USING WEATHER SURVEILLANCE RADAR TO IDENTIFY STOPOVER DISTRIBUTIONS OF MIGRATING BIRDS WITHIN NORTH CAROLINA

by

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ABSTRACT

In order to improve conservation of migratory songbirds, we must better understand their relationship with stopover landscapes. Weather surveillance radar permits such studies to be done by locating where high densities of birds are taking off during the onset of their nighttime flights. I used observations from 5 radars within the state of North Carolina to quantify how bird stopover densities have changed between the years of 2000-2003 and 2013-2015. I examined how these changes related to conversion of land cover between 2001 and 2011. The net change of land cover was 7.5% of the total land area within the five radars, which was primarily due to urbanization, deforestation, and afforestation. At a regional scale, bird density changes were generally associated to land cover changes and geographic location. Proximity to the Atlantic coastline was positively correlated with bird density declines as well as urbanization and deforestation. Birds generally stopped over consistently within forests and along lakes and coastal bodies of water at high densities. The association between bird densities and land cover change varied seasonally and between each radar. To improve our understanding of this relationship, future studies should be focused on longer timescales or in locations with high land turnover.

Chapter 1

INTRODUCTION

Currently, research conducted by Dr. Buler and the Aeroecology Program aims to categorize and analyze bird migration stopover sites based on data collected by the national network of weather surveillance radars (WSR-88D) in the United States. These radars measure electromagnetic radiation reflected off of birds (i.e., radar reflectivity) during the onset of their night time migratory flights (Gauthreaux and Belser 1998, Gauthreaux et al. 2003, Diehl and Larkin 2005). Using existing software developed by the Aeroecology Program, radar data can be analyzed to shed light on where birds stopover during their bi-annual migrations (Buler and Diehl 2009, Buler and Moore 2011, Buler and Dawson 2014). Stopover sites are categorized as locations where birds land along the way through their migration route.

Some of these stopover sites may be high quality feeding grounds where birds can refuel quickly to continue their migratory journey, or just resting stops where birds can avoid flying in hazardous weather or stop after a long flight. As birds migrate north and south, they seek food and shelter along the way. These long term flights are energetically expensive, thus refueling is essential to survival. In addition to replenishing their energy, basic cover is needed to hide from potential predators. Although our protection of critical breeding sites is important, a large portion of songbird mortality occurs during migration, likely contributing to limitations of their populations and conservation success (Sillett and Holmes 2002).

This is why understanding the quality and availability of highly used stopover sites is vital for migratory bird conservation (Mehlman et al. 2005).

I analyzed data collected at five WSR-88D stations (Wakefield, VA; Morehead City, NC; Wilmington, NC; Raleigh, NC and Greenville, SC) to quantify and map bird stopover distributions across the state of North Carolina. The compiled information will aid the North Carolina Wildlife Action Plan which calls for information on the status and distributions of priority bird species (which includes many migrating species), and identifying their vital habitats (North Carolina Wildlife Action Plan). More specifically, my goal was to investigate how bird stopover densities and distributions have changed from past to recent years in relation to land cover changes and differences between spring and fall migrations. This will allow us to understand when and what habitats are being used as well as what kind of land conversions will inhibit migratory bird use of stopover sites.

In the southeast, North Carolina has the highest rate of coastal population increase, 17%, followed by Florida (NOAA). Coastal development and expansion continuously encroaches deeper into wildlife habitats which have the potential to be important stopover sites for migrating songbirds (Bonter et al. 2009). I expect to find decreased bird densities in relation to the land cover changes, specifically in forest fragments that have been converted to agriculture or developed land cover throughout North Carolina.

Chapter 2

METHODS

The WSR-88D radars used in this research emit polarized, 10 cm (S band) electromagnetic waves at varying tilt angles. Radars emit 750 kW of energy at a 3 dB beam width of 0.95 degrees. Through the emission of these waves, the radar gets a returned signal from objects (in this study, birds) within a sampling volume of airspace. This signal, or reflectivity, is measured in units of Z within a logarithmic scale to a half decibel (.5 dB) in precision. In addition to measuring reflectivity, Doppler radars also measure radial velocity of objects, thus allowing us to determine the speed and direction of moving targets, or birds. Because these radars are designed for detecting weather, they function in two modes, 'precipitation' or 'clear air' mode. When in precipitation mode, the radar 'volume scans' the air approximately every 6 minutes, versus approximately every 10 minutes in 'clear air' mode. With each scan, multiple sweeps are taken at varying tilt angles (from 0.5 to 19.5 degrees above the horizon). These radars from the National Climate Data Center (NCDC) offer data as far back as 1995 and detect birds exiting stopover sites out to approximately 80 km from the radar (Buler and Dawson 2014). For this project, years were chosen based on the availability of archived and LiDAR data and available 'good' bird days, which will be defined below. After analysis of available years, fall and spring seasons were chosen for the years 2000-2002 and 2013-2014, while only spring seasons were chosen from 2003 and 2015. This large archive of information offers great insight to migration patterns and changes between seasons (fall and spring) and throughout the years. In 2008, all the WSR-88D radars underwent an upgrade in spatial resolution of sample volumes. Data prior to the upgrade, called “legacy” format has a 1 km x 1 degrees resolution in comparison to the newer “super” resolution format which is 250 m in range by .5 degrees.

The season dates for the chosen years are based on high migration flows in the fall, August 15th until November 7th, and in the spring, April 1st to May 31st. After filtering through the original year’s data, it was decided two more spring seasons would be added (2003 and 2015) for additional support. A sixth radar was eliminated due to its location in the Appalachian Mountains causing strong blockage of the radar beam. These data were initially screened to visually filter out days with obvious precipitation using NMQ (https://www.nssl.noaa.gov/projects/q2/) and MRMS (http://www.nssl.noaa.gov/projects/mrms/) websites. The clear days were then downloaded and further analyzed. These data were then viewed in the program IDV (Integrated Data Viewer) for anomalous propagation and clutter occurring one half hour after the onset of migratory flight. Clutter and analogous propagation can occur for a variety of reasons including: temperature and air density fluctuations, coastal sea breezes, or other biological activity. Using a processing software WDSS-II (Warning Decision Support System-Integrated Information) developed by the Universities of Oklahoma and Delaware, NCDC (National Climate Data Center) data were converted to netCDF formats. Once filtered, the remaining days were assessed for air speeds by radial velocity data (3.5 degree tilt angle) of radar targets by incorporating wind speed data from NARR (North American Regional Reanalysis). This was only done for hours approximately 3 hours after sunset, or peak time of migration exodus (Buler and Dawson 2014). Velocities aid to determine whether targets are insect dominated;

classified by velocities under 5 meters per second (Larkin 1991). Although this speed is a good indicator, it is not perfect. It assumes that all flying specimen are flying at the same trajectory, which can cause false assumptions for bird dominated days. In order to compensate for wind influences and obtain mean target airspeeds, wind speed vectors were subtracted by vectors from target groundspeed and direction obtained after dealiasing (fixing velocity distortions), velocities and generating VPR's or vertical profile of reflectivity for range correction in WDSS-II. The files used to generate the VPR tables are taken 3 hours after exodus. Days that are indistinctly birds or insects can be opened in IDV and visually screened to analyze direction based on whether targets are flying toward or away from the radar.

In past projects, sampling times were taken at a fixed sun angle below the horizon (or time) to sample the radar airfield. The original angle, 5.5 degrees, is the mean time when land birds were most dominant in their Mid-Atlantic migratory flight (Buler and Dawson 2014). Another project within the lab proved the limitations on this sampling technique in the Northeastern United States that led us to sample each day at an independent time. This permits variations across latitudes to give more pertinent exodus times. I utilized this study to empirically evaluate sun angles at an individual point for each bird night when the greatest change in densities of birds were taking off the ground. I used WDSS-II again to calculate VIR's (Vertically-Integrated Radar Reflectivity) which represents an approximation of cross sectional area of reflectivity from the ground to 1.5 km at a 0.5 tilt following Buler and Dawson (2014). Sample volumes that sampled less than 10% of the nightly VPR, or Vertical Profile of Reflectivity (i.e., were too high above the ground to detect birds) were censored for that given night. I determined the seasonal geometric mean (MN) and coefficient of variation (CV) of reflectivity for every sample volume that had < 25% of its samples censored across days. Furthermore, I excluded measures from sample volumes that were contaminated by persistent clutter or where the radar beam was partially blocked due to infrastructure or topography, which I determined by creating clutter maps following Buler and Dawson (2014).

To categorize highly used landscapes, I consider regions with high bird density, or high mean reflectivity, and low coefficient of variance valuable bird migratory stopover sites (Mehlman et al. 2005). In order to evaluate changes related to the hypothesis, early year bird densities were subtracted from late year bird densities and mapped in ArcGIS for both fall and spring seasons. Land cover maps were also generated by collecting data from the NLCD (National Landcover Dataset) for years 2001 and 2011. Statistical analyses were processed through the summaries run in R and ArcGIS.

Chapter 3

RESULTS

Throughout the total sample period, 17.6% of the days were considered usable bird days. Most data were eliminated due to precipitation, contaminating 38.4% of the data (Table 1).

Table 1 The number of days and type of classifications across five radar and two seasons. (*Insufficient Data was predominantly due to no available data, the rest was attributed to data processing problems and no birds present).

Season	Radar	Classification					
		Usable Bird Days	*Analogous Propagation*	*Clutter*	*Insects*	*Precipitation*	**Insufficient Data*
Fall	AKQ	49	36	27	60	148	105
	GSP	101	4	13	45	146	116
	LTX	58	44	28	54	183	58
	MHX	57	50	16	76	185	41
	RAX	104	14	16	70	174	47
Spring	AKQ	90	3	54	25	146	109
	GSP	122	7	24	38	180	56
	LTX	63	28	52	64	153	67
	MHX	45	25	20	97	172	68
	RAX	59	6	81	32	148	101
Total		**748**	**217**	**331**	**561**	**1,635**	**768**

Early Years Regional Classification:

Fall: High densities of birds occur along large bodies of water in addition to large forest and wetland habitats. Aside from the coast in LTX, major waterways, primarily coastal rivers, in both LTX and MHX were consistently visited in high densities. There are also notable forest patches that received high densities in North Carolina including national forests in MHX and wetlands surrounding coastal rivers. Additionally consistent high densities at the edge of GSP, crossing into North Carolina's border, is dominated by mixed forest habitat (Figure 1).

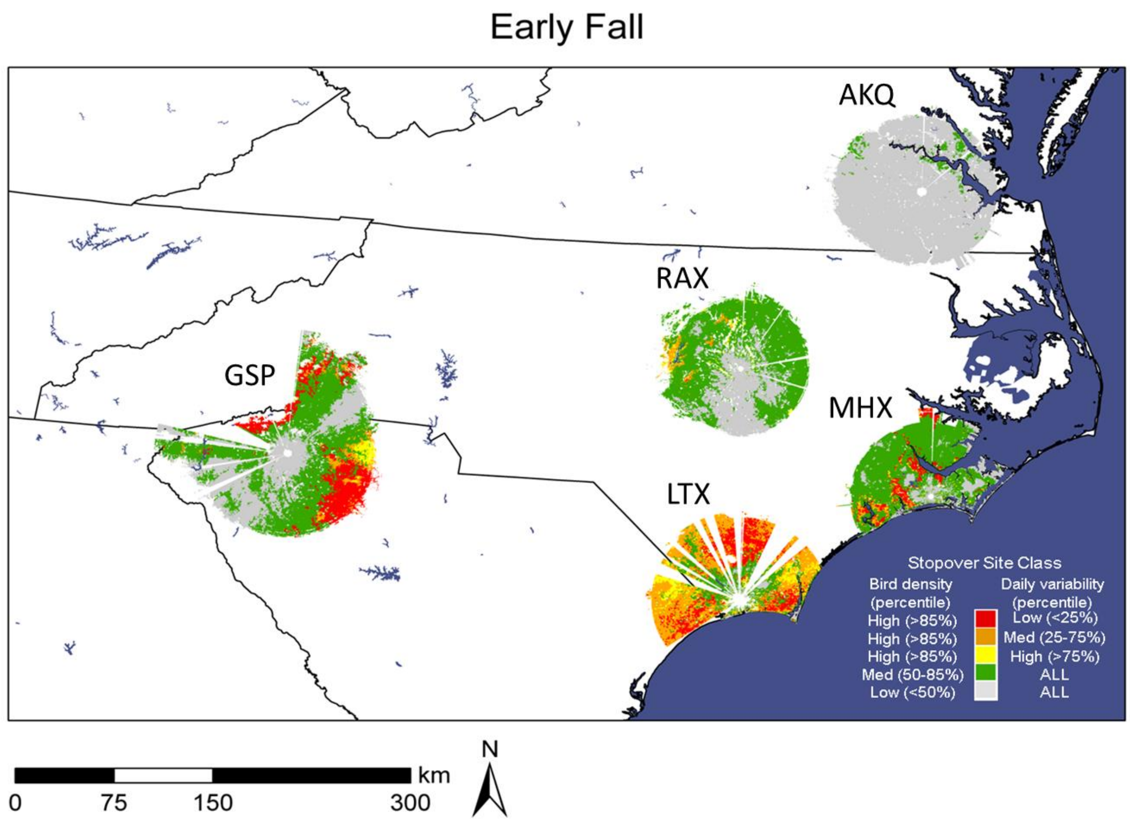

Figure 1 Bird density and daily variability across five radars in early years (2000-2003) during the fall season.

Spring: Consistent high densities did not favor coastal or large scale water habitats. Comparatively, GSP had the most frequently visited stopover sites in the entirety of its coverage in North Carolina. Although RAX had medium densities throughout a mixture of land cover types, birds tended to avoided large cities (Figure 2).

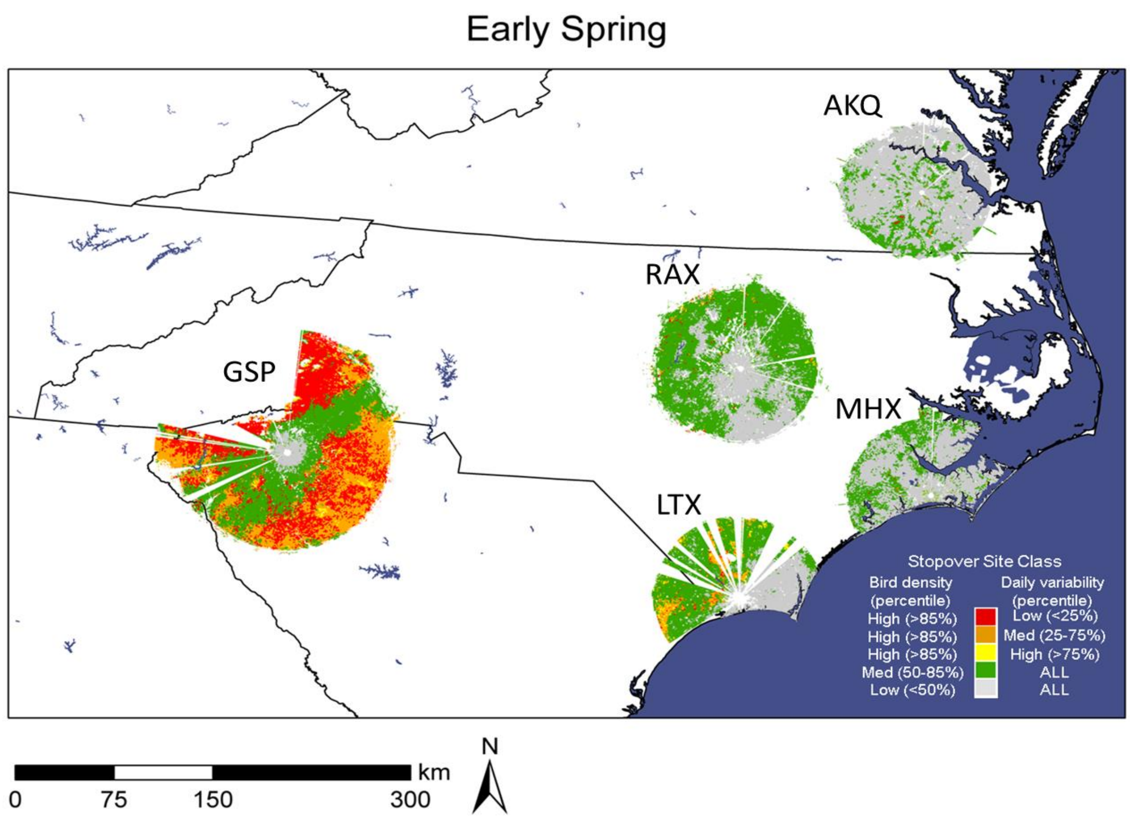

Figure 2 Bird density and daily variability across five radars in early years (2000-2003) during the spring season.

Late Years Regional Classification:

Fall: There are significant high densities with low variance along major water ways. This is clear in MHX, where the coastal rivers are bird dominated. This pattern holds true for both RAX and LTX radars. Birds also avoided major cities, again in RAX (figure 3).

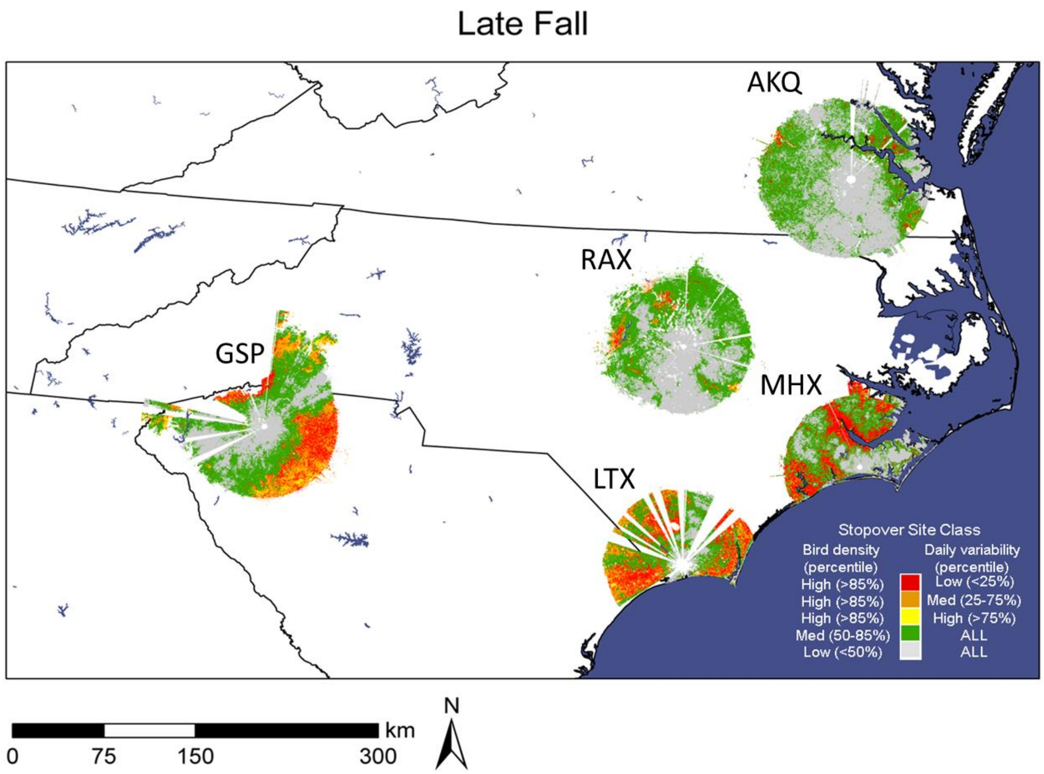

Figure 3 Bird density and daily variability across five radars in late years (2013-2015) during the fall season.

Spring: GSP had high density and low variability in its North Carolina coverage. All other radars were categorized by variable low to medium density of birds except on the most western border of RAX which is dominated by mixed forest and agriculture (figure 4).

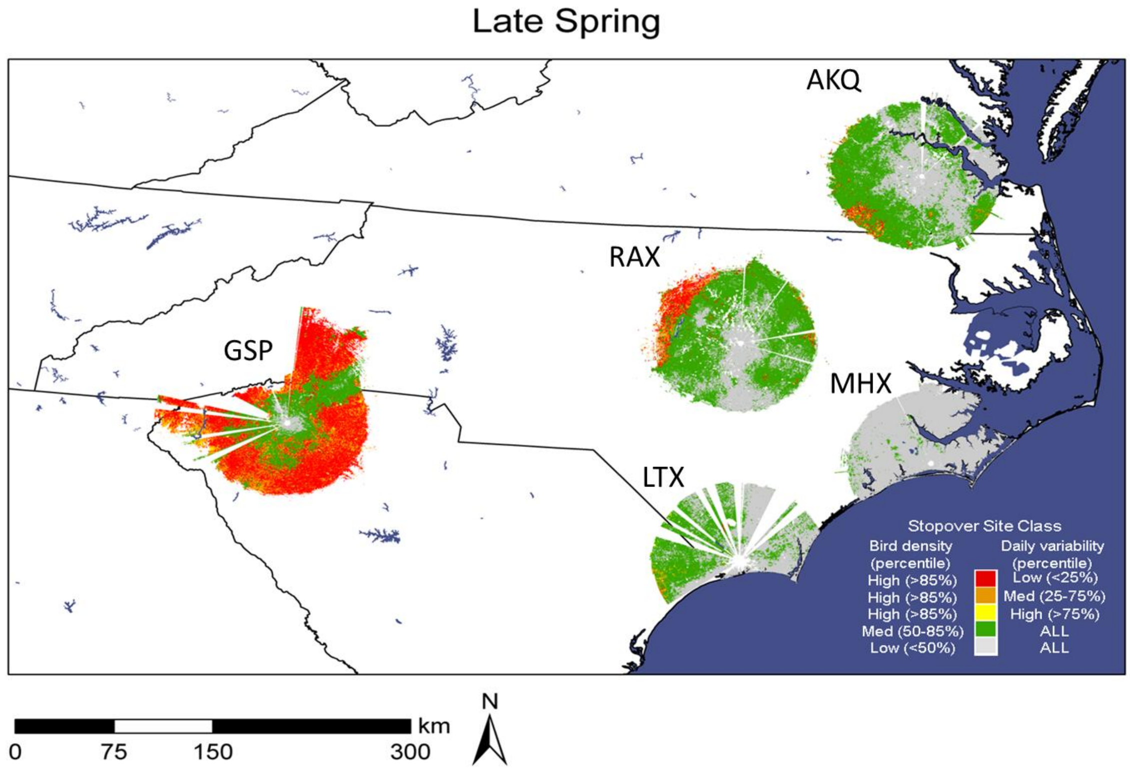

Figure 4 Bird densities and daily variability across five radars in late years (2013-2015) during the spring season.

Land Cover Changes:

There was a 7.5% net change in land cover from years 2001-2011 within the ranges of the five radars. There was a 0.96% increase in urban development and 3.2% decrease in forest cover. The deforestation was predominantly of evergreen forest. Shrubland additionally increased by 1.7%. The areas within the top 10% of radar domain area were associated with afforestation while deforestation and urbanization directly correlated with absolute decreases in bird densities (figure 5, figure 6).

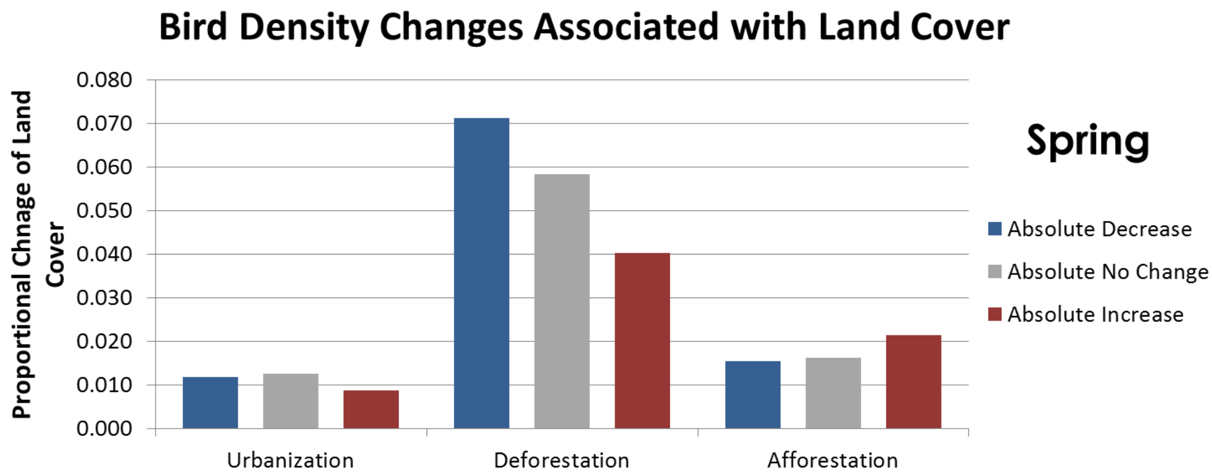

Figure 5 Absolute changes of bird densities with land cover change during the spring season.

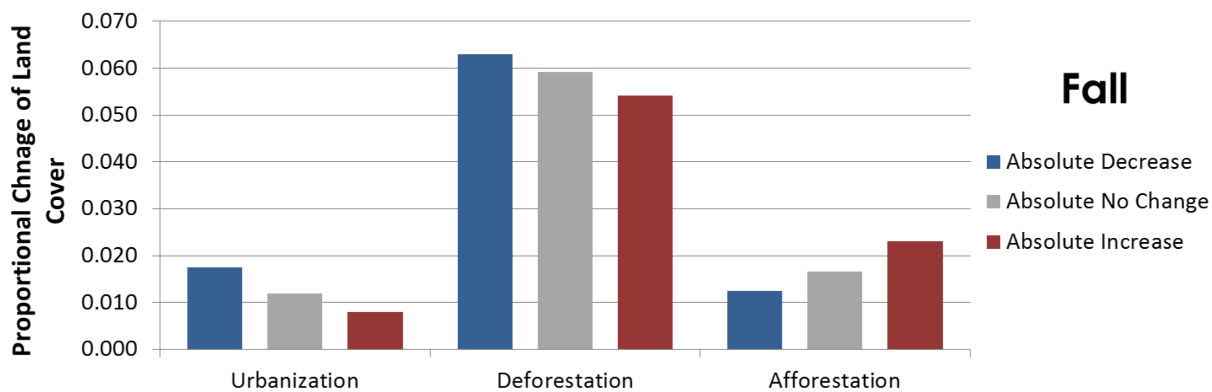

Figure 6 Absolute changes of bird densities with land cover change during the fall season.

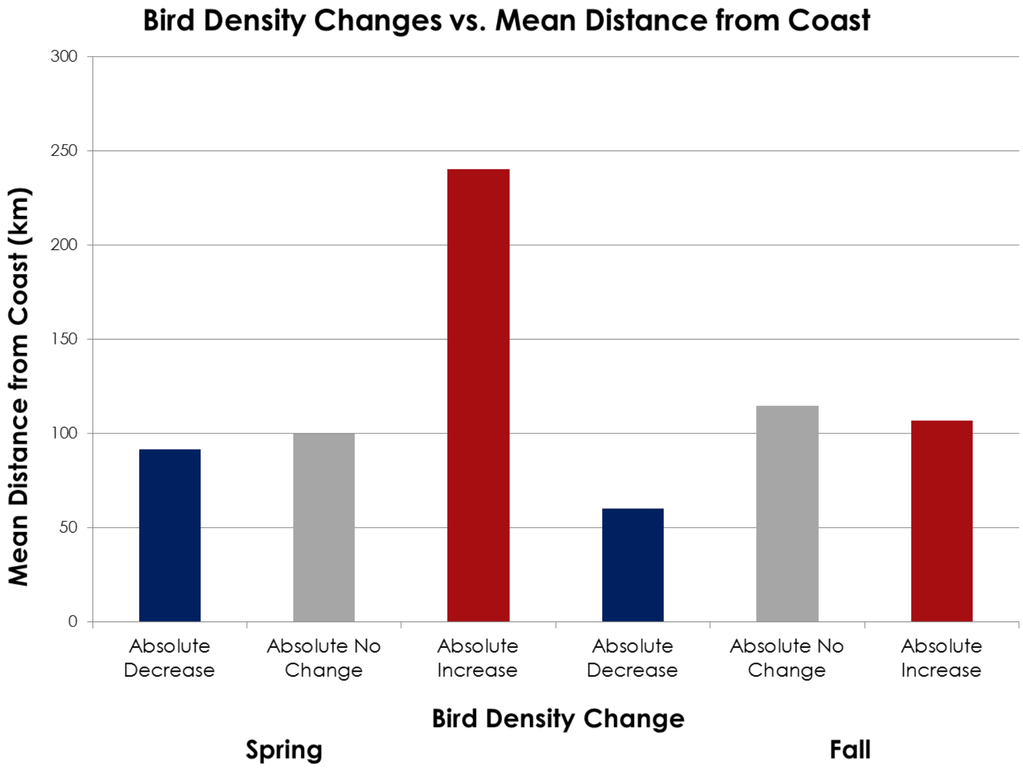

Figure 7 Absolute changes of bird densities in relation to distance from coast in the spring and fall season.

Relative Changes:

Fall: There were few regional decreases and increases of bird densities across the radars. Decreased bird densities were related directly to the mean distance from the coast, which was 60.0 km in the fall (figure 7). These findings can be visually seen along the lower coast of MHX. This land is primarily cultivated crops in both early and late years. LTX also had a strong decrease within the northern central array which is not associated with any specific land type (figure 8). There exist small, discrete, decreases through the radars that are associated with land cover change. This can be seen in a newly urbanized patch of land in RAX (figure 9).

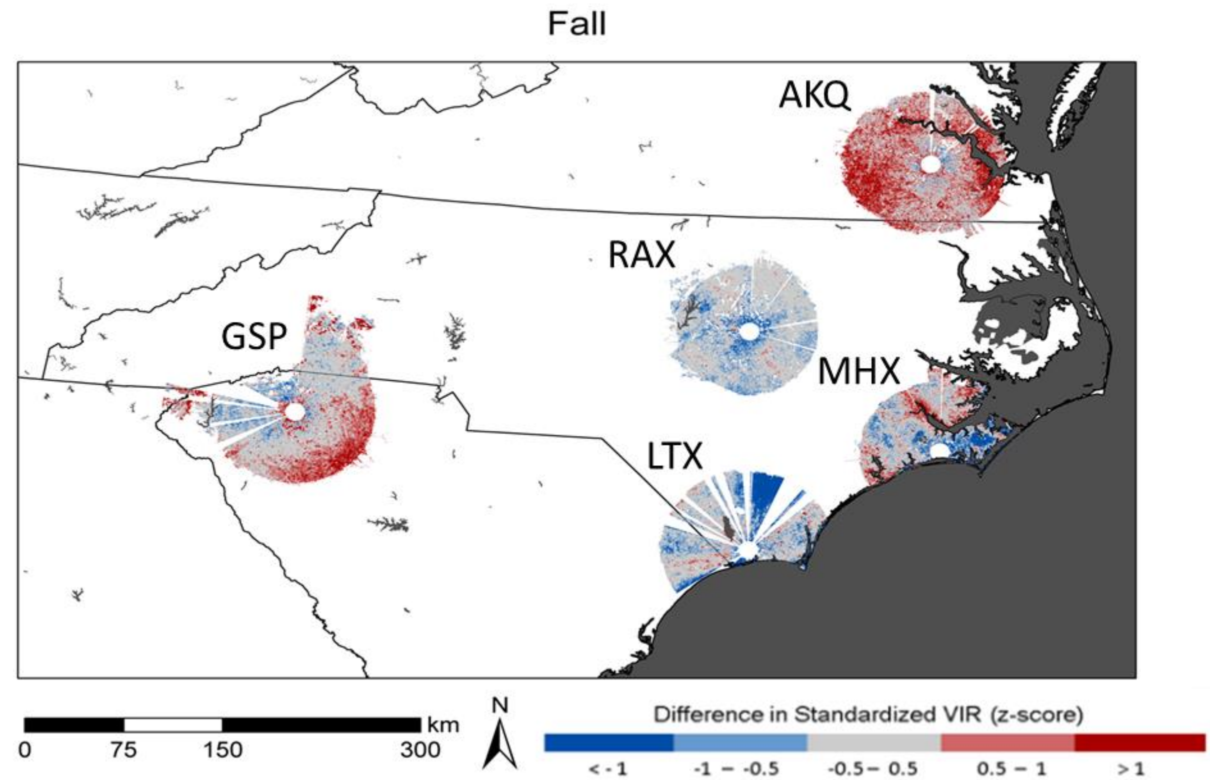

Figure 8 Bird density changes from early (2000-2003) to late (2013-2015) years across five radars in the fall season.

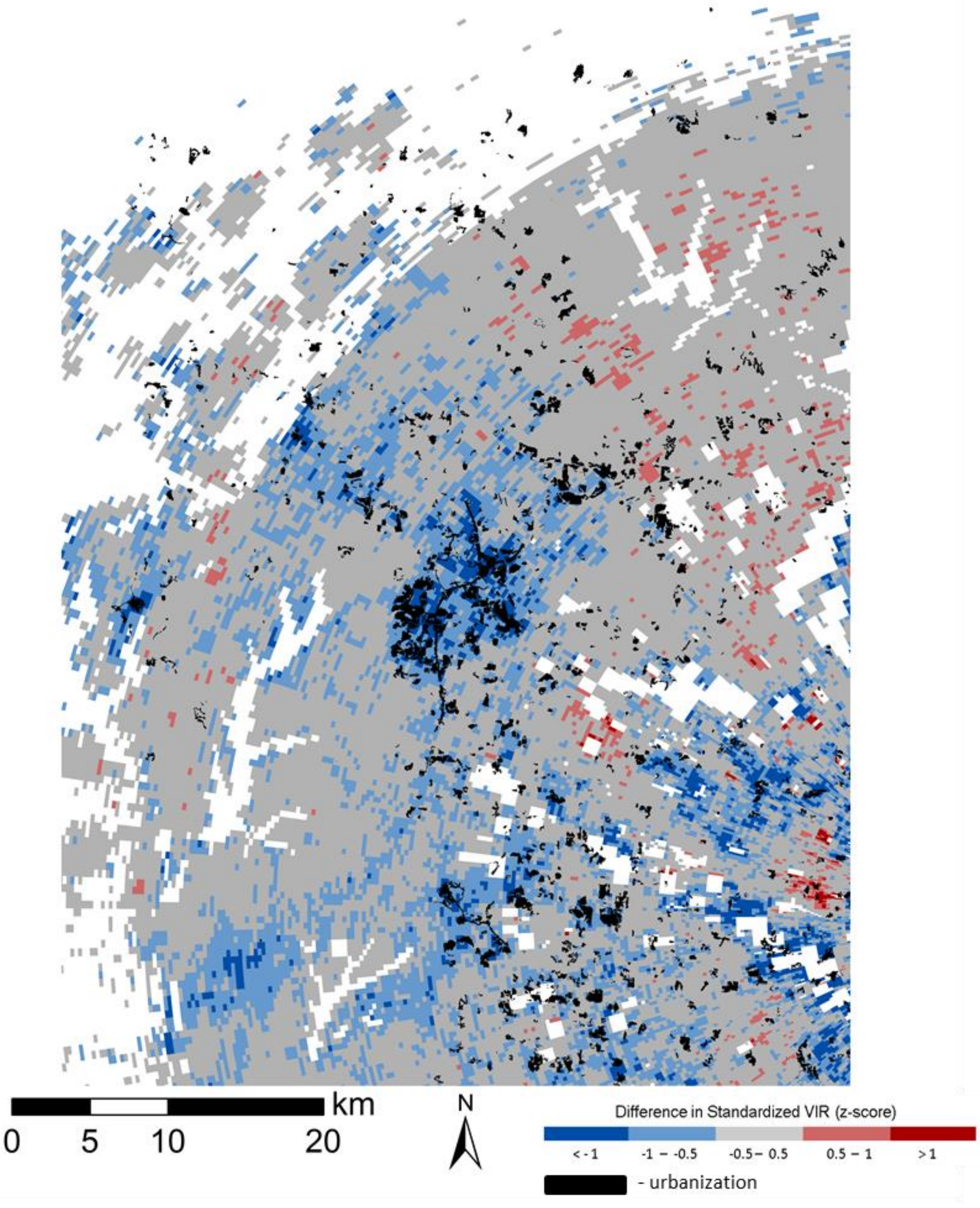

Figure 9 Decreased bird densities associated with urbanization in RAX during the fall season.

Spring: Heavy decreases occurred along the coastal radars, MHX and LTX. The mean distance to coast associated with decreases was 20.8 km. This landscape is composed of mixed forest, urban and agriculture landscape. The increases within LTX and RAX however, are surrounded by large scale water bodies. The increases in RAX are associated with medium to high urbanization while increases in LTX are within a diverse landscape as mentioned above (figure 10).

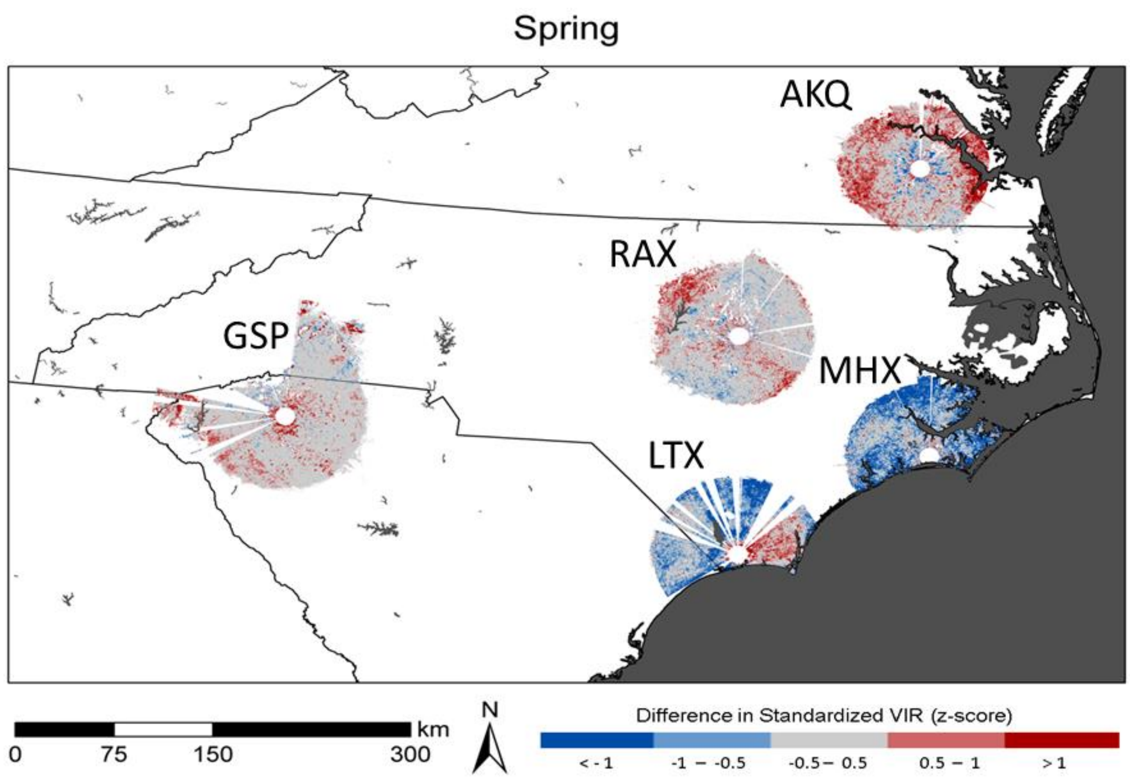

Figure 10 Bird density changes from early (2000-2003) to late (2013-2015) years across five radars in the spring season.

Chapter 4

DISCUSSION

Due to the large scope abilities of radar systems, I was able to look at both local and regional changes of bird densities. This is an important tool that can be utilized to focus on areas from a district to state wide study's or larger. In this case, decadal net land cover changes occurred at local scales, (i.e., no regional-scale land cover change was observed). Because of this, it is hard to relate regional patterns of bird density changes with land cover change. Despite this, we can focus in on specific, local, areas to analyze small scale changes in bird densities as seen in RAX.

The largest decreases in bird stopover densities occurred along coastal communities of radars, MHX and LTX during the spring. These decreases were weakly associated with land cover changes. Although there are decreases in properties where mixed forests had been converted into human infrastructure or agriculture, surrounding decreases had no such correlation.

Across the five radars, in both early and late years, birds tended to favor habitats in forest fragments as well as locations along the coast which is consistent with past studies done utilizing radar (Buler and Moore 2011, Buler and Dawson 2014). Since coastlines and hardwood forests are positively correlated with bird densities, this indicates that they are important stopover environments (Buler et al. 2007). This pattern could be seen in this study where events of urbanization and deforestation directly related to bird density declines. These land cover types have the largest net change in addition to increases in grassland and shrubland. The increase in early successional upland habitats and most of the decline in forests could tie directly to the cutting and regrowth of forests from timber industry, which is quite active in North Carolina. Although soft and hardwood forest are now timbered at similar or lower rates than in the early 2000’s, regrowth is a slow process and trees do not replace themselves as quickly as deforestation occurs (Brown and Vogt 2015).

Past studies have proved that fall migrants prefer more fruitful habitats, such as mature shrublands, to early successional forest, which could have important management implications (Mudrzynski and Norment 2013). With continued timbering activity, it will be useful to study the relationship between these early successional habitats and stopover quality for songbirds more in depth in both fall and spring seasons. Water cover, excluding coasts, was also positively correlated with bird densities which can be seen across a variety of lakes covered by these radars (Bonter et al. 2009). The difference maps had varying increases and decreases along these waterways, but again, lacked any extensive land cover changes.

Although there are examples of where bird densities changes are overlaid with land cover changes, there exists areas of sharp declines in bird densities in locations where no land cover change was measured. Due to these findings, other factors are likely to have caused these unexplained changes in bird densities. There are a variety of influences to birds such as weather that are extrinsic to the quality of habitats. Songbirds can be shifted due to wind patterns and change their migration behavior due to unfavorable weather (Akesson 2016). It is possible that these were stronger factors during the spring migrations causing the overall decreases along the coast. These differences between seasons may also relate to recruitment or demographic changes of the population. Fall migrations have a higher recruitment due to the large flux of juvenile individuals in the population. This may also affect the dispersal of birds due to the fact that juveniles tend to follow coastlines more heavily in the fall season and can also get disoriented more easily than adults of the same species (Ralph 1978).

Sampling bias could have also affected the results of this study since only 17.6% of the possible sample days were usable. The usable bird days could have skewed toward coastal sampling by over sampling those high density nights or under sampling nights when birds were inland.

Since there was no large scale land cover changes within the 10 years of data collected, we are restricted in what we can understand about bird density changes on a regional scale. Future research should be focused on larger time scales as well as in landscapes with high turn-over, i.e. regions with large deforestation events, etc. Limited radars located centrally in North Carolina in combination with blockage also hindered understanding the state density changes as a whole, although in-work predictive models will aid to bridge this gap.

In conclusion, birds favor mixed forests habitats (including wetlands) and coastal environments, indicating they are important migratory stopover sites. In the spring, birds have shifted more inland since the early 2000's while the recent fall data is more dominated by birds on inland bodies of water in addition to coastal waterways. In general, in both seasons, birds have declined along coastal environments.

It is important that we improve our understanding of these stopover habitats in order to more effectively conserve songbirds. These data can be useful to achieve this goal by quantifying what habitats birds generally favor as well as where local bird populations are changing densities in relation to land cover changes. This will aid to promote wise use land development as well as protecting areas where birds are moving into at higher densities.

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Appendix

Locally Classified and Absolute Change Radar Figures

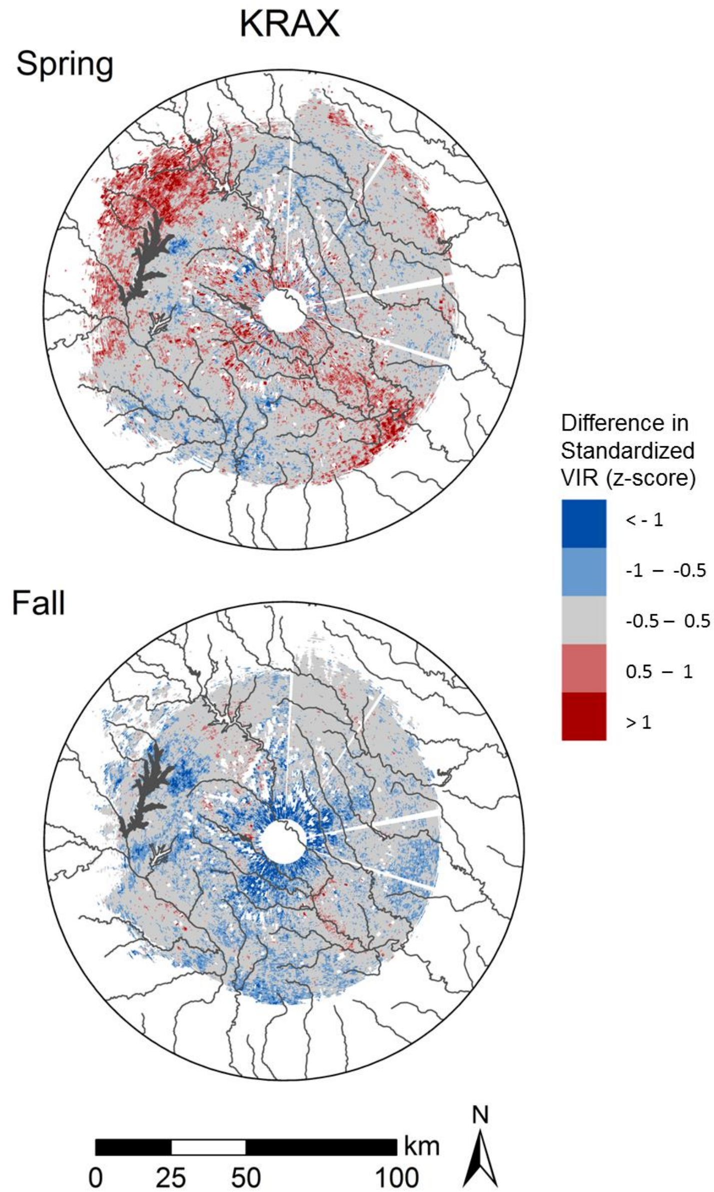

Figure 11 Absolute changes seen in RAX in the spring and fall season.

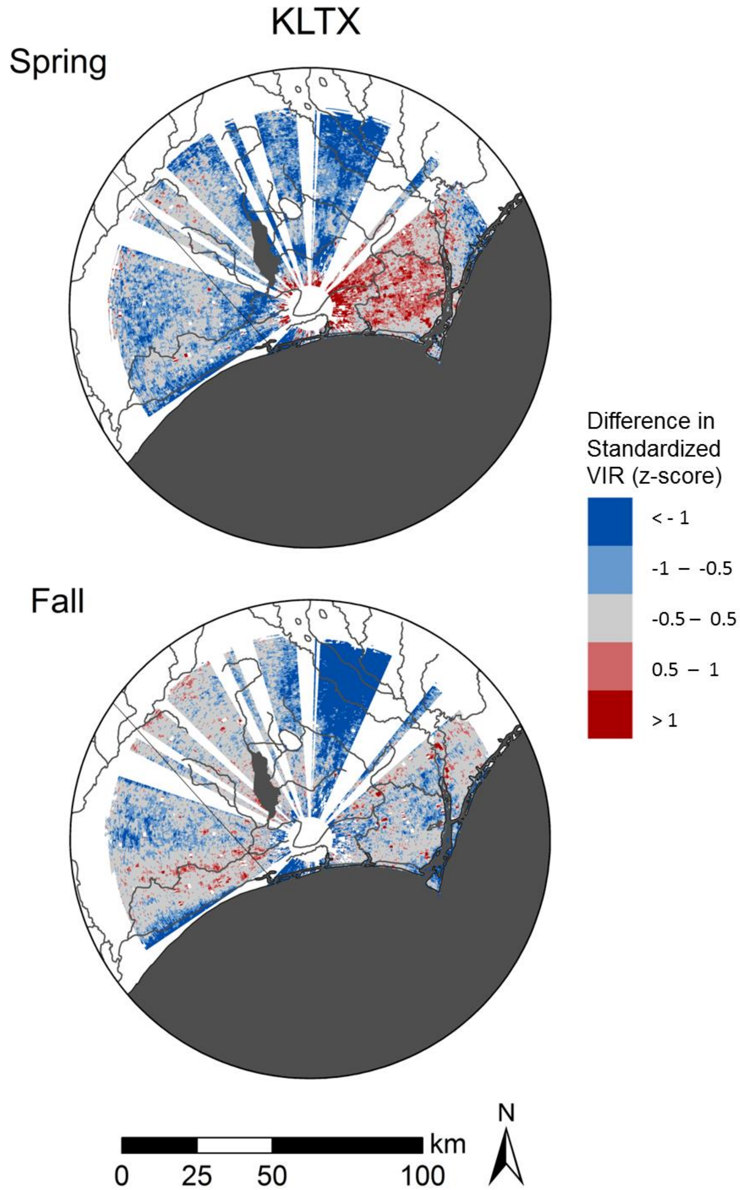

Figure 12   Absolute changes seen in LTX in the spring and fall season.

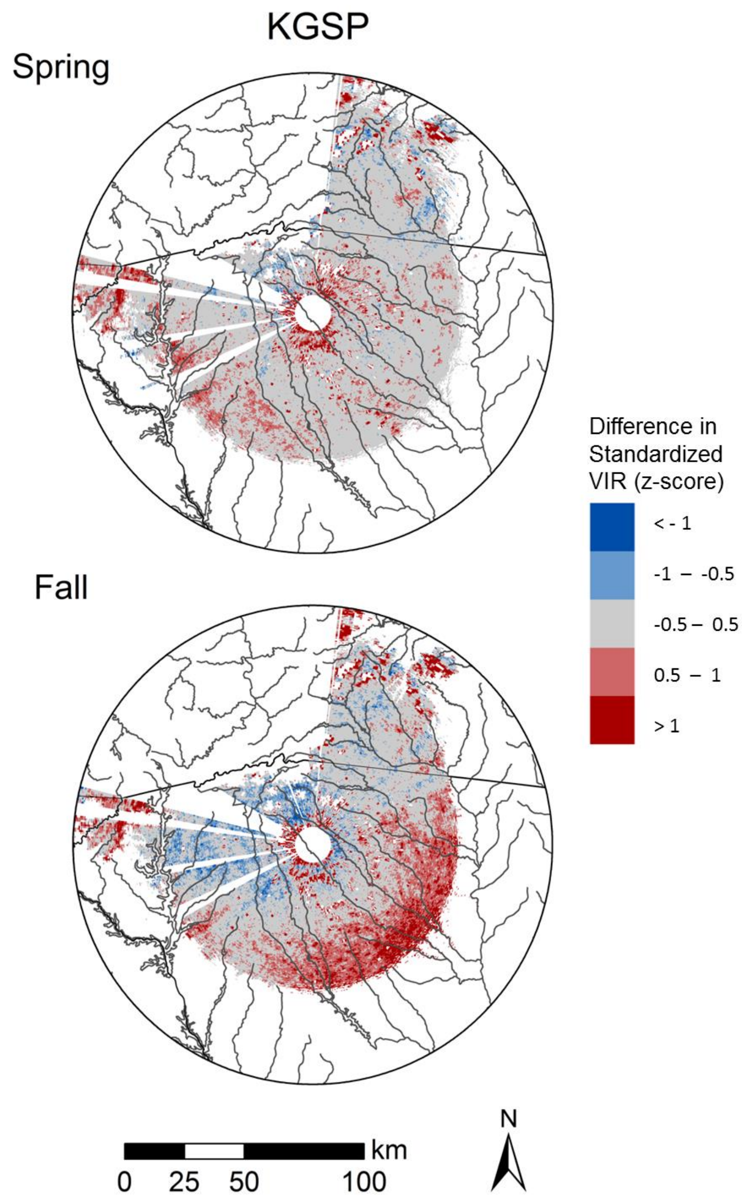

Figure 13 Absolute changes seen in GSP in the spring and fall season.

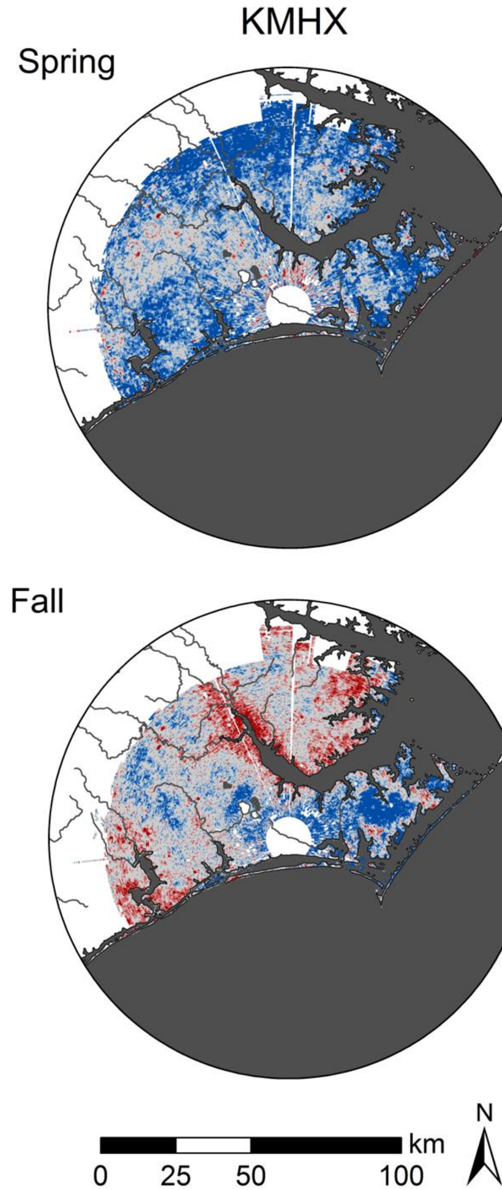

Figure 14 Absolute changes seen in MHX in the spring and fall season.

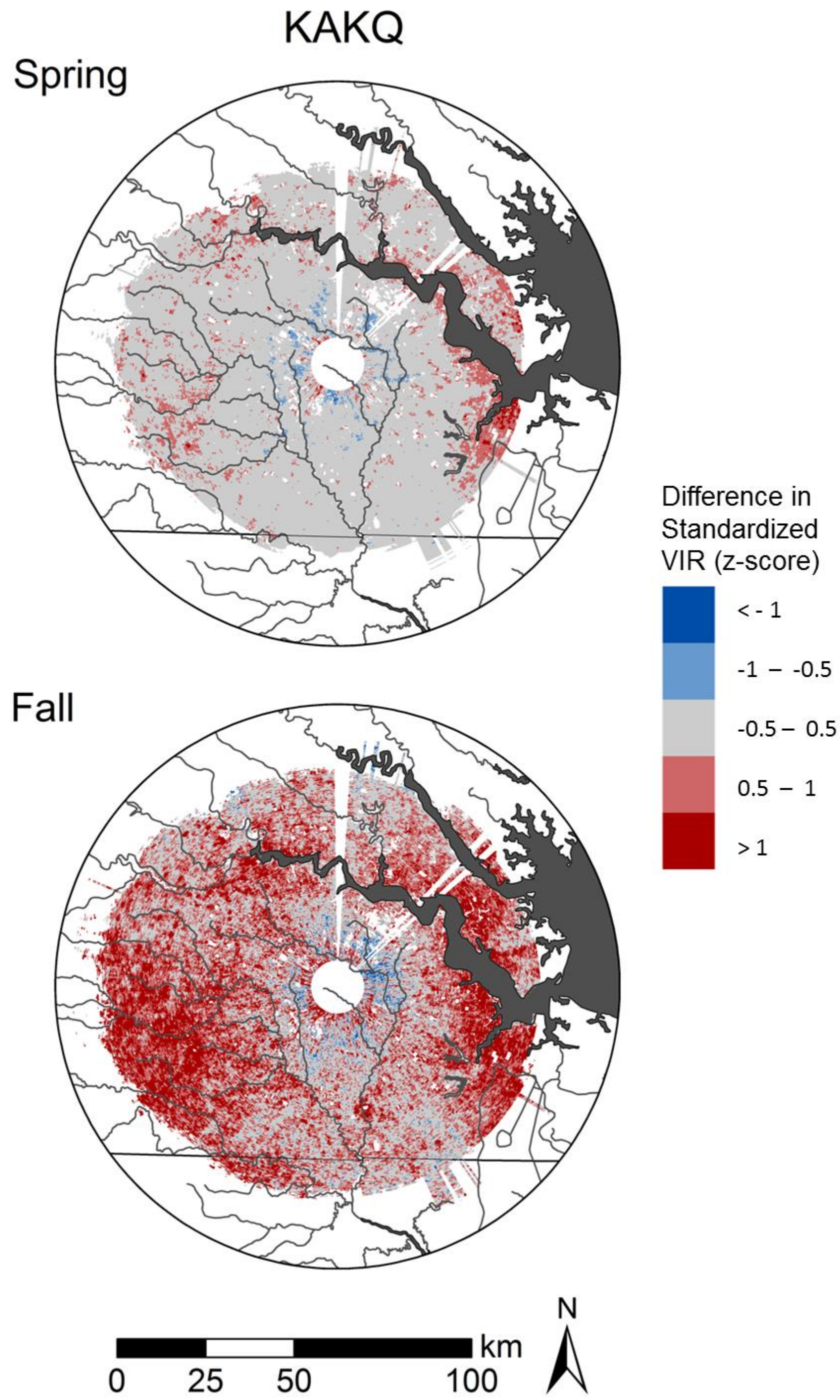

Figure 15 Absolute changes seen in AKQ in the spring and fall season.

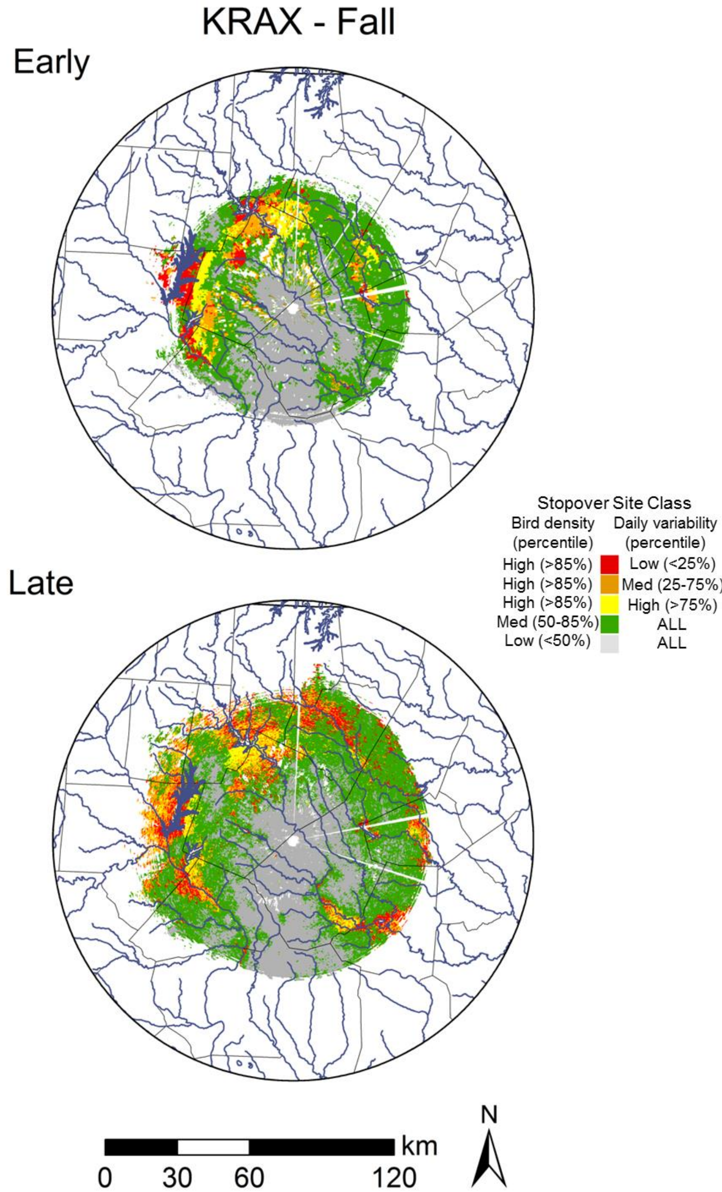

Figure 16 Locally classified densities and daily variability of RAX in early (2000-2003) and late years (2013-2015) in the fall season.

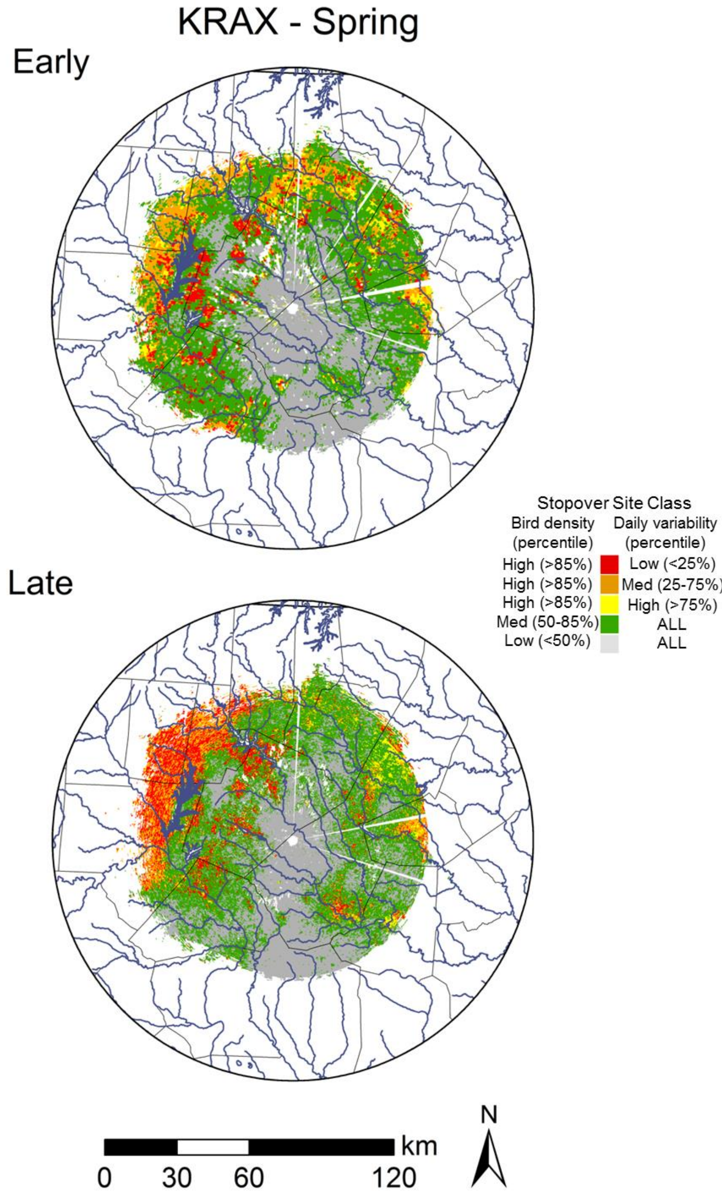

Figure 17 Locally classified densities and daily variability of RAX in early (2000-2003) and late years (2013-2015) in the spring season.

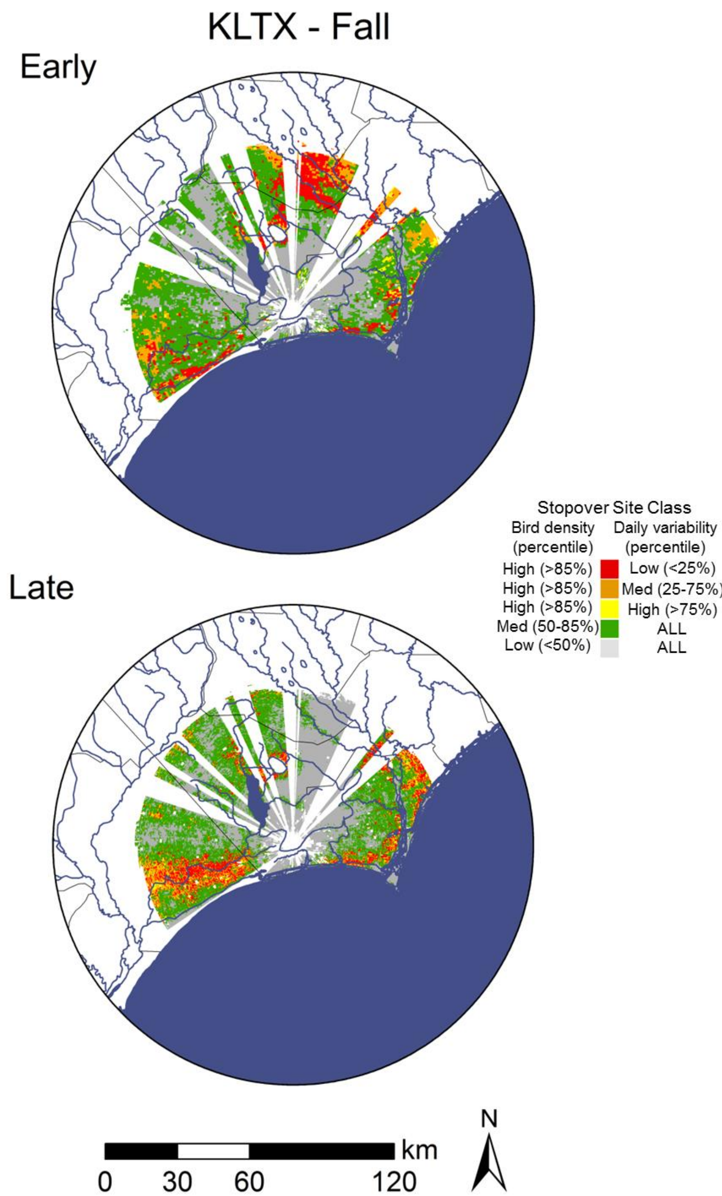

Figure 18 Locally classified densities and daily variability of LTX in early (2000-2003) and late years (2013-2015) in the fall season.

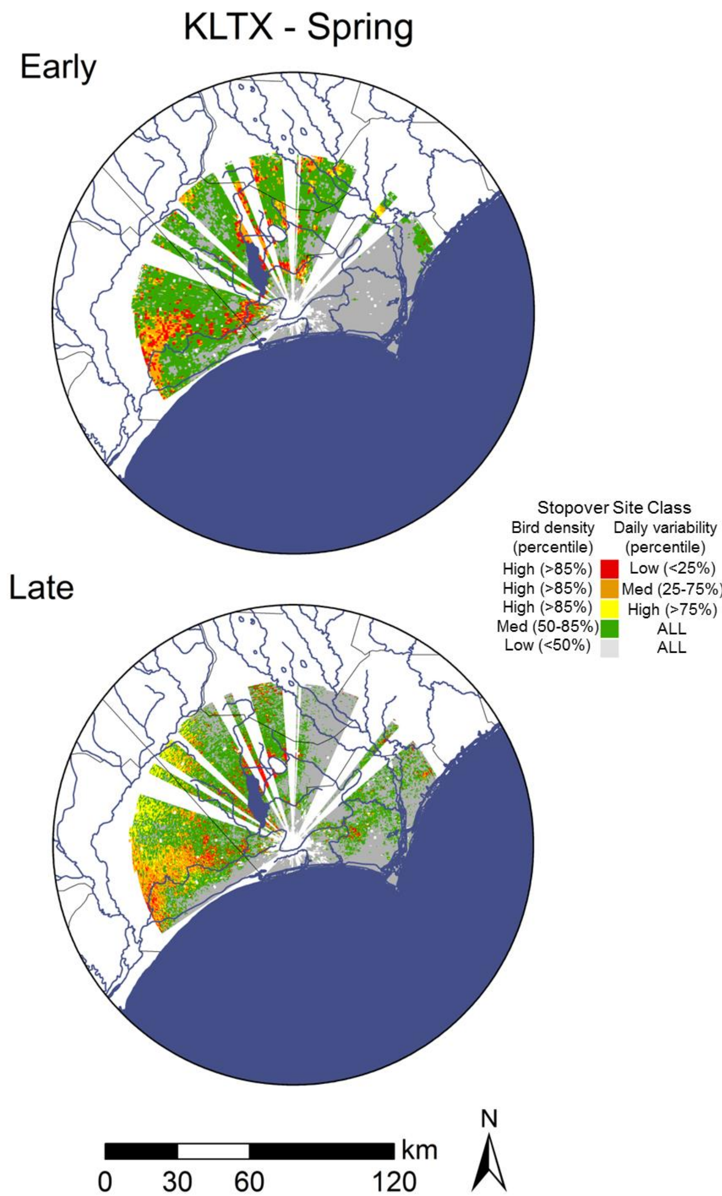

Figure 19 Locally classified densities and daily variability of LTX in early (2000-2003) and late years (2013-2015) in the spring season.

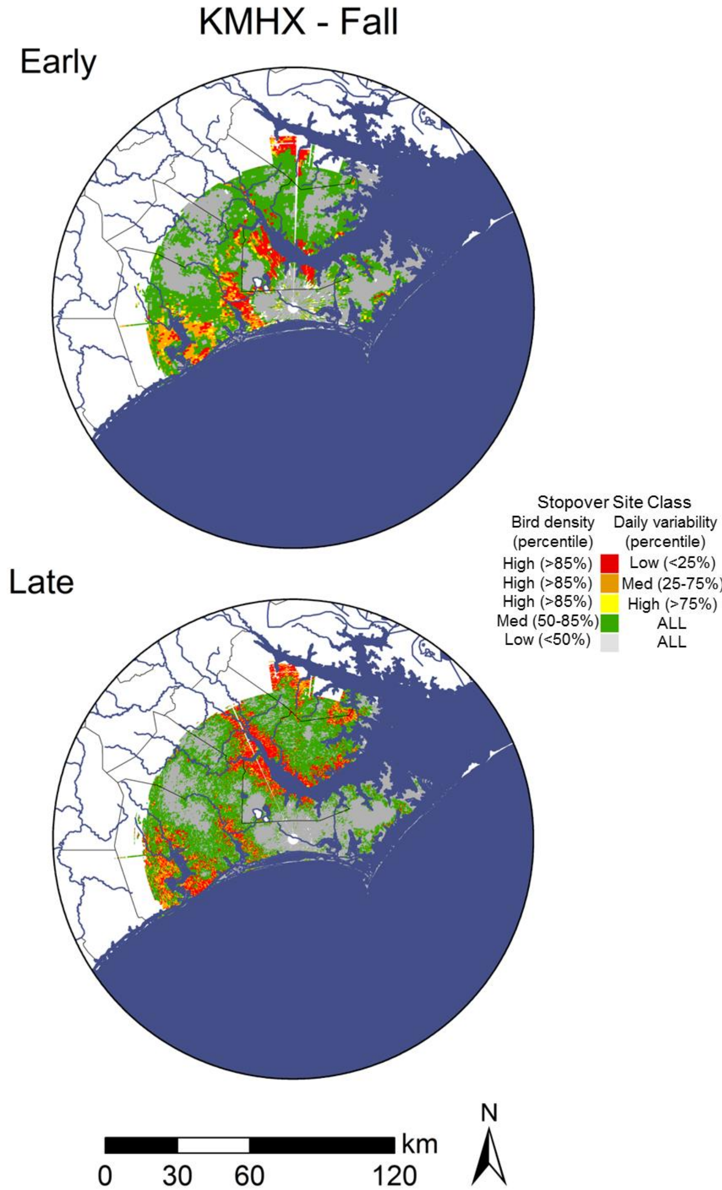

Figure 20 Locally classified densities and daily variability of MHX in early (2000-2003) and late years (2013-2015) in the fall season.

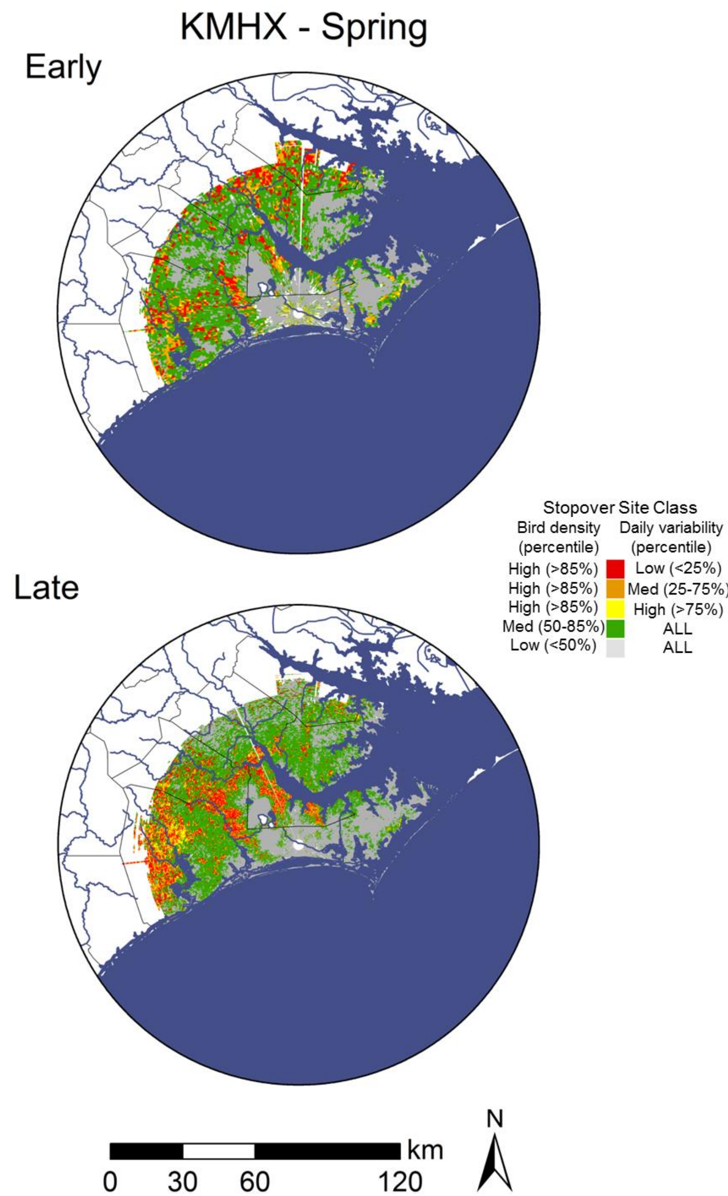

Figure 21 Locally classified densities and daily variability of MHX in early (2000-2003) and late years (2013-2015) in the spring season.

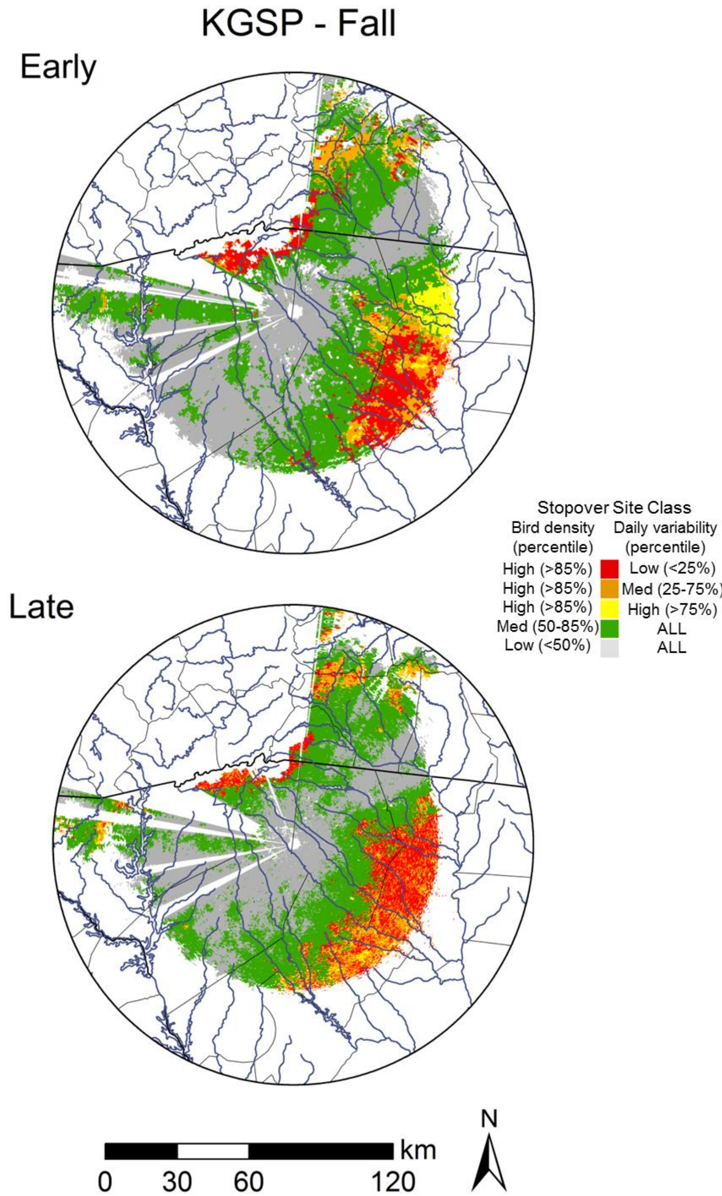

Figure 22 Locally classified densities and daily variability of GSP in early (2000-2003) and late years (2013-2015) in the fall season.

Figure 23

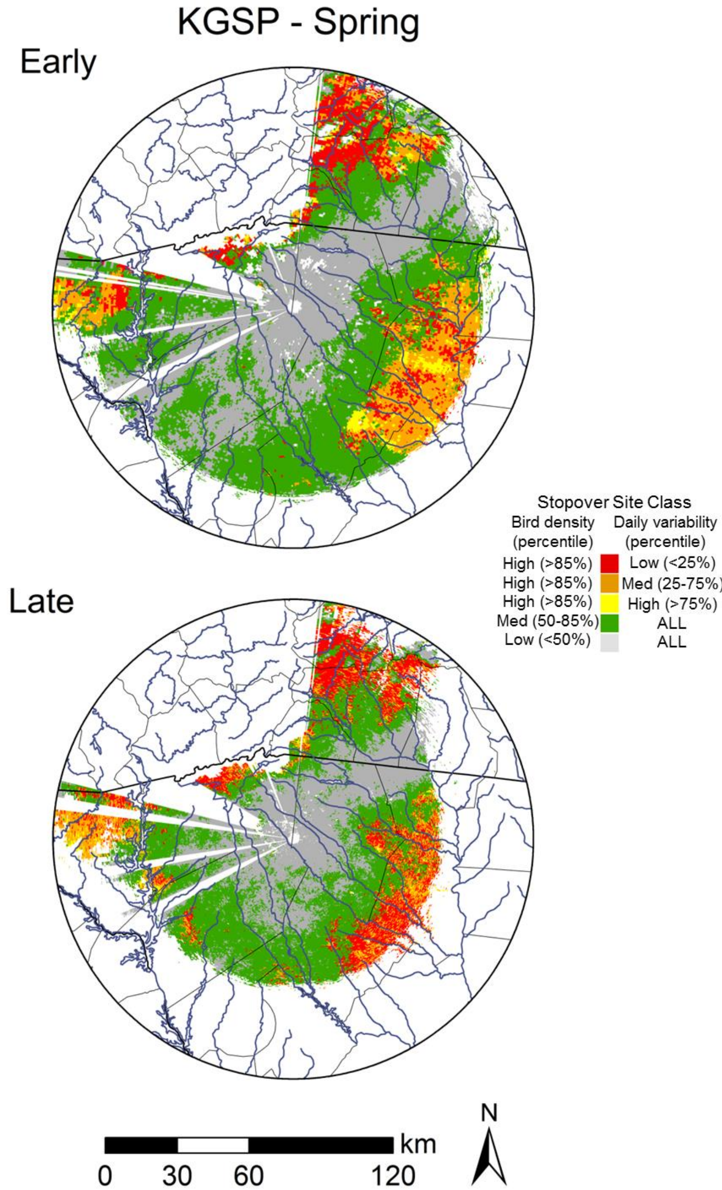

Figure 24 Locally classified densities and daily variability of GSP in early (2000-2003) and late years (2013-2015) in the spring season.

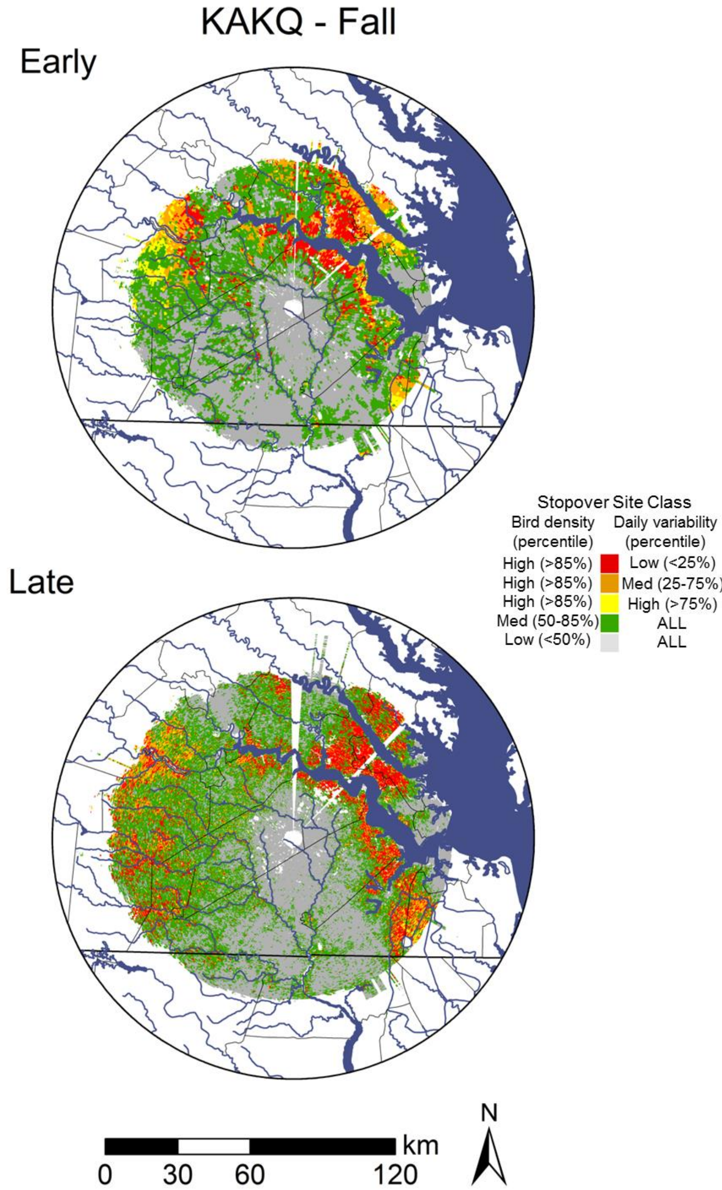

Figure 25 Locally classified densities and daily variability of AKQ in early (2000-2003) and late years (2013-2015) in the fall season.

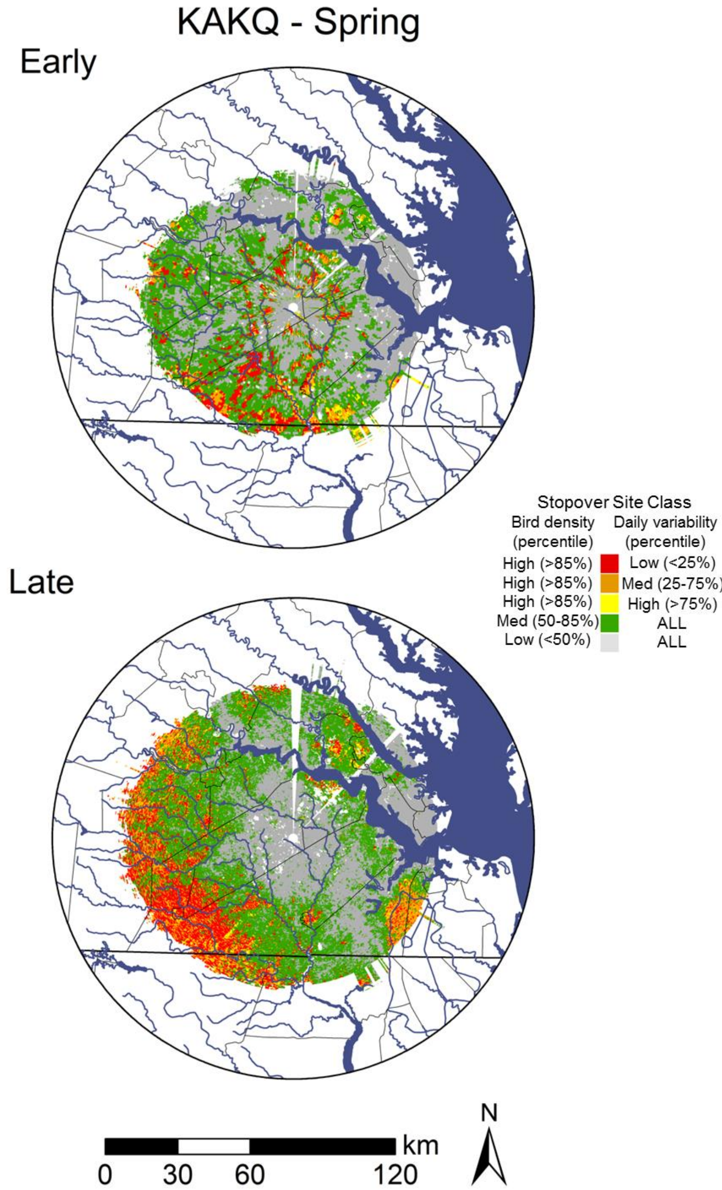

Figure 26 Locally classified densities and daily variability of AKQ in early (2000-2003) and late years (2013-2015) in the spring season.