Mourning Dove	Zenaida macroura	yr	111
Northern (Baltimore) Oriole	Icterus galbula	su	5
Northern (Yellow-shafted) Flicker	Colaptes auratus	wi	519
Northern Bobwhite	Colinus virginianus	yr	3
Northern Cardinal	Cardinalis cardinalis	yr	1200
Northern Mockingbird	Mimus polyglottos	yr	3
Northern Parula	Setophaga americana	mi	24
Northern Waterthrush	Parkesia noveboracensis	mi	5
Osprey	Pandion haliaetus	yr	6
Ovenbird	Seiurus aurocapillus	su	68
Palm Warbler	Setophaga palmarum	mi	1
Pileated Woodpecker	Dryocopus pileatus	yr	409
Pine Siskin	Spinus pinus	wi	1
Pine Warbler	Setophaga pinus	yr	319
Prothonotary Warbler	Protonotaria citrea	su	3
Purple Martin	Progne subis	su	15
Red-bellied Woodpecker	Melanerpes carolinus	yr	783
Red-breasted Nuthatch	Sitta canadensis	wi	3
Red-eyed Vireo	Vireo olivaceus	su	339

Red-headed Woodpecker	Melanerpes erythrocephalus	yr	37
Red-shouldered Hawk	Buteo lineatus	yr	48
Red-tailed Hawk	Buteo jamaicensis	yr	12
Red-winged Blackbird	Agelaius phoeniceus	yr	27
Rock Dove	Columba livia	yr	10
Rose-breated Grosbeak	Pheucticus ludovicianus	mi	10
Ruby-crowned Kinglet	Regulus calendula	wi	77
Ruby-throated Hummingbird	Archilochus colibris	su	19
Rusty Blackbird	Euphagus carolinus	wi	3
Scarlet Tanager	Piranga olivacea	su	33
Sharp-shinned Hawk	Accipiter striatus	yr	9
Snow Goose	Chen caerulescens	wi	1
Song Sparrow	Melospiza melodia	yr	5
Summer Tanager	Piranga rubra	su	80
Swainson's Thrush	Catharus ustulatus	mi	7
Swamp Sparrow	Melospiza georgiana	wi	1
Tree Swallow	Tachycineta bicolor	su	12
Turkey Vulture	Cathartes aura	yr	68
unidentified Accipiter	Accipiter sp.	yr	6
unidentified Catharus	Catharus sp.	mi	2
unidentified Crow	Corvus sp.	yr	1
unidentified Empidonax	Empidonax sp.		17
unidentified woodpecker (drum)			130
Unknown bird			594
Unknown Blackbird			66
Unknown Caprimulgidae		su	1
Unknown gull			14
Unknown hawk			7
Unknown Oriole	Icterus sp.	su	1
Unknown Owl			2
Unknown Swallow			4
Unknown tanager	Piranga sp.		1
Unknown vireo	Vireo sp.		6
Unknown Warbler			319
Unkown Kinglet	Regulus sp.	wi	1
Veery	Catharus fuscescens	mi	38
Warbling Vireo	Vireo gilvus	su	2
White-breasted Nuthatch	Sitta carolinensis	yr	166
White-eyed Vireo	Vireo griseus	su	125
White-throated Sparrow	Zonotrichia albicollis	wi	45
Wild Turkey	Meleagris gallopavo	yr	30
Winter Wren	Troglodytes hiemalis	wi	68
Wood Duck	Aix sponsa	yr	5
Wood Thrush	Hylocichla mustelina	su	73
Worm-eating Warbler	Helmitheros vermivorus	su	36
WOTH/CATH			14
Yellow-bellied Sapsucker	Sphyrapicus varius	wi	19
Yellow-billed Cuckoo	Coccyzus americanus	su	118
Yellow-breasted Chat	Icteria virens	su	3
Yellow-rumped (Myrtle) Warbler	Setophaga coronata	wi	324

Yellow-throated Vireo	Vireo flavifrons	su	31
Yellow-throated Warbler	Setophaga dominica	su	5